Review of the potential of bioactive compounds in seaweed to reduce histamine formation in fish and fish products

Muhammad Maskur,[1,2] Asep Awaludin Prihanto,[3] Muhamad Firdaus,[3] Rovina Kobun,[4] Rahmi Nurdiani[3]

[1]Doctoral Program, Faculty of Fisheries and Marine Science, Brawijaya University, Malang, East Java, Indonesia; [2]Polytechnic of Marine and Fisheries Bone, Bone, South Sulawesi, Indonesia; [3]Department of Fishery Product Technology, Faculty of Fisheries and Marine Science, Brawijaya University, Malang, East Java, Indonesia; [4]Food Security Research Lab, Faculty of Food Science and Nutrition, Universiti Malaysia Sabah, Kota Kinabalu, Sabah, Malaysia

Abstract

The formation of histamine in food is influenced by temperature, and histamine growth can be inhibited by maintaining a cold chain. However, simply relying on temperature control is insufficient, as certain bacteria can produce the enzyme histidine decarboxylase even at temperatures below 5°C. To address this issue, various methods, such as modified atmosphere packaging, high hydrostatic pressure, and irradiation, have been developed to control histamine in fishery products. However, these methods often require significant investments. Therefore, there is a need for a cost-effective solution to overcome this problem. This review explores a cost-effective solution through the utilization of bioactive compounds derived from underexplored seaweeds. Seaweed bioactive compounds, either in their pure form or as extracts, offer a promising alternative method to regulate histamine generation in fishery products due to their antibacterial activity, and this review provides comprehensive insights into the potential of different seaweed-derived bioactive compounds as inhibitors of histamine production, detailing their diverse applications in fishery products. It also explores the mechanism by which bioactive compounds prevent histamine formation by bacteria, focusing on the potential of seaweed bioactive compounds to inhibit bacterial histidine decarboxylase. Future trends in the inhibition of histidine decarboxylation are also discussed. The bioactive compounds considered, such as flavonoids, alkaloids, terpenes, and phenolic acids, exhibit their antibacterial effects through various mechanisms, including the inhibition of DNA and RNA synthesis, disruption of cytoplasmic and cell membranes, and inhibition of enzymes by reacting with sulfhydryl groups on proteins. In conclusion, the integration of underexplored seaweeds in fishery product preservation represents a promising and innovative approach for future food safety and sustainability.

Correspondence: Asep Awaludin Prihanto, Department of Fishery Product Technology, Faculty of Fisheries and Marine Science, Brawijaya University, Malang, East Java, Indonesia.
Tel.: +62 341553512.
E-mail: asep_awa@ub.ac.id

Key words: seaweed, marine bioactives, antibacterial, histidine decarboxylase.

Contributions: MM, data curation, writing - original draft preparation, writing - reviewing and editing; AAP, conceptualization, original draft preparation, writing - reviewing and editing, supervision; MF, writing - original draft preparation, validation; RK, RN, writing - reviewing and editing.

Conflict of interest: the authors declare that they have no conflicts of interest.

Ethics approval and consent to participate: not applicable.

Availability of data and materials: data are available from the corresponding author upon request.

Funding: none.

Acknowledgments: the authors would like to thank the Center for Marine Fisheries Education, the Maritime and Fisheries Extension and Human Resources Development Agency, Indonesia for facilitating the potential fee.

Received: 31 August 2024.
Accepted: 4 December 2024.
Early access: 30 January 2025.

Italian Journal of Food Safety 2025; 14:12994
doi:10.4081/ijfs.2025.12994

Introduction

Fishery products are a significant global source of animal protein (Golden *et al*., 2021). These products come from both capture fisheries and aquaculture (Gephart *et al*., 2021). Fish, being rich in animal protein and having a high water content and neutral pH, creates favorable conditions for microbial spoilage and biochemical processes (Ojagh *et al*., 2010; Ramezani *et al*., 2015). After the death of fish, enzymatic reactions, oxidation, and microbial activity occur, leading to changes in sensory and nutritional properties. These changes can reduce the shelf life of fish (Kostaki *et al*., 2009; Karoui and Hassoun, 2017; Olatunde and Benjakul, 2018). Histamine is commonly acknowledged as a significant indicator of food spoilage (Xie *et al*., 2017) and can serve as a measure of freshness or degree of spoilage (Alberto *et al*., 2002; Hwang *et al*., 2003). The gills and skin are the primary sources of histamine-producing bacteria (Phuvasate and Su, 2010; Costanza *et al*., 2013;

Bjornsdottir-Butler *et al*., 2015). Histamine is a biogenic amine produced when bacteria break down histidine in raw fish and fishery products. This breakdown occurs when the fish is not stored at the correct temperature and for the proper amount of time (Rawles *et al*., 1996). The production of histamine is primarily observed in Gram-negative bacteria (Emborg *et al*., 2006; Ibrahim *et al*., 2017). Histamine synthesis is known to increase significantly at temperatures around 32.2°C (90°F) according to the (FDA, 2022). However, there are certain types of bacteria, such as *Photobacterium damselae* (Kanki *et al*., 2007), *Raoultella planticola*, and *R. ornithinolytica* (Kim *et al*., 2000), that are capable of synthesizing histamine even at a temperature as low as 4°C. This ability can lead to poisoning. Histamine is produced in fish and fish products *via* the process of decarboxylation of the amino acid histidine. This conversion is facilitated by the bacterial enzyme histidine decarboxylase (Maldonado and Maeyama, 2013; Altieri *et al*., 2016;). The bacteria that can produce histamine include *Morganella morganii* (Emborg *et al*., 2006; Ibrahim *et al*., 2017; Wang *et al*., 2020), *Photobacterium* spp. (Bjornsdottir-Butler *et al*., 2018), *Proteus vulgaris*, *Enterobacter* spp. and *Klebsiella pneumoniae* (Rodtong *et al*., 2005; Ferrario *et al*., 2012; Gopi *et al*., 2016), *Aeromonas* spp., *Clostridium* spp., *Pseudomonas putida dan Acinetobacter lwoffii* (Okuzumi *et al*., 1994; López-Sabater *et al*., 1996;). Consuming fish and fish products that have a high histamine content can lead to poisoning, resulting in symptoms such as skin rash, hives, nausea, vomiting, diarrhea, and flushing (Chen *et al*., 2010; Silva *et al*., 2011; Evangelista *et al*., 2016; Elik *et al*., 2019). Furthermore, these noxious substances are recognized for inducing hyperallergic responses prompted by inflammation; however, they never result in fatality among those who ingest histamine-infused fish (Reber *et al*., 2017). For instance, between 1998 and 2008, there were 333 outbreaks of histamine poisoning in the United States that involved 1,383 people and resulted in 59 hospitalizations (Dewey-Mattia *et al*., 2018). In the United States and the European Union, fish consumption-related histamine poisoning accounts for approximately 40% of all cases of food poisoning; incidences range from 2 to 5 cases per million people in New Zealand, France, and Denmark to 31 cases per million people in Hawaii (Marcus, 2024). A 2017 incident of histamine poisoning in Italy was linked to tuna steak consumption, while a 2019 outbreak was linked to frozen raw tuna (Annunziata *et al*., 2022).

To address these issues, it is possible to inhibit the growth of microorganisms, namely bacteria that produce histamine. Blocking the histamine-forming bacteria may effectively limit the conversion of histidine into histamine by these bacteria. Elevated microbial decarboxylation activity leads to the production of larger levels of histamine, which can be harmful (Al Bulushi *et al*., 2009; De Mey *et al*., 2014). Once histamine is generated, it becomes challenging to eliminate it effectively, regardless of whether temperatures are high or low (Wendakoon and Morihiko, 1995). In general, the inhibition process can be achieved by introducing an inhibitor and bioactive chemicals derived from plants, particularly seaweed, either in the form of extracts or in their pure form. These plant-based substances can serve as a viable alternative for inhibiting certain processes. This review aims to present information regarding the utilization of different bioactive compounds as inhibitors of histamine synthesis and their diverse applications in fishery products. It also discusses the mechanism by which bioactive compounds prevent histamine formation by bacteria, highlighting the potential of seaweed bioactives in inhibiting bacterial histidine decarboxylase. Additionally, it explores future trends in the inhibition of the enzyme histidine decarboxylation.

Formation of histamine in fishery products

The production of histamine in fishery products is closely correlated with the quantity of its precursor, histidine, and the bacterial population in the product (Altieri *et al*., 2016). Microorganisms present in fish tissue can decarboxylate histidine, leading to the synthesis of histamine in fishery products (Harmoko *et al*., 2022). Several types of bacteria, such as *M. morganii*, *M. psychrotolerans*, *Photobacterium damselae*, *P. phosphorum*, *Raoultella planticola* and *Hafnia alvei*, have the ability to decarboxylate histidine into histamine (Tsai *et al*., 2006; Gardini *et al*., 2016; Ruiz-Capillas and Herrero, 2019; Visciano *et al*., 2020). Among these bacteria, enteric bacteria including *Proteus vulgaris*, *Enterobacter* spp., *M. morganii*, and *K. pneumoniae* are capable of producing histamine from histidine (Rodtong *et al*., 2005; Ferrario *et al*., 2012; Gopi *et al*., 2016;). Additionally, non-enteric bacteria such as *Aeromonas* spp., *Clostridium* spp., *Photobacterium* spp., *Pseudomonas putida*, and *Acinetobacter lwoffii*, also can produce histamine (Huang *et al*., 2010; Kung *et al*., 2015; Krell *et al*., 2021; Oktariani *et al*., 2022).

The production of histamine by histamine-forming bacteria is influenced by a number of factors, including temperature, pH, oxygen content, processing, packaging, and storage. For example, *M. morganii* when exposed to tuna (*Thunnus albacares*) for 24 hours at a temperature of 15-37°C and a pH of less than 7, can form histamine >5000 ppm (Kim *et al*., 2000), *P. phosphoreum*, at 5-37°C and pH <4 in cod, for 48 hours, can form histamine of 1188 ppm (Bjornsdottir-Butler *et al*., 2020) and *K. pneumoniae* at 37°C in tuna for 7 hours, can form histamine 442 ppm (Taylor *et al*., 1979). Studies (Mercogliano and Santonicola, 2019; Visciano *et al*., 2020) have shown that these factors play a role. Specifically, temperature and storage time are significant factors that impact the synthesis of histamine by histamine-forming bacteria in fishery products, as demonstrated by Nevado *et al*., 2023). The excessive growth of disease-causing microbes, combined with the production of histamine, occurs when fishery goods are subjected to improper temperature conditions during storage after fish are caught or harvested, as well as during the marketing process. Fishery products are typically stored in the freezer to inhibit the growth of microorganisms and enzymatic activity, as temperatures over 4°C might facilitate these processes (Nevado *et al*., 2023). This freezing method helps to slow down the breakdown of fishery products caused by the creation of biogenic amines (Koo and Lim, 2023).

According to (Tabanelli *et al*., 2012), bacteria that make histamine multiply quickly when the temperature exceeds 21.1°C. Additionally, the synthesis of histamine increases at 32.2°C since the activity of histidine decarboxylase is most effective at 30°C. Nevertheless, bacteria that produce histamine are capable of thriving at both cold (psychrophilic) and moderate (mesophilic) temperatures, with a range of 5°C (Takahashi *et al*., 2015) to 37°C in fishery products (Valiollah *et al*., 2012). Storage duration has a notable impact on the chemical and biological makeup of fishery products. In particular, inappropriate storage time and thermal conditions can negatively affect the shelf life of these products and facilitate the proliferation of histamine-forming bacteria, leading to histamine production (Nevado *et al*., 2023). Table 1 presents a comprehensive compilation of microorganisms that have the ability to produce histamine in fish and fishery products.

Certain bacteria, such as *M. morganii, P. damselae, P. phosphorum*, and *R. planticola*, are capable of producing histamine but are not active at cold temperatures. However, there are other histamine-producing bacteria, like *M. psychrotolerans*, that can still

produce histamine even when stored at low temperatures (Gardini *et al*., 2016; Wang *et al*., 2020). The optimal pH for histamine production in meals is within the mild acidic range of 4.0 to 5.0 (Diaz *et al*., 2020). For instance, *K. pneumoniae*, a bacteria commonly found in tuna, has the ability to convert histidine into histamine at a high rate when the pH is 4.0. However, this activity decreases when the pH is raised to 6.0 (Baranowski *et al*., 1985). It is worth noting that pH 4.0 is considered the optimal pH for the maximum production of biogenic amines, including histamine, in fermented fish. Additionally, the activity of microorganisms is significantly hindered at pH 3 due to changes in enzyme structure caused by extremely high or low pH levels (Meng *et al*., 2022). The activity of histidine decarboxylase persists despite the inactivation of bacterial activity (Gardini *et al*., 2016; Visciano *et al*., 2020). Therefore, it is crucial to take this into account when managing histamine synthesis in fish and fishery products by regulating both the bacteria and the enzymes they create. Mast cells in living fish store and release histamine, a process mediated by histidine decarboxylase, an essential enzyme involved in histamine production triggered by lipopolysaccharides and cytokines (Reite, 1972; Crivellato and Ribatti, 2010; Inami *et al*., 2021). Mast cells become triggered by directly interacting with particular microbial components or by host chemicals that are produced due to tissue damage (Gomez-Gonzalez *et al*., 2014). When mast cells are activated, they release different substances that cause inflammation and activate other white blood cells (Marshall, 2004). These substances include preformed mediators like histamine, tryptase, chymase, and tumor necrosis factor-α, as well as newly synthesized mediators like leukotrienes, cytokines, chemokines, and growth factors (Galli *et al*., 1991; Pater-huijsen *et al*., 1997; Triggiani *et al*., 1995). Furthermore, histamine is produced from scratch in different cells by activating histidine decarboxylase at sites of inflammation (Hirasawa, 2019). In these locations, histamine serves a crucial function in initiating inflammation, which is the initial reaction of living organisms to infection or cellular injury (Beer and Rocklin, 1987; Crivellato & Ribatti, 2010). This discussion demonstrates that the production of histidine decarboxylase in mast cells can be regulated while the fish is alive. However, once the fish is dead, the enzyme's activity persists and converts histidine into histamine through decarboxylation (Gardini *et al*., 2016; Visciano *et al*., 2020). Therefore, it is crucial to promptly control this enzyme after catching or harvesting the fish.

Mitigating histamine formation in fishery products: exploring seaweed-derived bioactives and their antimicrobial mechanisms

Bioactive compounds have the ability to regulate the production of histamine in fishery products. The process by which bioactive compounds reduce the levels of biogenic amines, including histamine, is primarily linked to their antimicrobial properties (Tsafack and Tsopmo, 2022). Examples of bioactive compounds that exhibit this effect include flavonoids, alkaloids, terpenes, and phenolic acids (Houicher *et al*., 2021). Figure 1 illustrates the antibacterial mechanism of bioactive substances.

Flavonoids are effective antimicrobials due to their ability to hinder energy metabolism, impede DNA and RNA synthesis, disrupt cytoplasmic membrane function, and alter membrane permeability. These are the primary mechanisms by which flavonoids exhibit antibacterial properties (Cushnie and Lamb, 2005; Xie *et al*., 2015). Furthermore, it suppresses the release of histamine from mast cells that produce histamine and the process of tyrosine phosphorylation, which is linked to the suppression of histidine decarboxylase activity (Yamashita *et al*., 2000; Rodríguez-Caso *et al*.,

Table 1. Presence of histamine-producing bacteria in fish and fishery products.

No	Histamine forming bacteria	Fishery products	Results	Reference
1	*M. morganii*	Japanese Spanish Mackerel (*Scomberomorus niphonius*)	Bacteria that produce dangerous levels of histamine at 935 ppm	Hwang *et al.*, 2019
2	*M. morganii*	Tuna albacores	Generated the most elevated histamine concentration, measuring 5.253 ppm	Kim *et al.*, 2000
3	*R. planticola and R. ornithinolytica*	Tuna, bonito and sardines	The histamine production capacity ranged from 2810 to 5250 mg	Kim *et al.*, 2000
4	*P. damselae*	Blue mackerel (*Scomber australasicus*)	Strong histamine producer (Average histamine level 4330 mg/L)	Chen *et al.*, 2012
5	*Enterbacter aerogenus*	Dried milkfish (*Chanos chanos*) products	Productive histamine formers with values > 500 ppm	Hsu *et al.*, 2009
6	*P. damselae*	*Mugil cephalus*	Histamine levels of 1053 µg/mL at 30°OC in 24 hours	Trevisani *et al.*, 2017
7	*Hafnia alvei*	Dried milkfish (*Chanos chanos*) products	Weak histamine formers with a value of 152 ppm	Hsu *et al.*, 2009
8	*Clostridium perfringens*	Tuna and Spanish mackerel	The histamine levels were measured at 6.345 ppm and 1.223 ppm	Kristin Bjornsdottir-Butler *et al.*, 2013
9	*M. psychrotolerans*	Tuna (*Thunnus albacares*) *of vacuum and modified atmosphere-packaging*	Histamine levels >5000 mg/kg at 1.7°C on day 24	Emborg *et al.*, 2005
10	*P. kishitanii*	Cod fish	Generate a concentration of 1545 ppm of histamine	Bjornsdottir-Butler *et al.*, 2020
11	*P. phosphoreum*	*Iwashi Maruboshi*	Histamine levels of 1700mg/kg stored at 4°C and 12°C	Kanki *et al.*, 2004

2003; Melgarejo *et al*., 2010). Flavonoids, specifically flavanols like quercetin and catechin, exhibit antibacterial properties by inhibiting the formation of adenosine triphosphate (Chinnam *et al*., 2010; Silva *et al*., 2016) and disrupting the cell membrane, as demonstrated (Ollila *et al*., 2002; Zhou *et al*., 2022).

Alkaloids can be classified based on their chemical structure. They are divided into two main groups: non-heterocyclic alkaloids, also known as protoalkaloids or biological amines, and heterocyclic alkaloids. Non-heterocyclic alkaloids include compounds like hordenine, N-methyltyramine, colchicine, and erythromycin. Heterocyclic alkaloids, on the other hand, are further categorized into subgroups such as pyrrole and pyrrolidine (which include hygrines) and quinoline (which includes qinine) (Evans, 2009). Alkaloids are capable of establishing hydrogen bonds with enzymes, receptors, and proteins due to the presence of nitrogen atoms that can take protons, as well as amine hydrogen atoms that can give protons (Othman *et al*., 2019). Alkaloids can serve as antimicrobials by inhibiting cell division, binding to bacterial enzymes to impede respiration, disrupting cell membranes, and deactivating virulence genes.

Virstatin is an isoquinoline alkaloid that can inhibit the regulatory protein ToxT, thereby inhibiting the virulence factors (Yang *et al*., 2011). Additionally, alkyl methyl quinolone alkaloids exhibit potent and specific antibacterial activity by inhibiting respiration (Tominaga *et al*., 2002). Agelasine D, a diterpene alkaloid, inhibits bacterial enzymes (Arai *et al*., 2014). Squalamine is a polyamine alkaloid that functions by disrupting the outer cell membrane and causing depolarization of the membrane of Gram-positive bacteria (Alhanout *et al*., 2010). Alkaloids like berberine have been found to impede cell division (Boberek *et al*., 2010), while ungeremine has the ability to hinder bacterial topoisomerase (Casu *et al*., 2011).

Tannins are a group of polymeric phenolic compounds that can be categorized into two main groups, namely hydrolyzable tannins and condensed tannins. Whereas condensed tannins derived from flavonoid monomers are more common in nature. The biological properties of tannins are closely related to their structural characteristics, particularly their oxidation patterns and polymerization, which affect their interactions with biological systems (Cano *et al*., 2020; Štumpf *et al*., 2023). Tannins exhibit significant antimicrobial activity, primarily through their ability to form complexes with proteins, which occurs *via* covalent and non-covalent interactions. This complexation can inhibit bacterial growth and protease activity by binding to the bacterial cell wall, thereby disrupting essential cellular functions (Biswas *et al*., 2013). Additionally, tannins can bind to components of the bacterial cell wall, causing mechanical inhibition of growth (Dimech *et al*., 2013; Neumann *et al*., 2022). This binding not only disrupts the structural integrity of the bacterial cell wall but also affects the activity of extracellular and soluble proteins, which are crucial for the survival and proliferation of bacteria (Biswas *et al*., 2013). The structural characteristics of tannins, such as molecular weight and flexibility, play an important role in their antimicrobial efficacy. Tannins with higher molecular weights tend to exhibit stronger antibacterial activity, as they can more effectively penetrate bacterial cell walls and disrupt cellular functions, thereby enhancing their antimicrobial effects (Olchowik-Grabarek *et al*., 2020).

Phenolic acids, such as cinnamic acid and caffeic acid, are characterized by their phenolic rings with varying degrees of substitution and hydroxylation. The degree of hydroxylation in these compounds is closely related to their antimicrobial activity. In general, the more oxidized the structure of phenolic acids, the greater their inhibitory effect on microbial growth and enzyme activity (Oh and Jeon, 2015; Purnamasari *et al*., 2021). The mechanism of phenolic acid inhibition primarily involves interaction with the sulfhydryl groups on proteins. By reacting with these groups, phenolic compounds can inhibit the activity of enzymes that are crucial for the survival and proliferation of microbes (Sánchez-

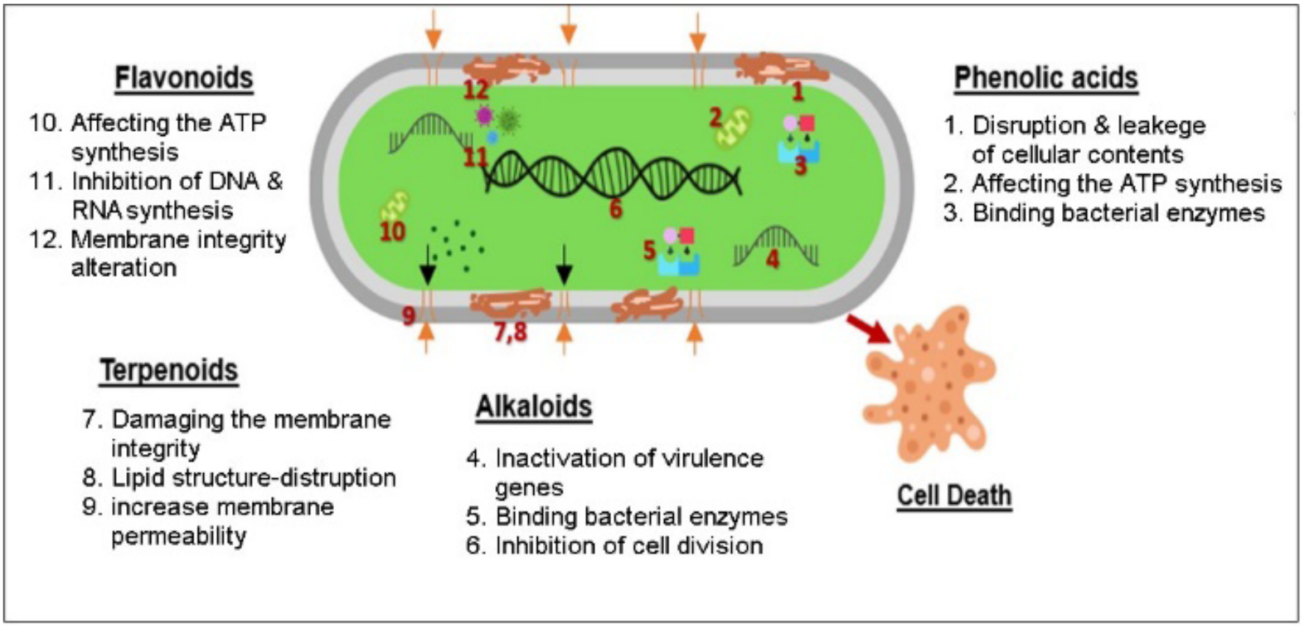

Figure 1. Antimicrobial mechanism of action of bioactive compounds. ATP, adenosine triphosphate.

Maldonado *et al*., 2011). The structural characteristics of phenolic acids, including the presence of hydroxyl groups, play an important role in their antimicrobial properties. The presence of multiple hydroxyl groups is often correlated with increased antimicrobial activity, as these groups enhance the ability of phenolic acids to interact with and disrupt microbial membranes (Yamazaki and Kawano, 2010).

Application of bioactive compounds for histamine inhibition

Implementing a cold chain is an effective method for regulating histamine levels in food. The synthesis of this histamine is affected by temperature, and keeping temperatures low can inhibit microbial growth and reduce the activity of decarboxylating enzymes (Mah *et al*., 2019; Sun *et al*., 2016; Sun *et al*., 2019). However, simply controlling temperature is not enough, as certain bacteria can produce histamine at temperatures below 5°C (Tsafack and Tsopmo, 2022). One such bacterium is *Photobacterium damselae*, a halophilic bacterium found widely in marine environments, which possesses the capability to produce histamine (Chen *et al*., 2012; Trevisani *et al*., 2017) It is a potent histamine producer, as demonstrated by studies conducted by (Bjornsdottir-butler *et al*., 2010; Bjornsdottir *et al*., 2009). It has the capability to generate over 500 mg/kg of histamine at a temperature of 4^0C during a 24-hour period. Additionally, it can sustain 50% - 60% of its original effectiveness in dried tuna and sauri fish for a duration of up to 12 weeks at a temperature of -20°C (Kanki *et al*., 2007). Various techniques, such as modified atmospheric packaging, high hydrostatic pressure, and irradiation, have been developed to manage biogenic amines (Naila *et al*., 2010). A further method for regulating the production of histamine in fishery products involves the utilization of secondary metabolites in their pure form or as extracts (Tsafack and Tsopmo, 2022), as indicated in Table 2. The utilization of secondary metabolites, either in their pure form or as extracts, for the regulation of histamine in fresh fish meat, involves immersion in water at a specified concentration and duration (Houicher *et al*., 2015; Ozogul *et al*., 2011). In fishery products, this is achieved by incorporating extracts or pure compounds at designated concentrations and times (Cai *et al*., 2015; Zhou *et al*., 2016).

The concentration of secondary metabolites must be carefully evaluated, as it significantly influences the sensory attributes of the final product. For instance, the application of secondary metabolites like polyphenols at concentrations of 0.2%, 0.3%, 0.4%, and 0.5% demonstrates that all natural ingredients at these levels can effectively regulate histamine formation. However, treatments at 0.4% and 0.5% may induce sensory detriments, such as undesirable taste or discoloration of the product (Cai *et al*., 2015). The application of unsuitable phenolic concentrations frequently results in heightened bitterness and astringency, potentially deterring consumers (Esteves *et al*., 2020). Furthermore, secondary metabolites like tannins can influence the color stability of food products, as they have been demonstrated to interact with proteins and other phenolic compounds, thereby impacting sensory attributes (Al-Hijazeen *et al*., 2016).

Various bioactive compounds have been identified as effective in controlling the formation of biogenic amines. These compounds

Table 2. The application of bioactive compounds for the controlling of histamine levels in fishery products.

No	Fishery products	Treatment	Results	Reference
1	Pacific Mackerel Fillets	Gallic acid 5% with storage for 12 days at 4°C	63-84% reduction	Wu *et al*., 2016
2	Sardine (*Sardina pilchardus*) Fillets	Phenolic compounds in 1% ethanol extract at 21 days of storage at 3°C	27-66% reduction	Houicher *et al*., 2015
3	Sardine (*Sardina pilchardus*) Fillets	Phenolic compounds in 1% ethanol extract at 20 days of storage at 3°C	18-25% reduction	Ozogul *et al*., 2011
4	Shrimp paste	Polyphenols in 0.3% tea at 120 days 25°C storage	54-68% reduction	Cai *et al*., 2015
5	Fish sauce	Garlic ethanol extract 2% at 15 days fermentation temperature 30°C	18-37% reduction	Zhou *et al*., 2016

Table 3. Antimicrobial properties of bioactive compounds in seaweed.

No	Seaweed species	Bioactive compounds	Extraction method	Reference
1	*Caulerpa racemosa*	Phenolics and tannins	Maceration with methanol solvent produces the best antibacterial activity	Palaniyappan *et al*., 2023
2	*Caulerpa sertularioides* and *Caulerpa racemosa*	-	Maceration with methanol solvent with *Caulerpa sertulariodes* has antibacterial activity on more bacterial strains.	Avila-Romero *et al*., 2023
3	*Padina tetrastromatica and sargassum muticum*	Phenolics and flavonoids	Maceration with methanol, ethanol and acetone solvents with methanol extract gave the best antibacterial activity.	Afrin *et al*., 2023
4	*Caulerpa racemosa*	Polyphenols, flavonoids and tannins	Soxhlet with methanol, chloroform and hexane solvents.	Belkacemi *et al*., 2020
5	*Caulerpa racemose* and *Caulerpa lentillifera*	Phenolics and flavonoids	Maceration with chloroform, methanol and water.	Yap *et al*., 2019
6	*Sargassum latifolium* and *Cladhopora sosialis*	Phenol	Maceration with methanol and acetone solvents. The best antibacterial activity on brown seaweed seeds is with methanol solvent while green seaweed with acetone.	Moubayed *et al*., 2017

include polyphenols such as (Tsafack and Tsopmo, 2022), quercetin, 4-hexylresorcinol, and cinnamic acid as studied by (Qian *et al*., 2018). Gallic acid, phloretin, and flavonoids have also been found to be effective in this regard (Wu *et al*., 2016; Wang *et al*., 2019). Catechins, specifically epicatechin, epigallocatechin, epicatechin gallate, and epigallocatechin gallate, have also demonstrated their ability to control biogenic amine formation (Lee *et al*., 2018). The mechanism of action of these bioactive compounds is primarily attributed to their ability to inhibit microbial growth.

The inhibition of histamine by bioactive compounds is typically linked to their antimicrobial activity (Tsafack and Tsopmo, 2022). Consequently, numerous reviews have been conducted to explore the use of bioactive compounds in inhibiting histamine formation in fish and fishery products by targeting histamine-forming bacteria (Chen *et al*., 2012; Trevisani *et al*., 2017; Hwang *et al*., 2019). However, the regulation of histamine by inhibiting the activity of histidine decarboxylase is not commonly practiced, particularly in relation to bioactive substances derived from seaweed. Therefore, utilizing seaweed bioactives as inhibitors of bacteria and histamine-forming enzymes poses a future challenge. This is due to the promising potential of bioactive chemicals found in seaweed that can be utilized to effectively block histamine in fish and fishery products.

Possible utilization of seaweed bioactive compounds as histamine inhibitors in fishery products

Seaweeds are a diverse set of photosynthetic communities that thrive in the marine environment and can be harnessed as a sustainable resource (Ragunath *et al*., 2020). Furthermore, seaweed cultivation is relatively straightforward, with a brief production cycle and minimal production expenses (Adharini *et al*., 2019; Lomartire and Gonçalves, 2022). Seaweed is an excellent choice for substituting synthetic compounds with natural compounds because it is non-toxic, edible, and cost-effective (Lomartire and Gonçalves, 2022). Seaweed-derived bioactive compounds possess various biological activities, including antimicrobial properties. Alkaloids, flavonoids, phenols, and tannins are examples of bioactive compounds found in antibacterial seaweed (Marraskuranto *et al*., 2021; Qurniasih *et al*., 2022). Moreover, the bioactive compounds in seaweed possess the ability to suppress bacterial proliferation and enzymatic function. Extracts from brown algae have been demonstrated to markedly suppress the proliferation of *Morganella morganii*, a notable histamine-producing bacterium, thereby diminishing histamine buildup in fish muscle. This suppression correlates with the presence of phenolic compounds and polysaccharides in seaweed, which not only impede bacterial proliferation but also directly block the enzymatic activity of histidine decarboxylase (Kim *et al*., 2014; Nitta *et al*., 2016). The utilization of these seaweed bioactive antimicrobials is illustrated in Table 3.

Seaweed has abundant phenolic compounds that possess antibacterial properties, making them suitable for use as agents to combat microorganisms in fish and fishery products. Seaweed contains phenolic compounds that can hinder the growth of microorganisms (Reguant *et al*., 2000; Alberto *et al*., 2002). The effectiveness of these compounds depends on their composition and concentration. The inhibitory activity also varies depending on the solvent used and the type of seaweed (Manilal *et al*., 2009). Some bioactive substances found in seaweed can dissolve in certain solvents but not in others. Methanol is the most suitable solvent for extracting antimicrobial compounds from brown seaweed, while acetone is the preferred solvent for green seaweed (Cox, 2010). Seaweed possesses a biological activity that acts as an antibacterial agent. This antibacterial property has the potential to be utilized as an inhibitor of histamine synthesis in fish and fishery products.

Currently, there is limited research on the use of bioactive seaweed to inhibit histidine decarboxylase activity. This presents a

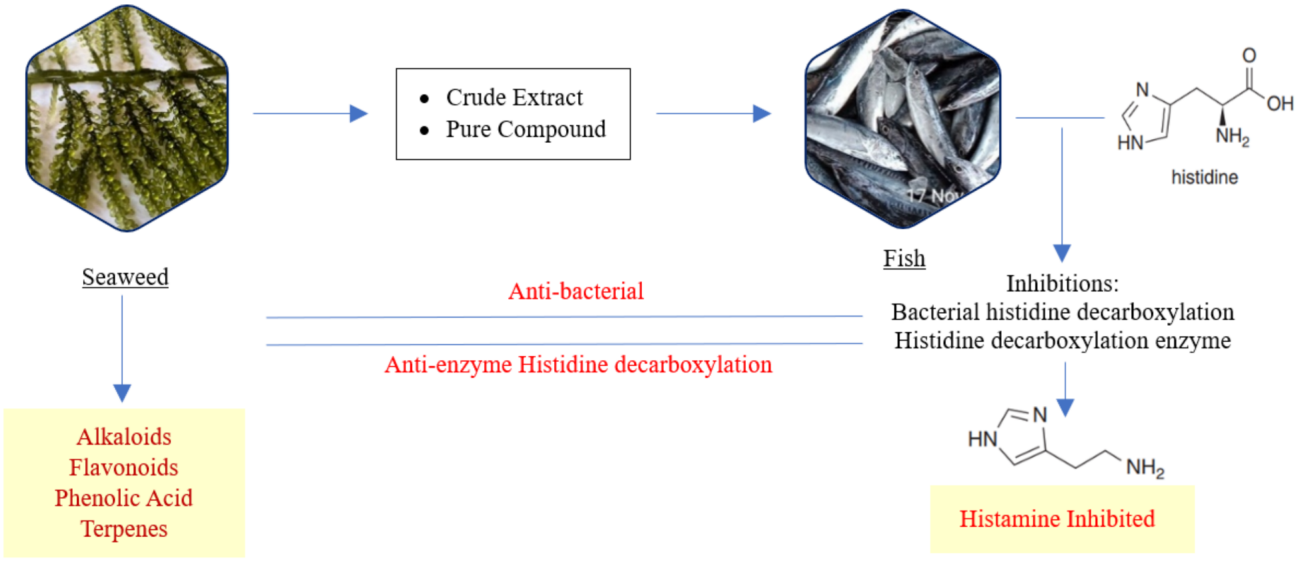

Figure 2. Antimicrobial mechanism of action of bioactive compounds.

future challenge. Bioactive seaweed, in the form of crude extracts or pure compounds, not only has antibacterial properties but also has the potential to be used as an inhibitor of histidine decarboxylase activity in fish and fishery products. Figure 2 illustrates the process of inhibiting histamine in fish and fishery goods during storage. This is achieved by utilizing bioactive chemicals derived from seaweed, which act as antibacterial agents and inhibit the activity of histidine decarboxylase, an enzyme responsible for histamine production in fish and fishery products.

Conclusions

The level of histamine in fishery products is determined by the quantity of histidine and bacteria in the product. Histidine in fish tissue is converted into histamine by bacteria that have the ability to produce histamine, resulting in the synthesis of histamine in fishery goods. Bioactive compounds can serve as an alternative method for controlling the formation of histamine in fishery products. The reduction of histamine by these compounds is linked to their antimicrobial properties. Examples of such bioactive compounds include flavonoids, alkaloids, terpenes, and phenolic acids. These compounds act as antibacterial agents by inhibiting the synthesis of DNA and RNA, disrupting the function of the cytoplasmic membrane, preventing the release of histamine from mast cells, and damaging cell membranes.

The ongoing development of utilizing bioactive chemicals derived from seaweed as antibacterials is a prevailing trend. There is currently limited use of histamine inhibition in fish and fishery products. Therefore, it is necessary to explore the future potential of inhibiting histamine using crude extracts or pure chemicals derived from seaweed. The mechanism of inhibition targets not only the bacterial histidine decarboxylase, but also the enzymatic activity of histidine decarboxylase. This enzyme remains active even when the bacteria are in a dormant or deceased state. Moreover, it is imperative to devise novel or contemporary extraction techniques to address the limitations of conventional extraction procedures like maceration. Ultrasonically aided extraction stands out among contemporary extraction techniques due to its cost-effectiveness, minimal reliance on organic solvents, ability to achieve high compound yields, and reduced extraction time. Therefore, it is imperative to further advance this method for seaweed extraction.

References

Adharini RI, Suyono EA, Suadi Jayanti AD, Setyawan AR, 2019. A comparison of nutritional values of Kappaphycus alvarezii, Kappaphycus striatum and Kappaphycus spinosum from the farming sites in Gorontalo Province, Sulawesi, Indonesia. J Appl Phycol 31:725-30.

Al Bulushi I, Poole S, Deeth HC, Dykes GA, 2009. Biogenic amines in fish: Roles in intoxication, spoilage and nitrosamine formation - a review. Crit Rev Food Sci Nutr 49:369-77.

Alberto MR, Arena ME, Manca de Nadra MC, 2002. A comparative survey of two analytical methods for identification and quantification of biogenic amines. Food Control 13:125-9.

Alhanout K, Malesinki S, Vidal N, Peyrot V, Rolain JM, Brunel JM, 2010. New insights into the antibacterial mechanism of action of squalamine. J Antimicrob Chemother 65:1688-93.

Al-Hijazeen M, Lee EJ, Mendonca A, Ahn DU, 2016. Effects of tannic acid on lipid and protein oxidation, color and volatiles of raw and cooked chicken breast meat during storage. Antioxidants 5:19.

Altieri I, Semeraro A, Scalise F, Calderari I, Stacchini P, 2016. Determination of histamine in fish products by a HPLC – UV-DAD method. Food Chem 211:694-9.

Annunziata L, Schirone M, Campana G, De Massis MR, Scortichini G, Visciano P, 2022. Histamine in fish and fish products: An 8-year survey. Follow up and official control activities in the Abruzzo region (Central Italy). Food Control 133:108651.

Arai M, Yamano Y, Setiawan A, Kobayashi M, 2014. Identification of the target trotein of agelasine, a marine sponge diterpene alkaloid as an anti-dormant mycobacterial Substance. Chembiochem 15:117-23.

Baranowski JD, Brust A, Frank HA, 1985. Properties of its histidine decarboxylase system in resting cells. J Food Biochem 9:349-60.

Beer DJ, Rocklin RE, 1987. Histamine modulation of lymphocyte biology: membrane receptors, signal transduction and functions. Crit Rev Immunol 7:55-91.

Biswas B, Rogers K, McLaughlin F, Daniels D, Yadav A, 2013. Antimicrobial activities of leaf extracts of guava (Psidium guajava l) on two gram-negative and gram-positive bacteria. Int J Microbiol 2013:746165.

Bjornsdottir-Butler K, Abraham A, Harper A, Dunlap PV, Benner RA, 2018. Biogenic amine production by and phylogenetic analysis of 23 Photobacterium species. J Food Prot 81:1264-74.

Bjornsdottir-Butler K, Bolton GE, Clellan-green PDMC, Jaykus L, Green DP, 2009. Detection of gram-negative histamine-producing bacteria in fish : a comparative study. J Food Prot 72:1987-91.

Bjornsdottir-butler K, Bolton GE, Jaykus L, Mcclellan-green PD, Green DP, 2010. Development of molecular-based methods for determination of high histamine producing bacteria in fish. Int J Food Microbiol 139:161-7.

Bjornsdottir-Butler K, Bowers JC, Benner RA, 2015. Prevalence and characterization of high histamine-producing bacteria in Gulf of Mexico fish species. J Food Prot 78:1335-42.

Bjornsdottir-Butler K, May S, Hayes M, Abraham A, Benner RA, 2020, Characterization of a novel enzyme from Photobacterium phosphoreum with histidine decarboxylase activity. Int J Food Microbiol 334:108815.

Boberek JM, Stach J, Good L, 2010. Genetic evidence for inhibition of bacterial division protein ftsz by berberine. PLoS One 5:e13745.

Cai L, Liu S, Sun L, Wang Y, Ji H, Li J, 2015. Application of tea polyphenols in combination with 6-gingerol on shrimp paste of during storage : biogenic amines formation and quality determination. Front Chem 6:981.

Cano A, Andres M, Chiralt A, González-Martinez C, 2020. Use of tannins to enhance the functional properties of protein based films. Food Hydrocolloids 100:105443.

Casu L, Cottiglia F, Leonti M, Logu A De, Agus E, Tse-dinh Y, Lombardo V, Sissi C, 2011. Letters Ungeremine effectively targets mammalian as well as bacterial type I and type II topoisomerases. Bioorg Med Chem Lett 21:7041-4.

Chen HC, Huang YR, Hsu HH, Lin C Saint, Chen WC, Lin CM, Tsai YH, 2010. Determination of histamine and biogenic amines in fish cubes (Tetrapturus angustirostris) implicated in a food-borne poisoning. Food Control 21:13-8.

Chen M, Chiu T, Cho Y, 2012. Development of random ampli fi ed

polymorphic DNA-based speci fi c polymerase chain reaction primers for the detection of the histamine-producing bacterium Photobacterium damselae subsp damselae. Food Control 26:466-71.

Chinnam N, Dadi PK, Sabri SA, Ahmad M, Kabir MA, Ahmad Z, 2010. Dietary bioflavonoids inhibit Escherichia coli ATP synthase in a differential manner. Int J Biol Macromol 46:478-86.

Costanza C, Cecchini M, Mancusi R, Mosso A, Giani G, Rosmini R, Trevisani M, 2013. Evaluation and identification of histamine-forming bacteria on fish products of middle Adriatic Sea. Ital J Food Saf 2:e7.

Cox S, 2010. An assessment of the antioxidant and antimicrobial activity of six species of edible irish seaweeds an assessment of the antioxidant and antimicrobial activity of six species of edible irish seaweeds. Int Food Res J 17:205-20.

Crivellato E, Ribatti D, 2010. The mast cell: an evolutionary perspective. Biol Rev 85:347-60.

Cushnie TPT, Lamb AJ, (2005). Antimicrobial activity of flavonoids. Int J Antimicrob Agents 26:343-56.

De Mey E, De Klerck K, De Maere H, Dewulf L, Derdelinckx G, Peeters MC, Fraeye I, Vander Heyden Y, Paelinck H, 2014. The occurrence of N-nitrosamines, residual nitrite and biogenic amines in commercial dry fermented sausages and evaluation of their occasional relation. Meat Sci 96:821-8.

Dewey-Mattia D, Manikonda K, Hall AJ, Wise ME, Crowe SJ, 2018. Surveillance for foodborne disease outbreaks - United States, 2009-2015. MMWR Surveill Summ 67:1-11.

Diaz M, Ladero V, Redruello B, Fernández M, Cruz M, Alvarez MA, 2020. Histamine production in Lactobacillus vaginalis improves cell survival at low pH by counteracting the acidification of the cytosol. Int J Food Microbiol 321:108548.

Dimech GS, Alberto L, Soares L, Ferreira MA, Gabrielle A, Oliveira VDe, Carvalho C, Ximenes EA, 2013. Phytochemical and antibacterial investigations of the extracts and fractions from the stem bark of Hymenaea stigonocarpa Mart . ex hayne and effect on ultrastructure of Staphylococcus aureus Induced by Hydroalcoholic Extract, 2013. ScientificWorldJournal 2013:862763.

Elik A, Altunay N, Gürkan R, 2019. Ultrasound-assisted low-density solvent-based dispersive liquid–liquid microextraction coupled to spectrophotometry for the determination of low levels of histamine in fish and meat products. Food Anal Methods 12:489-502.

Emborg J, Dalgaard P, Ahrens P, 2006. Morganella psychrotolerans sp. nov., a histamine-producing bacterium isolated from various seafoods. Int J Syst Evol Microbiol 56:2473-9.

Esteves FC, Pontelo J, Vieira V, Silva E, Melo V, Vinícius V, Ferreira A, 2020. Yogurt griego adicionado de harinas integrales de sorgo: potencial antioxidant evaluación sensorial. Rev Chil Nutr 47:272-80.

Evangelista WP, Silva TM, Guidi LR, Tette PAS, Byrro RMD, Santiago-Silva P, Fernandes C, Gloria MBA, 2016. Quality assurance of histamine analysis in fresh and canned fish. Food Chem 211:100-6.

Evans WC, 2009. Pharmacognosy. Sixteenth edition Saunders, Edinburgh, London, New York, Philadelphia, St Louis, Sydney, Toronto.

FDA, 2022. Fish and fishery products hazards and controls guidance. Available from: https://www.fda.gov/food/seafood-guidance-documents-regulatory-information/fish-and-fishery-products-hazards-and-controls.

Ferrario C, Pegollo C, Ricci G, Borgo F, Fortina MG, 2012. PCR detection and identification of histamine-forming bacteria in filleted tuna fish samples. J Food Sci 77:M115-20.

Galli SJ, Gordon JR, Wershel BK, 1991. Cytokine production by mast cells and basophils. Current Opinion in Immunology 3:865–873.

Gardini F, Ozogul Y, Suzzi G, Tabanelli G, Ozogul F, 2016. Technological factors affecting biogenic amine content in foods: a review. Front Microbiol 7:1218.

Gephart JA, Henriksson PJG, Parker RWR, Shepon A, Gorospe KD, Bergman K, Eshel G, Golden CD, Halpern BS, Hornborg S, Jonell M, Metian M, Mifflin K, Newton R, Tyedmers P, Zhang W, Ziegler F, Troell M, 2021. Environmental performance of blue foods. Nature 597:360-5.

Golden CD, Koehn JZ, Shepon A, Passarelli S, Free CM, Viana DF, Matthey H, Eurich JG, Gephart JA, Fluet-Chouinard E, Nyboer EA, Lynch AJ, Kjellevold M, Bromage S, Charlebois P, Barange M, Vannuccini S, Cao L, Kleisner KM, Thilsted SH, 2021. Aquatic foods to nourish nations. Nature 598:315-20.

Gomez-Gonzalez NE, Garcia-Garcia E, Montero J, Garcia-Alcazar A, Meseguer J, Garcia-Ayala A, Mulero V, 2014. Isolation of mast cells from the peritoneal exudate of the teleost fish gilthead sea bream (Sparus aurata L). Fish Shellfish Immunol 40:225-32.

Gopi M, Thankappanpillai AKT, Prakash S, Mohan GC, 2016. Opportunistic pathogen Klebsiella pneumoniae isolated from Maldive's clown fish Amphiprion nigripes with hemorrhages at Agatti Island, Lakshadweep archipelago. IJFAS 4:464-7.

Harmoko H, Kartasasmita RE, Munawar H, Rakhmawati A, Budiawan B, 2022. Determination of histamine in different compositions of commercially canned fish in Indonesia by modified QuEChERS and LC-MS/MS. J Food Comp Anal 105:104256.

Hirasawa N, 2019. Expression of histidine decarboxylase and its roles in inflammation. Int J Mol Sci 20:376.

Houicher A, Bensid A, Regenstein JM, Ozogul F, 2021. Control of biogenic amine production and bacterial growth in fish and seafood products using phytochemicals as biopreservatives : A review. Food Biosci 39:100807.

Houicher A, Kuley E, Ozogul F, Bendeddouche B, 2015. Effect of natural extracts (Mentha spicata l and Artemisia campestris) on biogenic amine formation of sardine vacuum-packed and refrigerated (Sardina pilchardus) fillets. J Food Processing Preservation 39:2393-403.

Huang YR, Liu KJ, Hsieh HS, Hsieh CH, Hwang DF, Tsai YH, 2010. Histamine level and histamine-forming bacteria in dried fish products sold in Penghu Island of Taiwan. Food Control 21:1234-9.

Hwang BS, Wang JT, Choong YM, 2003. A rapid gas chromatographic method for the determination of histamine in fish and fish products. Food Chem 82:329-34.

Hwang C, Tseng P, Lee Y, Kung H, Huang C, Chen H, Tsai Y, 2019. Determination of histamine in Japanese Spanish mackerel (Scomberomorus niphonius) meat implicated in a foodborne poisoning. J Food Prot 82:1643-9.

Ibrahim HK, Almayah AA, Issa AH, 2017. Molecular detection of environmental morganella morganii as histamine producing bacteria molecular detection of environmental Morganella morganii as histamine producing bacteria. Donnish J Med Med Sci 4:8-13.

Inami Y, Fukushima M, Murota H, 2021. Expression of histidine decarboxylase in melanocytes of the human skin. Biochem

Biophys Res Commun 535:19-24.
Kanki M, Yoda T, Tsukamoto T, Baba E, 2007. Histidine decarboxylases and their role in accumulation of histamine in tuna and dried saury. Appl Environ Microbiol 73:1467-73.
Karoui R, Hassoun A, 2017. Efficiency of rosemary and basil essential oils on the shelf-life extension of Atlantic mackerel (Scomber scombrus) fillets stored at 2°C. J AOAC Int 100:335-44.
Kim DH, Kim KB. Cho JY, Ahn DH, 2014. Inhibitory effects of brown algae extracts on histamine production in mackerel muscle via inhibition of growth and histidine decarboxylase activity of Morganella morganii. J Microbiol Biotechnol 24:465-74.
Kim SH, Ben-Gigirey B, Barros-Velázquez J, Price RJ, An H, 2000. Histamine and biogenic amine production by Morganella morganii isolated from temperature-abused albacore. J Food Prot 63:244-51.
Koo P, Lim G, 2023. A review on analytical techniques for quantitative detection of histamine in fish products. Microchem J 189:108499.
Kostaki M, Giatrakou V, Savvaidis IN, Kontominas MG, 2009. Combined effect of MAP and thyme essential oil on the microbiological, chemical and sensory attributes of organically aquacultured sea bass (Dicentrarchus labrax) fillets. Food Microbiol 26:475-82.
Krell T, Gavira JA, Velando F, Fernández M, Roca A, Monteagudo-Cascales E, Matilla MA, 2021. Histamine: a bacterial signal molecule. Int J Mol Sci 22:6312.
Kung HF, Huang CY, Lin CM, Liaw LH, Lee YC, Tsai YH, 2015. The histamine content of dried flying fish products in Taiwan and the isolation of halotolerant histamine-forming bacteria. J Food Drug Anal 23:335-42.
Lee J, Kim Y, Her J, Kim MK, Lee K, 2018. Reduction of biogenic amine contents in fermented soybean paste using food additives. LWT 98:470-6.
Lomartire S, Gonçalves AMM, 2022. An overview of potential seaweed-derived bioactive compounds for pharmaceutical applications. Mar Drugs 20:141
López-Sabater EI, Rodríguez-Jerez JJ, Hernández-Herrero M, Mora-Ventura MT, 1996. Incidence of histamine-forming bacteria and histamine content in scombroid fish species from retail markets in the Barcelona area. Int J Food Microbiol 28:411-8.
Mah J, Park YK, Jin YH, Lee J, Hwang H, 2019. Bacterial production and control of biogenic amines in asian fermented soybean foods. Foods 8:85.
Maldonado M, Maeyama K, 2013. Simultaneous electrochemical measurement method of histamine and N τ-methylhistamine by high-performance liquid chromatography- amperometry with o-phthalaldehyde-sodium sulfite derivatization. Anal Biochem 432:1-7.
Manilal A, Sujith S, Kiran GS, Selvin J, Shakir C, Gandhimathi R, Lipton AP, 2009. Antimicrobial potential and seasonality of red algae collected from the southwest coast of India tested against shrimp, human and phytopathogens. Ann Microbiol 59:207-19.
Marcus EN, 2024. Scombroid (histamine) poisoning. Available from: https://www.uptodate.com/contents/scombroid-histamine-poisoning.
Marraskuranto E, Nursid M, Utami S, Setyaningsih I, Tarman K, 2021. Phytochemical content antibacterial and antioxidant potency of Caulerpa racemosa extracted with different solvents. JPB Kelautan dan Perikanan 16:1-10.
Marshall JS, 2004. Mast-cell responses to pathogens. Nat Rev Immunol 4:787-99.
Melgarejo E, Urdiales JL, Sánchez-Jiménez F, Medina MÁ, 2010. Targeting polyamines and biogenic amines by green tea epigallocatechin-3- gallate. Amino Acids 38:519-23.
Meng J, Yang Q, Wan W, Zhu Q, Zeng X, 2022. Physicochemical properties and adaptability of amine-producing Enterobacteriaceae isolated from traditional Chinese fermented fish (Suan yu). Food Chem 369:130885.
Mercogliano R, Santonicola S, 2019. Scombroid fish poisoning: factors influencing the production of histamine in tuna supply chain: a review. LWT 114:108374.
Naila A, Flint S, Fletcher G, Bremer P, Meerdink G, 2010. Control of biogenic amines in food - existing and emerging approaches. J Food Sci 75:R139-50.
Neumann N, Honke M, Povydysh M, Guenther S, Schulze C, 2022. Evaluating tannins and flavonoids from traditionally used medicinal plants with biofilm inhibitory effects against MRGN E. coli. Molecules 27:2284.
Nevado DL, Santos SD, Bastian G, Deyta J, Managuelod EJ, Fortaleza JA, De Jesus R, 2023. Detection, Identification, and Inactivation of histamine-forming bacteria in seafood: a mini-review. J Food Prot 26:100049.
Nitta Y, Yasukata F, Kitamoto N, Ito M, Sakaue M, Kikuzaki H, Ueno H, 2016. Inhibition of Morganella morganii histidine decarboxylase activity and histamine accumulation in mackerel muscle derived from Filipendula ulumaria extracts. J Food Prot 79:463-7.
Oh E, Jeon B, 2015. Synergistic anti-campylobacter jejuni activity of fluoroquinolone and macrolide antibiotics with phenolic compounds. Front Microbiol 6:1129.
Ojagh SM, Rezaei M, Razavi SH, Hosseini SMH, 2010. Effect of chitosan coatings enriched with cinnamon oil on the quality of refrigerated rainbow trout. Food Chem 120:193-8.
Oktariani AF, Ramona Y, Sudaryatma PE, Dewi IAM, Shetty K, 2022. Role of marine bacterial contaminants in histamine formation in seafood products: a review. Microorganisms 10:1197.
Okuzumi M, Himishi A, Kobayashi T, Fujii T, 1994. Photobacterium histaminum sp. nov., a histamine-producing marine bacterium. Int J Syst Bacteriol 44:631-6.
Olatunde OO, Benjakul S, 2018. Natural preservatives for extending the shelf-life of seafood: A revisit. Compr Rev Food Sci Food Saf 17:1595-612.
Olchowik-Grabarek E, Sekowski S, Bitiucki M, Dobrzynska I, Shlyonsky V, Ionov M, Burzynski P, Roszkowska A, Swiecicka I, Abdulladjanova N, Zamaraeva M, 2020. Inhibition of interaction between Staphylococcus aureus α-hemolysin and erythrocytes membrane by hydrolysable tannins: structure-related activity study. Sci Rep 10:11168.
Ollila F, Halling K, Vuorela P, Vuorela H, Slotte JP, 2002. Characterization of flavonoid – biomembrane interactions. Arch Biochem Biophys 399:103-8.
Othman L, Sleiman A, Abdel-massih RM, 2019. Antimicrobial activity of polyphenols and alkaloids in middle eastern plants. Front Microbiol 10:911.
Ozogul F, Kuley E, Kenar M, 2011. Effects of rosemary and sage tea extract on biogenic amines formation of sardine (Sardina pilchardus) fillets. Int J Food Sci Technol 46:761-6.
Pater-huijsen FLD, Pompen M, Jansen HM, Out TA, 1997. Products from mast cells influence T lymphocyte proliferation

and cytokine production - relevant to allergic asthma. Immunol Lett 57:47-51.

Phuvasate S, Su YC, 2010. Effects of electrolyzed oxidizing water and ice treatments on reducing histamine-producing bacteria on fish skin and food contact surface. Food Control 21:286-91.

Purnamasari F, Kuspradini H, Mitsunaga T, 2021. Estimation of total phenol content and antimicrobial activity in different leaf stage of Lepisanthes amonea. Adv Biol Sci Res 11:163-5.

Qian Y, Yang S, Ye J, Xie J, 2018. Effect of quercetin-containing preservatives and modified atmospheric packaging on the production of biogenic amines in Pacific white shrimp (Litopenaeus vannamei). Aquaculture Fisheries 3:254-9.

Qurniasih I, Safitri I, Aritonang AB, Warsidah W, Helena S, 2022. Total phenolic contents in methanol and ethyl acetate extracts of Caulerpa racemosa. Indonesian J Pure Appl Chem 5:96.

Ragunath C, Kumar YAS, Kanivalan I, Radhakrishnan S, 2020. Phytochemical screening and GC-MS analysis of bioactive constituents in the methanolic extract of Caulerpa racemosa (Forssk.) j. agardh and Padina boergesenii allender & kraft. Curr Appl Sci Technol 20:380-93.

Ramezani Z, Zarei M, Raminnejad N, 2015. Comparing the effectiveness of chitosan and nanochitosan coatings on the quality of refrigerated silver carp fillets. Food Control 51:43-8.

Rawles DD, Flick GJ, Martin RE, 1996. Biogenic amines in fish and shellfish. Adv Food Nutr Res 39:329-65.

Reber LL, Hernandez JD, Galli SJ, 2017. The pathophysiology of anaphylaxis. J Allergy Clin Immunol 140:335-48.

Reguant C, Bordons A, Arola L, Rozès N, 2000. Influence of phenolic compounds on the physiology of Oenococcus oeni from wine. J Appl Microbiol 88:1065-71.

Reite OB, 1972. Comparative physiology of histamine. Physiol Rev 52:778-819.

Rodríguez-Caso C, Rodríguez-Agudo D, Sánchez-Jiménez F, Medina MA, 2003. Green tea epigallocatechin-3-gallate is an inhibitor of mammalian histidine decarboxylase. Cell Mol Life Sci 60:1760-3.

Rodtong S, Nawong S, Yongsawatdigul J, 2005. Histamine accumulation and histamine-forming bacteria in Indian anchovy (Stolephorus indicus). Food Microbiol 22:475-82.

Ruiz-Capillas C, Herrero AM, 2019. Impact of biogenic amines on food quality and safety. Foods 8:62.

Sánchez-Maldonado AF, Schieber A, Ganzle MG, 2011. Structure-function relationships of the antibacterial activity of phenolic acids and their metabolism by lactic acid bacteria. J Appl Microbiol 111:1176-84.

Silva LN, Zimmer KR, Macedo AJ, Trentin DS, 2016. Plant natural products targeting bacterial virulence factors. Chem Rev 116:9162-236.

Silva TM, Sabaini PS, Evangelista WP, Gloria MBA, 2011. Occurrence of histamine in Brazilian fresh and canned tuna. Food Control 22:323-7.

Štumpf S, Hostnik G, Langerholc T, Pintarič M, Kolenc Z, Bren U, 2023. The influence of chestnut extract and its components on antibacterial activity against Staphylococcus aureus. Plants 12:2043.

Sun Q, Chen Q, Li F, Zheng D, Kong B, 2016. Biogenic amine inhibition and quality protection of harbin dry sausages by inoculation with Staphylococcus xylosus and Lactobacillus plantarum. Food Control 68:358-66.

Sun Q, Sun F, Zheng D, Kong B, Liu Q, 2019. Complex starter culture combined with vacuum packaging reduces biogenic amine formation and delays the quality deterioration of dry sausage during storage. Food Control 100:58-66.

Tabanelli G, Torriani S, Rossi F, Rizzotti L, Gardini F, 2012. Effect of chemico-physical parameters on the histidine decarboxylase (HdcA) enzymatic activity in Streptococcus thermophilus PRI60. J Food Sci 77:M231-7.

Takahashi H, Ogai M, Miya S, Kuda T, Kimura B, 2015. Effects of environmental factors on histamine production in the psychrophilic histamine-producing bacterium Photobacterium iliopiscarium. Food Control 52:39-42.

Taylor SL, Guthertz LS, Leatherwood M, Lieber ER, 1979. Histamine production by Klebsiella pneumoniae and an incident of scombroid fish poisoning. Appl Environ Microbiol 37:274-8.

Tominaga K, Higuchi K, Hamasaki N, Hamaguchi M, Takashima T, Tanigawa T, Watanabe T, Fujiwara Y, Tezuka Y, Nagaoka T, Kadota S, Ishii E, Kobayashi K, Arakawa T, 2002. In vivo action of novel alkyl methyl quinolone alkaloids against Helicobacter pylori. J Antimicrob Chemother 50:547-52.

Trevisani M, Mancusi R, Cecchini M, Costanza C, 2017. Detection and characterization of histamine-producing strains of Photobacterium damselae subsp damselae Isolated from Mullets. Vet Sci 4:31.

Triggiani M, Oriente A, Crescenze GD, Marine G, 1995. Metabolism of lipid mediators in human basophils and mast cells. Chem Immunol 61:135-47.

Tsafack PB, Tsopmo A, 2022. Effects of bioactive molecules on the concentration of biogenic amines in foods and biological systems. Heliyon 8:e10456.

Tsai YH, Lin CY, Chien LT, Lee TM, Wei CI, Hwang DF, 2006. Histamine contents of fermented fish products in Taiwan and isolation of histamine-forming bacteria. Food Chem 98:64-70.

Valiollah K, Vadood R, Abolhassan K, Alireza S, 2012. Histamine-producing bacteria isolated from frozen longtail tuna (Thunnus tonggoh). Afr J Microbiol Res 6:751-6.

Visciano P, Schirone M, Paparella A, 2020. An overview of histamine and other biogenic amines in fish and fish products. Foods 9:1795.

Wang D, Yamaki S, Kawai Y, Yamazaki K, 2020. Histamine production behaviors of a psychrotolerant histamine □ producer, Morganella psychrotolerans, in various environmental conditions. Curr Microbiol 77:460-7.

Wang J, Fang J, Wei L, Zhang Y, Deng H, Guo Y, Hu C, Meng Y, 2019. Decrease of microbial community diversity, biogenic amines formation and lipid oxidation by phloretin in Atlantic salmon fillets. LWT 101:419-26.

Wang Z, Shi C, Wang H, Wan X, Zhang Q, Song X, Li G, Gong M, Ye S, Xie G, Huang J, 2020. A novel research on isolation and characterization of Photobacterium damselae subsp. damselae from Pacific white shrimp, Penaeus vannamei, displaying black gill disease cultured in China. J Fish Dis 43:551-9.

Wendakoon CN, Morihiko S, 1995. Inhibition of amino acid decarboxylase activity of Enterobacter aerogenes by active components in spices. J Food Prot 58:280-3.

Wu C, Li Y, Wang L, Hu Y, Chen J, 2016. Efficacy of chitosan-gallic acid coating on shelf life extension of refrigerated pacific mackerel fillets. Food Bioprocess Technol 9:675-85.

Xie Y, Yang W, Tang F, Chen X, Ren L, 2015. Antibacterial activities of flavonoids : structure-activity relationship and mechanism. Curr Med Chem 86:132-49.

Xie Z, Wang Y, Chen Y, Xu X, Jin Z, Ding Y, Yang N, Wu F, 2017. Tuneable surface enhanced raman spectroscopy hyphenated to

chemically derivatized thin-layer chromatography plates for screening histamine in fish. Food Chem 230:547-52.

Yamashita K, Suzuki Y, Matsui T, Yoshimaru T, Yamaki M, Suzuki-Karasaki M, Hayakawa S, Shimizu K, 2000. Epigallocatechin gallate inhibits histamine release from rat basophilic leukemia (RBL-2H3) cells: role of tyrosine phosporylation pathway. Biochem Biophys Res Commun 274:603-8.

Yamazaki Y, Kawano Y, 2010. Inhibitory effect of hydroxyindoles and their analogues on human melanoma tyrosinase. Z Naturforsch C J of Biosci 65:49-54.

Yang J, Tauschek M, Robins-browne RM, 2011. Control of bacterial virulence by arac-like regulators that respond to chemical signals. Trends Microbiol 19:128-35.

Zhou P, Tang D, Zou J, Wang X, 2022. An alternative strategy for enhancing stability and antimicrobial activity of catechins by natural deep eutectic solvents. Lwt 153:112558.