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REVIEW

Biogenic amines in seafood: a review

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Abstract The biogenic amines are low molecular weight organic bases present normally in the body with biological activity influencing important physiological functions. The physiological functions of these molecules are achieved by very low concentrations in the tissues. However, significantly high amounts of biogenic amines are produced during processing and storage of seafood as a result of microbial contamination and inadequate storage conditions. Microorganisms having decarboxylase enzyme activity convert amino acids to their respective biogenic amines. Biogenic amines in seafood have been implicated as a major causative agent of food borne illness, where intoxication results from the ingestion of foods containing higher amount of biogenic amines. Hence its identification, quantitation and awareness of this food borne toxin are important in relation to food safety and spoilage. The aim of this paper is to review the basic concepts of seafood quality and safety in relation to biogenic amines along with its control measures and future areas for research.

Keywords Biogenic amines · Histamine · Scombrotoxin · Fish

Introduction

Biogenic amines (BA) are basic nitrogenous compounds of low molecular weight formed by decarboxylation of amino acids or amination and transamination of aldehydes or ketones (Askar and Treptow 1986). Removal of the α-carboxyl group from a proteinous amino acid leads to the corresponding BA (Karovicova and Kohajdova 2005). BA are found in a variety of food products including seafood, meat, dairy, fruits, vegetables, nuts, chocolates and fermented products (Brink et al. 1990). According to the chemical structure, BA are classified into heterocyclic (histamine and tryptamine), aliphatic (putrescine and cadaverine) or aromatic (tyramine and phenylethylamine) compounds (Santos 1996). Depending on the number of amine groups, amines are classified into mono amines (tyramine and phenylethylamine), diamines (histamine, putrescine and cadaverine) or poly amines (spermidine and spermine) (EFSA 2011). The most common BA found in food are histamine, tyramine, cadaverine, 2-phenylethylamine, spermine, spermidine, putrescine, tryptamine, and agmatine. Octopamine and dopamine are also found in meat and seafoods (Naila 2012).

The important biogenic amines in seafood are histamine, tyramine, tryptamine, putrescine, and cadaverine. These are formed from their respective free amino acids histidine, tyrosine, tryptophan, ornithine and lysine (Figs. 1 and 2). Spermidine and spermine are produced from putrescine (Zarei et al. 2011). The concentration of free amino acids especially histidine is important since histidine is the precursor in the biosynthesis of histamine (Table 1). Ezzat et al. (2015) found that histidine content was 2.1–2.2 % of total amino acid content in natural and acid assistant fermented fish product 'ikan pekasam' produced from Javanese carp. Glutamic acid together with lysine, arginine, leucine, aspartic acid, isoleucine, glycine, alanine, threonine and valine represented 77.6 % of total amino acids in naturally fermented fish.

The biogenic amines are produced through decarboxylation of specific free amino acids by exogenous decarboxylase enzymes released by microorganisms associated with seafood (Lee et al. 2015a). Decarboxylase enzymes belong to

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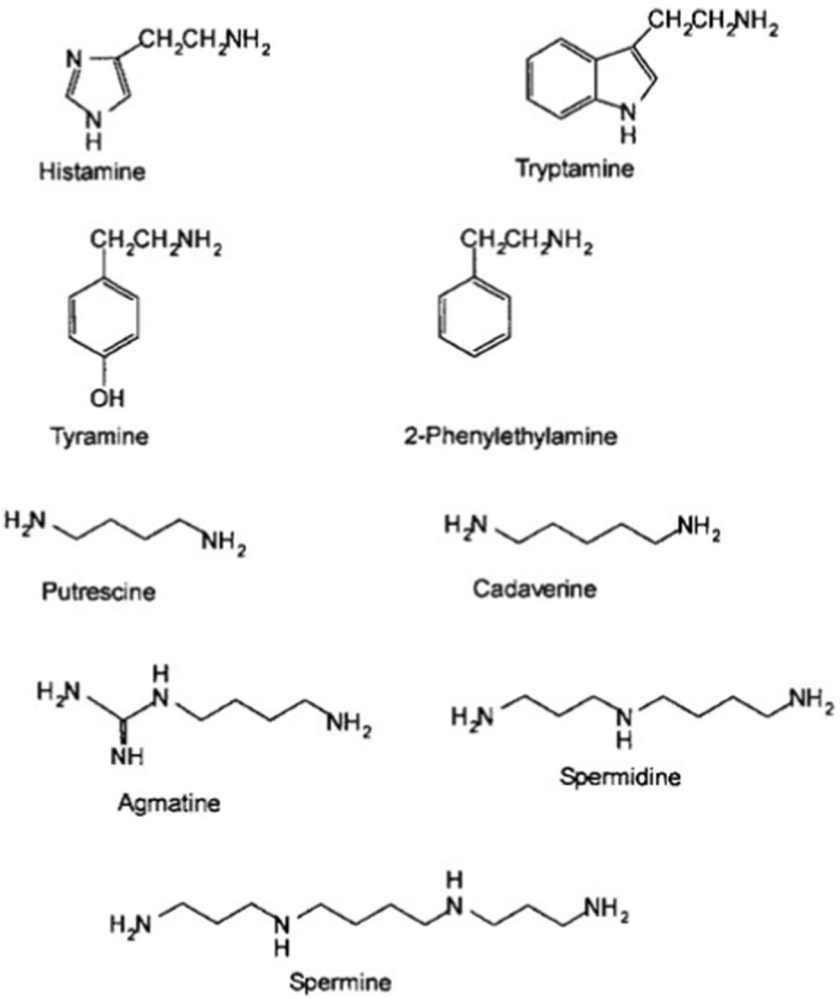

Fig. 1 Structure of biogenic amines (Onal 2007)

pyridoxal-phosphate dependent enzyme (PLP) group which use pyridoxal-5′-phospahte as a coenzyme. Histamine decarboxylases are of two different classes. One group requires pyridoxal phosphate as a cofactor and the other group uses a covalently bound pyruvoyl moiety as the prosthetic group (EFSA 2011). Tyrosine decarboxylase converts tyrosine to

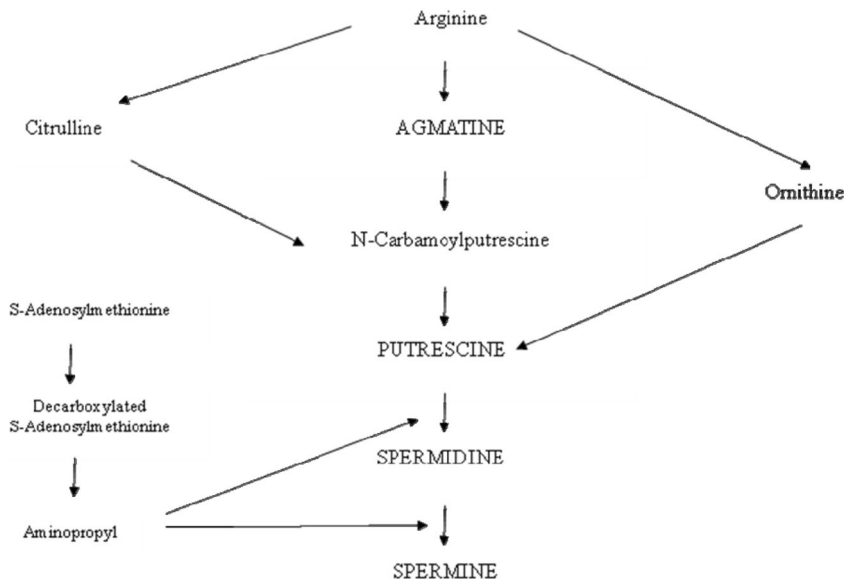

Fig. 2 Biosynthesis of polyamines (Lima and Gloria 1999)

Table 1 Free histidine content in the skeletal muscle of some commercially important fishes

Common name	Scientific name	Histidine (mg/Kg)
Frigate mackerel	*Auxius tapeinocephalus*	1460
Skipjack tuna	*Katsuwonus pelamis*	1340
Yellow fin tuna	*Thunnus albacares*	1220
Little tuna	*Euthunnus affinis*	1090
Blue fin tuna	*Thunnus maccoyii*	667
Big eye tuna	*Thunnus obesus*	745
Yellow tail	*Seriola quinqueradiata*	1160
Yellow tail	*Seriola aureovittata*	732
Rudder fish	*Seriola purpurascens*	286
Sword fish	*Makaira mitsukurii*	831
Black marlin	*Makaira mazora*	763

(Suyama and Yoshizawa 1973)

tyramine and it also catalyses L-dopa decarboxylation. Lysine decarboxylase converts lysine to cadaverine and the cadaverine production is mainly associated with gram negative bacteria (Bover-Cid and Holzapfel 1999). Putrescine is formed from ornithine by ornithine decarboxylase. Arginine is converted to agmatine by arginine decarboxylase and is further converted into putrescine by agmatine deiminase system, which is formed by three enzymes viz agmatine deiminase, putrescine carbamoyltransferase and carbamate kinase (Arena and Manca de Nadra 2001). Putrescine and cadaverine are oxidized by diamine oxidase to form aldehydes (Askar and Treptow 1986). During the degradation of these amines, there are always redox reactions catalyzed by amine oxidases and aldehyde dehydrogenases. The interconversion pathway of polyamine metabolism allows the increase in size of molecules from putrescine to spermidine and from spermidine to spermine by sequential transfer of aminopropyl groups in reactions catalyzed by spermidine and spermine synthase respectively (Medina et al. 2003). Of all the biogenic amine Histamine is the most significant and thoroughly studied amine.

Microorganisms associated with biogenic amines formation

Many of the bacterial species are able to convert histidine to histamine. Enterobacteriaceae are generally considered to be the primary cause of histamine development in scombroid fish. *Morganella morganii*, *Klebsiella pneumoniae* and *Hafnia alvei* are the strongest histamine producers (EFSA 2011). Other bacterial species capable of producing histamine include *Morganella psychrotolerans*, *Photobacterium phosphoreum*, *Photobacterium psychrotolerans* (Ozogul and Ozogul 2006), *Clostridium spp*, *Vibrio alginolyticus*, *Acinetobacter lowffi*, *Plesiomonas shigelloides*, *Pseudomonas putida*, *Pseudomonas fluorescens*, *Aeromonas spp.* (Yatsunami and Echigo 1993; Hwang et al. 2010). Enteric bacterial species with histamine producing capacity include *Proteus vulgaris*, *Proteus mirabilis*, *Enterobacter aerogenes*, *Enterobacter cloacae*, *Serratia fonticola*, *Serratia liquefaciens* and *Citrobacter freundii* (Tsai et al. 2005; Kung et al. 2009). *Staphylococcus spp.*, *Vibrio spp*, and *Pseudomonas spp* were found as histamine producing bacteria in fermented fish by Yatsunami and Echigo (1993).

Fifteen histamine forming bacteria were isolated from tuna dumpling products by Kung et al. (2010). These are *R. ornithinolytica* (four strains), *E. aerogenes* (two strains), *Abaylyi* (one strain) for prolific histamine formers and *Pantoeasp* (one strain), *S. marcescens* (one starin), *B. megaterium* (one starin), *K. oxytoca* (two strains) and *K. pneumoniae* (one strain). Kung et al. (2009) identified *H. alvei* to be a weak histamine former, *R. planticola* and *R. ornithinolytica* as prolific histamine formers with the ability to produce >500 ppm histamine in tuna sandwiches. Hwang et al. (2010) identified *Staphylococcus piscifermentans*, *Bacillus spp*, and *Bacillus subtilis* as week histamine formers in tuna candy products. *Bacillus*, *Citrobacter*, *Clostridium*, *Klebsiella*, *Escherichia*, *Proteus*, *Pseudomonas*, *Salmonella*, *Schigella*, *Photobacterium*, *Lactobacillus*, *Pediococcus*, *Streptococcus* are capable of decarboxylating one or more amino acids (Brink et al. 1990). Lee et al. (2015a) identified ten histamine producing bacterial strains from milk fish having a capacity to produce 373–1261 ppm of histamine in trypticase soy broth supplemented with 1 % L-histidine. The microorganisms identified were *Enterobacteraerogenes* (4 strains), *E cloacae* (1 strain), *Morganella morganii* (2 strains), *Serratia marcescens* (1 strain), *Hafnia alvei* (1 strain) and *Raoultella orithinolytica* (1 strain). Kung et al. (2015) identified *Staphylococcus xylosus*as, a halotolerant bacterium from dried flying fish products that had a consistent ability to produce more than 300 ppm of histamine at 3 % sodium chloride concentration. In fermented seafood, *Staphylococcus* and *Tetragenococcus spp* produce histamine (Yatsunami and Echigo 1993). *Bacillus coagulans* and *Bacillus megaterium* were identified as week histamine formers in fermented fish products by Tsai et al. (2006). The main phenylethylamine producers are tyrosine decarboxylating bacteria and its production is associated with tyramine production. According to Hu et al. (2012), the growth of mesophilic and psychrophilic bacteria in blue scad and octopus positively correlated with the formation of amines such as putrescine, cadaverine, histamine and tyramine during chill storage.

Toxicological effects of biogenic amines

The BA content of seafood was extensively studied by various researchers because of their toxicological effects. Low levels

of biogenic amines do not cause a serious risk to human health, since the amine oxidase (mono amine oxidase and diamine oxidase) in human intestine can detoxify these amines. Histamine can also be detoxified by methylation by methyl transferases or acetylation (Lehane and Olley 2000). However the ingestion of higher levels of biogenic amines may result in toxicological symptoms (Ladero et al. 2010). In some cases the diamine oxidase activity becomes insufficient to affect the metabolism of even low levels of biogenic amines due to gastrointestinal diseases, secondary effects of medicines or alcohol. Some biogenic amines, e.g. histamine and tyramine are considered as antinutritional compounds. For sensitive individuals they represent a health risk especially when their effect is potentiated by other substances (Veciana-Nogues et al. 1997). Fish species of the Scombridae familiy have been found to contain higher levels free histidine which is being converted into histamine during spoilage (Montel et al. 1999). The consumption of food containing high amount of biogenic amines can result in histamine poisoning and tyramine toxicity (Chong et al. 2011). The histamine intoxication is also called as scombroid poisoning since the syndrome occurs as a result of ingesting spoiled fish of Scombridae and Scombresocidae and the fishes include tuna, mahi mahi, blue fish, bonito, skip jack, saury, mackerel and others (FDA 2001). However several non scombroid fish such as sardine, anchovy, herring, marlin, western Australian salmon, sockeye salmon, amberjack, cape yellow tail, sword fish have often been implicated in incidence of scombroid poisoning (Price and Melvin 1994).

Consumption of histamine in the range of 8–40 mg, 40–100 mg or higher than 100 mg in one meal may cause slight, intermediate and severe poisoning respectively (Parente et al. 2001). Scombroid fish poisoning will occur in a healthy individual only when a dose of at least 50 mg histamine is consumed. This generally occurs when the fish is having a histamine level of more than 200 mg/kg. Freshly caught scombrotoxin forming fish typically contain histamine level less than 2 mg/kg (FAO/WHO 2013). Symptoms of scombrotoxin poisoning include tingling and burning sensation around the mouth or throat, rashes or hives on the upper body, head ache, dizziness, itching, nausea, vomiting, diarrhea, heart palpitation, respiratory difficulty etc. The symptoms usually start within a few hours of consumption and last from 12 h to a few days (Lehane and Olley 2000). The severity of symptoms depends on the concentration of poison ingested and the sensitivity of individual towards histamine. The histamine food poisoning symptoms are sometimes confused with Salmonella infection and food allergy (Lehane and Olley 2000).

Biogenic amines like putrescine, cadaverine, spermine and spermidine do not have any adverse health effect, but sometimes they react with nitrite to form carcinogenic nitrosoamines (Hernandez-Jover et al. 1997; Onal et al. 2013). These amines successively undergo deamination and cyclization to secondary amines before reacting with nitrozating agent, ie NO^+. By this way cadaverine is converted into N-nitrosopiperidine, while putrescine, spermine and spermidine are converted in to N-nitrosopyrrolidine (Hernandez-Jover et al. 1997). The acidic conditions of stomach favour the formation of nitrous anhydride and nitrosyl compounds which nitrosate amines to form nitrosamines (Zeisel and DaCosta 1986). Nitrosoproline, a non metabolizable nitrosamine is synthesized in humans following the ingestion of an amine, proline and nitrate (Oshima and Bartsch 1981). Nitrosamines have been detected in smoked fish (Gadbois et al. 1975), fish meal (Sen et al. 1972) and salted marines fish (Zou et al. 1994).

Putrescine, cadaverine, spermine, spermidine in fish tissue can potentiate the toxic effect of histamine by inhibiting intestinal histamine metabolizing enzymes like diamine oxidase (Hungerford and Arefyev 1992) and histamine N-methyltransferase (Stratton et al. 1991). It potentiates the histamine uptake and liberation of endogenous histamine in the intestinal fluids (Ibe et al. 1991). Tyramine and β-phenylethylamine are considered as the initiators of hypertensive crisis in certain patients and dietary induced migraine (Onal 2007). Tyramine intoxication may result in head ache, migraine, nausea, vomiting. In sensitive individuals, it may result in increase of blood pressure leading to the hypertensive crisis (Kantaria and Gokani 2011). The oral toxicity level of putrescine, spermine, and spermidine are 2000, 600 and 600 ppm respectively. Acute toxicity level of tyramine and cadaverine is greater than 2000 ppm (Til et al. 1997). Mohamed et al. (2009) observed that the free amino acid and biogenic amine content in Egyptian salted-fermented fish (Feseekh) increased during ripening and storage. Feseekh can be consumed without any health risk between 20 and 40 days, but it could be hazardous after 60 days due to the increased biogenic amine content.

Determination of biogenic amines

Various analytical methods are developed for the determination of biogenic amines. Biological methods were the first methods for evaluation of scombroid toxin. It was measured as the amount of concentration of histamine that induces response in histamine sensitive organ like guinea pig ileum. The first AOAC method for determination of histamine in food was biological method. The analytical methods used for the separation and quantification of biogenic amines in seafood are by chromatographic methods. It includes gas chromatography, thin layer chromatography (TLC), high performance liquid chromatography (Karovicova and Kohajdova 2005) and paper electrophoresis (Bajc and Gacnik 2009). Most of the biogenic amines quantification methods applied in seafood are based on reverse phase high performance liquid chromatography (HPLC) with pre-column or post-column

derivatization (Malle et al. 1996). Different pre-colum derivatization chemical reagents include benzoyl chloride, dansyl and dabsyl chloride, fluoresceine, 9-fluorenylmethyl chloroformate and post-column derivatization chemical reagents include ninhydrine and o-phthalaldehyde (Wei et al. 1990). Various liquid chromatographic detection techniques include ultra violet detection, fluorescence detection and mass spectrophotometric detection. Chromatography coupled with mass spectrometry is gaining importance due to its high specificity and sensitivity. Moreover, the tedious procedures of derivatization and cleanup are not required when mass spectrometer is the detector.

Gas chromatography is not commonly used in the determination of biogenic amines due to the tailing problem. Biogenic amines are derivatized into trifluoroacetyl, trimethylsilyl or 2, 4-dinitrophenyl forms for its determination. Flame ionization, electron capture and thermal conductivity detectors are mainly used for biogenic amines (Silla-Santos 1996). Thin layer chromatography with pre clean-up of sample and derivatization of BA are used to detect chlorides, 3,5-dinitrobenzamides dansyl and fluorescein derivatives of biogenic amines (Askar and Treptow 1986). One of the most rapid method for the detection of histamine is based on flow injection analysis (FIA). It is capable of detecting of sixty sample extracts in an hour (Hungerford and Wu 2012).

Nishikawa et al. (2012) developed a simple method for the measurement of polyamine as indicator of food decomposition with fluorometer by using 4-(1-Pyrene) butyric and N-hydroxysuccinimide ester (PSE). PSE reacts with primary and secondary amino moieties of polyamines and produces the intra molecular excimer fluorescence. Excimer fluorescence with broad peak at around 470 nm was clearly detected in linear type biogenic amines such as putrescine, cadaverine, spermine and spermidine at 10 mM level. Chen et al. (2010) demonstrated a HPLC method by dansylating with dansyl chloride for detecting the biogenic amine content in fish meat. But the drawback of that method was derivatization and liquid phase extraction. Derivatization steps can be avoided by using TSK gel Amide-80 column under HPLC conditions with subsequent electrospray ionization MS/MS detection. Self et al. (2011) developed a method for the simultaneous quantitative determination of eight biogenic amines by matrix solid phase dispersion (MSPD) extraction followed by ultra-high performance hydrophilic interaction chromatography (UHPLC-HILIC) with orbitrap mass spectrometric detection. The method was able to detect and quantify histamine, agmatine, cadaverine, phenylethylamine, putrescine, tryptamine, tyramine and urocanic acid from canned and frozen tuna matrices. The method was further extended to analyze the same biogenic amines by using MSPD/UHPLC-HILIC/Orbitrap-MS in non-tuna food matrices known to be associated with scombroid poisoning including canned/frozen mackerel, frozen mahi-mahi, sockeye salmon, and fish sauce made with anchovy (Self and Wu 2012). The ultra-high pressure liquid chromatography method coupled with on-line OPA post column derivatization were described by Latorre-Moratalla et al. (2009) for the determination of 12 biogenic amines in a single chromatographic run. Fluorimetric detection at 340 nm for excitation and 445 nm for emission was applied. Recently commercial test kits are available based on selective antibody and immunoassay methods for the determination of histamine (Hungerford and Wu 2012) with advantages of rapidity and not requiring expensive equipment.

Biogenic amine index

The amines are produced during the end of shelf life and hence their levels can be considered as a spoilage indices rather than a quality index (Ozogul and Ozogul 2006). The quality index and biogenic amine index can be calculated according to the method described by Mieltz and Karmas (1977); Veciana-Nogues et al. (1997) respectively. The formulas used are as follows

$$\text{Quality index} = (\text{histamine} + \text{putrescine} + \text{cadaverine})/(1 + \text{spermidine} + \text{spermine})$$
$$\text{Biogenic amine index (BAI)} = (\text{histamine} + \text{putrescine} + \text{cadaverine} + \text{tyramine})$$

According to Mieltz and Karmas (1977), the limit of fish acceptability for quality index is 10. Biogenic amine index value exceeding 10 is regarded as representing some kind of loss in quality (Karovicova and Kohajdova 2005). The usefulness of biogenic amines as a quality index depends on the nature of product. According to Dawood et al. (1988), the putrescine and cadaverine could be used to assess the freshness of rainbow trout. Sato et al. (1995) observed that histamine and other biogenic amines are not reliable spoilage indices in the case of common mackerel. All spoilage microorganisms do not decarboxylate free amino acids and even within the same species, not all strains develop the same decarboxylating capacity. Hence a low biogenic amine concentration may not represent a product with good microbial quality (Stadnik and Dolatowski 2010).

Legal limits of biogenic amines

Biogenic amines like histamine, putrescine and cadaverine are considered as indicators of fish spoilage. So it is important to monitor the level of biogenic amines to assess the degree of freshness of a product. Currently the only biogenic amine for which the maximum limits have been set in the EU and USA is histamine because of its toxicological effects (Table 2). According to USFDA the food is considered as spoiled if the histamine level reaches to 50 ppm. The Codex Alimentarius standards for fish provide histamine level as indicator for decomposition and hygiene and handling. For decomposition, the relevant standard is: the products shall not contain more than 10 mg/100 g (100 mg/kg) of histamine based on average of sample unit tested in the species of Clupeidae, Scombridae, Scomberesocidae, Pomatomidae, and Coryphaenidae. For hygiene and handling the relevant standard is: no sample unit shall contain histamine that exceeds 200 mg/kg in Scombridae, Clupeidae, Coryphaenidae, Scombreresocidae and Pomatomidae families (EFSA 2011). In Canada, Switzerland, and Brazil the maximum permissible limit of histamine in fish and fishery products is 100 mg/kg. The Australian and New Zealand Food Standards Code states that the level of histamine in fish or fish products must not exceed 200 mg/kg (Ezzat et al. 2015). According to Commission regulation (EC) No 2073/2005 nine samples should be taken from each sample for histamine analysis and the mean must not exceed 100 mg/kg. Two samples may have a value of more than 100 mg/kg but less than 200 mg/kg. No sample may have a value greater than or equal to 200 mg/kg.

Control measures

The amount of biogenic amines formed in seafood depends on the availability of free amino acids, microbial growth, presence of decarboxylase enzymes and the favourable environment for the decarboxylation activity (Brink et al. 1990). Free amino acids either occur as such or may be liberated through proteolysis. The levels of free amino acids in seafood gradually increase with prolonged time due to the proteolysis by endogenous and exogenous protease enzymes (Makarios-Laham and Lee 1993). The microbial strains with high proteolytic enzyme activity potentially increase the biogenic amine formation in seafoods. Hence the control of biogenic amine formation is mainly focused on controlling the growth of biogenic amines forming bacteria. According to Halasz et al. (1994), the amino acid decarboxylase activity is stronger in acidic environment and the optimum activity is between 4.00 and 5.5. Biogenic amine formation by bacteria is also influenced by temperature. Temperature between 20 and 37 °C is optimum for the growth of microorganisms containing decarboxylase (Maijala et al. 1993). Hence storage temperature is an important factor contributing to the biogenic amine formation especially for fish that is exposed to warm waters or air and for tunas which generate heat in their tissues (FDA 2011). Thus once chilled, the fish should be maintained at a temperature close to the freezing point until it is consumed and exposure of temperature above 4.4 °C should be minimized. Defrosting of frozen seafood disrupts the cell membranes and releases proteolytic enzymes and free amino acids. Increase of bacterial population may occur while defrosting and further processing of frozen tuna. Contamination with histamine producing bacteria can also occur from the environment or from the equipment in the processing plants (Zarei et al. 2011).

The most effective way to prevent the scombroid fish poisoning is by proper refrigeration of fish starting from the point of production to the final end user. Once the enzyme histidine decarboxylase is present in fish, it can produce histamine in fish even though the bacteria are not active. The enzyme can be activated at or near refrigeration temperatures. Unlike bacterial pathogens, once histamine is produced it cannot be removed by freezing or cooking, including retorting (FDA 1996; Lehane and Olley 2000).

Table 2 Regulatory limits of Histamine in seafood

Country	Limit	Reference
EU	1. Fishery products from fish species associated with high amount of histidine $n=9$, $c=2$, $m=100$ mg/kg, $M=200$ mg/kg	Commission regulation (EC) No 2073/2005
	2. Fishery products which have undergone enzyme maturation treatment in brine $n=9$, $c=2$, $m=200$ mg/kg, $M=400$ mg/ kg	
USFDA	50 ppm (50 mg/kg)	FDA 2011
Australia, Germany and New Zealand Food Standards Code (FSC)	200 mg/kg	Ezzat et al. (2015)
South Africa and Italy	100 mg/kg	Ezzat et al. (2015)

N number of units comprising the sample, *c* number of sample units giving values over *m* or between *m* and *M*

FDA has issued guidelines for the safe processing of seafood based on hazard analysis critical control points (HACCP) approach. The following recommendations were made for chilling fish after harvest by FDA (2011):

- Fish exposed to air or water above 28.3 °C should be placed in ice or refrigerated sea water, ice slurry or brine at 4.4 °C or lower soon after catch but not more than 6 h from the time of death.
- Fish exposed to air or water temperatures of 28.3 °C or lower should be placed in ice or in refrigerated sea water or ice slurry or brine at 4.4 °C or lower as soon as after harvest.
- Fish that are gilled and gutted before chilling should be placed in ice or in refrigerated seawater, ice slurry or brine at 4.4 °C or lower as soon as possible not more than 12 h from the time of death.

Gutting and removal of gills will, delay the production of hazardous levels of histamine. Refrigerated storage at 4.4 °C will reduce the growth of mesophilic histamine producing bacteria. Freezing and frozen storage (−18 °C) will stop the growth of all bacteria and further formation of histamine. Frozen products should not be kept in temperature zone where histamine producing bacteria can grow and produce histamine for long enough to become hazard while thawing. Heating is another method to eliminate histamine producing bacteria, however histamine is heat stable. Hence cooking will eliminate bacteria but not histamine (FAO/WHO 2013).

Other factors influencing the formation of biogenic amines are pH, water activity, salt, acidulant and sweetening agents concentration which may influence the microbial population in fish and lead to difference in BA formation (Chong et al. 2011). The effect of various food additives on biogenic amine formation was studied by Mah and Hwang (2009) and found that glycine is an extremely effective food additive in inhibiting BA formation during the ripening of salted and fermented anchovy. Sodium chloride also showed an inhibitory effect on the decarboxylase activity of biogenic amine production in mackerel (Tsai et al. 2005). Sodium chloride activates tyrosine decarboxylase activity and inhibits histidine decarboxylase activity (Silla-Santos 1996). Presence of histamine, agmatine, and putrescine inhibit the histidine decarboxylation of *Photobacterium phosphorum* N-14. (Halasz et al. 1994).

Oxygen supply has significant role in the formation of BA. According to Halasz et al. (1994) *Enterobacter cloacae* produces about half the quantity of putrescine in anaerobic condition compared to aerobic conditions. During anaerobic conditions, *Klebsiella pneumonia* synthesizes significantly less cadaverine but it acquires the ability to produce putrescine under anaerobic conditions. The effect of oxygen scavenger on BA formation in seer fish during chill storage was investigated by Mohan et al. (2009). Oxygen scavengers were effective in reducing the BA formation in oxygen scavenger packs compared to the control air packs. Biogenic amine formation in barramundi fillets at 8 °C kept in modified atmosphere packs (MAP) was studied by Yassoralipour et al. (2012). It was observed that MAP composition of 75–100 % CO_2 could be the most appropriate gas composition to reduce the production of biogenic amines for barramundi fillets kept at 8 °C up to 16 days. The effect of modified atmosphere packaging on histamine formation in tuna was studied by Emborg et al. (2005) and has observed that MAP with 40 % CO_2/60 %O_2 had strong inhibitory effect on microbial growth and histamine formation by psychrotolerant *M. morganii* and *P. phosphoreum*. High hydrostatic pressure and irradiation are other methods to reduce the histamine producing bacteria. Irradiation controls biogenic amine formation by radiolysis of biogenic amines and by reducing the number of bacteria responsible for biogenic amine formation (Kim et al. 2003). The effect of electrolyzed oxidizing water and ice containing 100 ppm chlorine was studied for soaking salmon and yellow fin tuna (Phuvasate and Su 2010). Soaking in electrolyzed oxidizing water reduced *Enterobactera erogenes* and *Morganella morganii* by 1.3 and 2.2 log CFU/cm^2 respectively for salmon while soaking of yellow fin tuna in electrolyzed oxidizing ice reduced the same microorganisms by 2.4 and 3.5 log CFU/cm^2 respectively (Naila et al. 2010).

The application of bacteria possessing the biogenic amine degrading enzymes or starter cultures are novel techniques explored for reducing biogenic amine concentration in fermented fish products. Eight histamine degrading bacteria were isolated by Lee et al. (2015b) from salted fish products and identified as *Rummelii bacillusstabekisii* (1 isolate), *Agrobacterium tumefaciens* (1 isolate), *Bacillus cereus* (2 isolates), *Bacillus polymyxa* (1 isolate), *Bacillus amyloliquefacines* (1 isolate) and *Bacillus subtilis* (1 isolate). Lee et al. (2015c) used Bacillus polymyxa DO5-1 isolated from salted fish as a starter culture for salted fish fermentation. After 120 days of fermentation, histamine and other biogenic amines in the samples were reduced by 34 and 30 % respectively. Enzymes like diamine oxidase or bacteria that possess diamine oxidase can be used to degrade the biogenic amines that are already formed in the food. Naila et al. (2012) used diamine oxidase enzyme to degrade histamine from 500 mg/L to safer levels (<0.5 ppm) in Rihaakuru, a fish paste produced from tuna soup.

Conclusion

Biogenic amines play an important role in the physiological functions of animals including fishes and in normal conditions the exogenous amines are detoxified by amine oxidase or by conjugation. But if ingested in high levels it leads to intoxication. The maximum acceptable limit for histamine in seafood

as per FDA regulation is 100 mg/Kg or 100 ppm. Hence estimation of biogenic amines is important not only from the point of view of the toxicity and freshness of product, but also for smooth conduct of seafood trade across continents. Higher amount of biogenic amines are formed in seafood mainly due to microbial contamination and it can be prevented by good hygiene practices during processing and strict temperature control during storage. Novel emerging techniques including amine oxidizing enzymes, decarboxylase inhibitors and starter culture combinations need to be further investigated for utilization during handling and processing of seafood to get shelf stable products.

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