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REVIEW ARTICLE

Biogenic amines in fish: Prevention and reduction

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Abstract

High-quality proteins, vital vitamins, minerals, and essential fatty acids may be obtained from fish and fish products. Fish decomposition and the generation of toxicants such as biogenic amines may counteract the benefits of fish consumption on human health, such as protection against coronary heart disease and some cancers. Annually, histamine consumption is recognized as the cause of numerous cases of food poisoning. Even small or moderate doses of histamine or tyramine-containing fish might cause food sensitivity. Cadaverine, putrescine, and tyramine have also been identified as histamine poisoning potentiators. Biogenic amine accumulation in fresh fish and fish products has been linked mostly to the growth of bacteria with amino acid decarboxylase activity, which is aided by a lack of sanitary conditions and proper temperature control during storage. Biogenic amines are used to assess the hygienic quality of various marine and freshwater species and their potential toxicity. Different conventional and modern methods have been employed to control biogenic amine buildup. This review article aims to bring current knowledge concerning biogenic amine content in fresh fish and fish products, as well as the efficacy of present and emerging management techniques, up to date and combined.

Novelty impact statement: This article focuses on the current, emerging prevention and reduction methods of biogenic amines formation in fish and fish products, which is the strength of the manuscript. Furthermore, the first results of the control strategies that are currently the focus of research are discussed.

1 | INTRODUCTION

Fish and fish products are perishable food that usually spoils faster than other meats. The main reason for its spoilage is microbial growth, which leads to the production of toxic metabolites, among which are biogenic amines (BAs) (Gram & Dalgaard, 2002). BAs are low molecular weight compounds that occur naturally in homogeneous and heterocyclic aromatic aliphatic compounds. They are also present in many raw and processed food (Arulkumar et al., 2021).

Histamine (HIS), tyramine (TYR), cadaverine (CAD), 2-phenylethylamine (PHE), spermine (SPM), spermidine (SPD), putrescine (PUT), tryptamine (TRY), agmatine (AGM), octopamine (OCT), and dopamine (DOP) are the most frequent BAs in fish. The concentration of BAs in fresh fish is very low and increases during storage (Kordiovská et al., 2006). Bacteria involved in the decarboxylation of free amino acids (AAs) to form BAs are active in fish and fish products (Chong et al., 2014). Raw material, method of processing, transport, and storage conditions impact the formation of BAs. Moreover, it is also affected by natural flora on the raw material's surface, and enzymes present in fish or microorganisms (Ruiz-Capillas & Jiménez-Colmenero, 2005). Even though fish contains many BAs, only three of them, HIS, CAD, and PUT, are relevant in judging fish quality and safety (Bulushi et al., 2009). Histamine is also one of the most important toxins. It can induce harmful effects in humans, comparable to normal food allergies when it accumulates in some fish (Arulkumar et al., 2021). The fishes that contain red muscles are rich in free histidine which varies from 1 g/kg in herring to as much as 15 g/kg in tuna. The free histidine may convert into histamine by the enzymes' activity at certain conditions (Hassan et al., 2017). The symptoms of HIS poisoning include swelling, rash,

hives, asthma-like symptoms, as well as gastrointestinal symptoms (Arulkumar et al., 2021).

Cooking, smoking, or freezing will not eliminate histamine because it is a thermostable BA (Lázaro & Conte-Junior, 2018). Tuna is still one of the most common sources of histamine toxicity in fish (Visciano et al., 2020). Several histamine poisoning incidences have been documented worldwide as a result of eating raw (fresh or frozen) or processed tuna (canned tuna, smoked, fermented, dried) (Yemmen & Gargouri, 2022). Importantly, BAs cannot be degraded using traditional food preservation methods such as freezing, cooking, drying, and smoking (Houicher et al., 2021). On the other hand, many chemical food additives are added to seafood products to prevent the formation of BAs by inhibiting bacterial growth or decarboxylase activity and thus delaying the formation of the amine. Although these common chemical additives are approved in many countries globally, the potential health problems associated with them have prompted the need to replace them with natural ones. However, these alternatives must prove their efficiency in ensuring food safety and satisfying consumers' desires. Among the most important biopreservatives are plant extracts, bacteriocins, chitosan, and enzymes, which may be used alone or in combination with one of the other preservation methods to control the formation of BAs in fish and fish products (Naila et al., 2010; Prester, 2011; Visciano et al., 2012).

Therefore, it is necessary to think of effective solutions to reduce the formation of BAs in fish and their products due to their association with the occurrence of many cases of food poisoning (Ruiz-Capillas & Jiménez-Colmenero, 2005). This article aims to review available scientific publications about BAs in fish and fish products in terms of prevention and reduction methods.

2 | OPTIMAL CONDITIONS FOR BIOGENIC AMINES FORMATION

BAs are formed by decarboxylation, transamination, reductive amination, and degradation of certain precursor amino compounds (Özogul & Özogul, 2019; Santos, 1996; Zhai et al., 2012). Decarboxylation of free AAs is the most common way (Özogul & Özogul, 2019). The formation of BAs depends on (I) type and amount of free AAs, (II) presence of decarboxylase-positive bacteria, (III) availability of appropriate conditions for growth decarboxylase-positive bacteria and production of BAs, and (IV) extent of application hygienic practices and food safety standards, Figure 1 (Ten Brink et al., 1990; Suzzi & Gardini, 2003; Kordiovská et al., 2006; De Las Rivas et al., 2008; EFSA Panel on Biological Hazards [BIOHAZ], 2011; World Health Organization [WHO], 2013).

Histidine, tyrosine, hydroxytryptophan, tryptophan, lysine, and ornithine are free precursor amino acids that create histamine, tyramine, serotonin, tryptamine, cadaverine, and putrescine (Doeun et al., 2017; Özogul & Özogul, 2019). Furthermore, the concentration of AAs in fish depends on the type of feeding and the fishing season. It was found that fish had higher amounts of lysine and arginine in summer than other seasons (Rabie et al., 2009). AAs are present in food in free form and may also be released from proteins due to proteolytic activity. (Ten Brink et al., 1990).

The type of bacteria present in fish depends on the environmental conditions in the natural habitat of the fish (Huss, 1995). It varies between gram-positive and gram-negative bacteria. Decarboxylase can be produced by both positive and negative bacteria, although in various ways (BIOHAZ, 2011; Björnsdóttir-Butler et al., 2010; WHO, 2013). Bacteria-producing BAs are likely to be found on

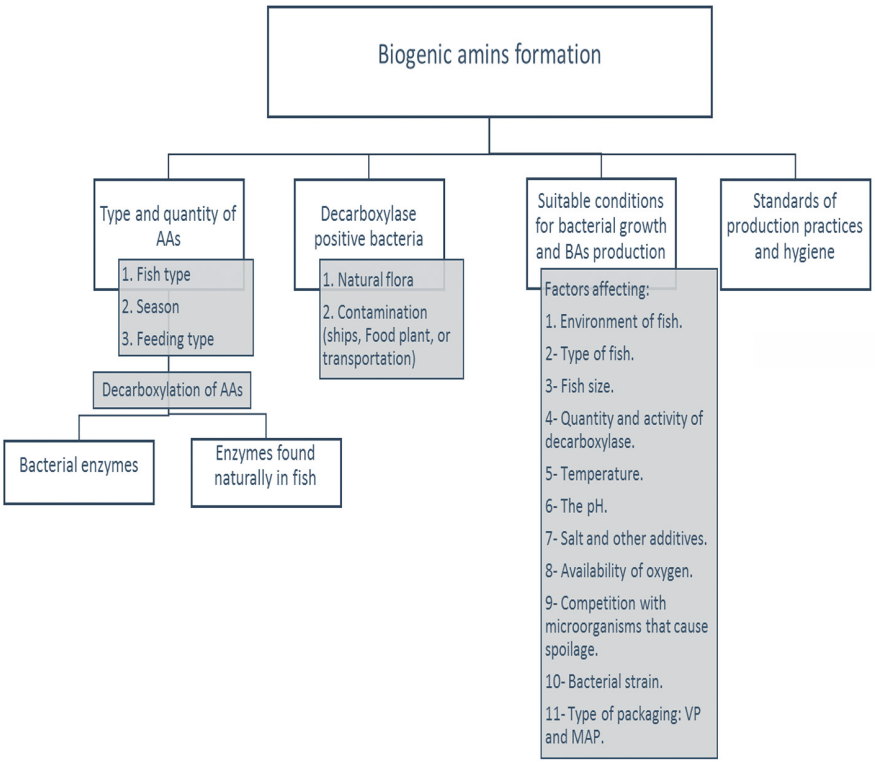

FIGURE 1 Biogenic amines formation in fish and fish products

the gills, skin, and gastrointestinal systems of fish (WHO, 2013). Transmission may occur from the gastrointestinal tract after hunting, through migration, or by rupture or leakage of gastric contents during evisceration. Also, microorganisms can be transmitted from the skin or gills during slaughter (WHO, 2013).

Bacteria that produce AAs decarboxylase and produce BAs are limited to Enterobacteriaceae, *Clostridium*, *Lactobacillus*, *Streptococcus*, *Micrococcus*, Pseudomonaceae, *Enterococcus* (BIOHAZ, 2011). Furthermore, they are part of the natural flora of food or are present due to contamination before, during, or after food processing (Ten Brink et al., 1990). In addition, fish type and size, handling conditions, and cooling techniques affect the growth of HIS-producing bacteria (Joshi & Bhoir, 2011).

Bacteria involved in the production of HIS can be found in abundance in the marine environment. They are naturally present on and/or in the fish, as previously stated, and do not damage the live fish. After death, mechanisms of fish defense no longer inhibit bacterial growth in muscle tissue and thus HIS-forming bacteria may begin to grow, causing the HIS production (FAO, 2011). Although some of them are indigenous bacteria, the most are from contamination after fishing at fishing boats, the factory, or at distribution (Lehane & Olley, 2000). *Proteus vulgaris*, *Proteus mirabilis*, *Clostridium perfringens*, *Enterobacter aerogenes*, and *Vibro alginolyties* were isolated from fish and found to be able to produce HIS (Frank et al., 1985; Yoshinaga & Frank, 1982). *Acinetobacter lwoffii*, *Pseudomonas putrefaciens*, and *Aeromonas hydrophila* were among the 14 bacteria found in decomposing fish that have the HIS-decarboxylase enzyme (Middlebrooks et al., 1988). Among the bacteria responsible for histamine production are *Morganella morganii*, *Morganella psychrotolerans*, *Hafnia alvei*, *Klebsiella oxytoca*, *Staphylococcus hominis*, *Enterococcus hirae*, *P. vulgaris*, *E. aerogenes*, *Photobacterium damselae*, *Photobacterium phosphoreum*, and *Raoultella planticola* (Alves et al., 2002; BIOHAZ, 2011; Economou et al., 2007; Emborg et al., 2006; Kim et al., 2002; Rodtong et al., 2005; Veciana-Nogues et al., 2004). It was found that *Staphylococcus* spp. and *Tetragenococcus* spp. produced HIS in fermented seafood (Satomi et al., 2011). A total of 26 isolates of HIS-producing bacteria were identified in fresh fish sold in Libyan markets. The majority of them belonged to the Enterobacteriaceae family (Hassan et al., 2018). In addition, HIS formation depends on the strain of bacteria (WHO, 2013).

The quantity of BAs produced in fish depends on the quantity and activity of BAs decarboxylases. The quantity of decarboxylase is related to the number of bacteria and their ability to grow and increase. Several factors can affect the growth of BAs-producing bacteria (WHO, 2013). Temperature and time are the main determinants (Chong et al., 2011). Thus, the concentration of BAs depends on the combined effect of time and temperature. Longer times and higher temperatures will lead to greater growth and BA formation (WHO, 2013). Other important factors include pH, water activity, salt concentration, oxygen availability, food additives, and competition from other spoilage microorganisms (Suzzi & Gardini, 2003; WHO, 2013).

3 | HEALTHY EFFECTS OF BIOGENIC AMINES

BAs have received attention and study due to their role in food safety, especially histamine poisoning, and their use as an indicator of spoilage in several products (Gram, 2009; Lehane & Olley, 2000). BAs also have an important role in physiological processes such as cell growth and development, altering stomach pH, influencing brain activity, and blood pressure regulation (Arulkumar et al., 2021). However, consuming foods high in BAs or failing to detoxify them properly can result in their entry into the bloodstream, resulting in the release of adrenaline and noradrenaline, stimulation of stomach acid secretion, increased cardiac output, migraine headaches, tachycardia, elevated blood sugar, and elevated blood pressure (Arulkumar et al., 2021; Kantaria & Gokani, 2011).

In addition, nausea, shortness of breath, hot flash, bright red rash, and burning in the mouth (Ten Brink et al., 1990). Symptoms often appear within minutes to a few hours of consumption and persist from 12 h to a few days (Food and Drug Administration [FDA], 2011). It was also investigated the possibility of BAs being precursors for the formation of mutagenic materials. Because some BAs can be nitrosated or act as precursors for other chemicals that can create nitrosamines, which are carcinogenic in many animals and potentially harmful to human health (Shalaby, 1996).

Although low concentrations of BAs are essential for many physiological functions (Mohan et al., 2009). However, in the digestive system of mammals, there is a detoxification system, which is effective to certain limits. It can metabolize the normal daily intake of BAs from food through monoamine oxidase (MAO) and diamine oxidase (DAO). They play a major role in detoxification (Ten Brink et al., 1990). However, the body's ability to get rid of toxicity stops if large quantities of BAs are ingested from spoiled or fermented food.

Furthermore, the variety of BAs consumed, individual susceptibility, level of intestinal detoxification activity, smoking (cigarette smokers have a 30% reduction in MAO activity), alcohol, and acetaldehyde have all been identified as factors that increase the toxicity of BAs by increasing the permeability of the intestinal wall (Kantaria & Gokani, 2011; Ten Brink et al., 1990). Determining the level of toxic BAs is very difficult due to its dependence on individual characteristics and the presence of other amines. However, a maximum allowable level of total BAs has been suggested as 750–900 mg/kg (Ladero et al., 2010). As a result, BAs must be in low concentrations in food or reduced by manufacturing processes. Several studies were carried out to investigate the effect of food processing on lowering levels of these compounds.

HIS is an endogenous substance that occurs naturally in the human body and develops from the decarboxylation of the amino acid histidine (Figure 2). HIS can be found in certain food containing free histidine, as in fish due to the activity of certain bacteria during spoilage and fermentation processes (Comas-Basté et al., 2019; Taylor & Eitenmiller, 1986). Endogenous HIS has important physiological functions related to an autoimmune response, gastric acid secretion, and neuromodulation. HIS-rich food may cause food

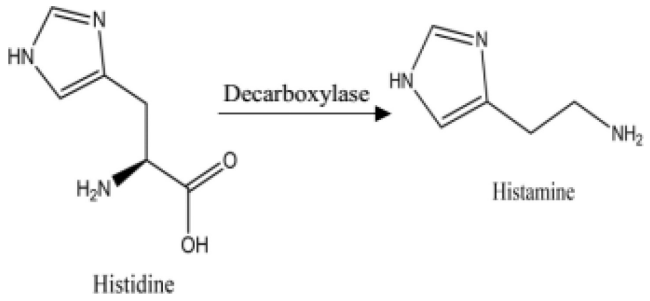

FIGURE 2 Histamine formation by decarboxylation (Peivasteh-Roudsar et al., 2020)

intolerance in sensitive individuals and HIS in fish and fish products may cause food poisoning (Comas-Basté et al., 2019; Taylor & Eitenmiller, 1986).

Scombroid fish poisoning, also known as histaminosis, is caused by eating fish with high HIS levels (Chaves-López et al., 2006; Comas-Basté et al., 2019). HIS was known as a cause of poisoning in the forties (Morrow et al., 1991), which results from the consumption of food, especially certain types of fish and cheese that contain high levels of HIS. Furthermore, HIS is considered one of the major problems in marine fish, while it is not important in freshwater fish, where its quantity is low compared to marine fish. HIS is a mild disease. However, it is an essential factor in food safety (Lehane & Olley, 2000). It is worth noting that poisonous fish can be known before eating it, as the presence of large quantities of toxic substances leads to a decrease in the different sensory quality standards of fish (Kordiovská et al., 2006).

Furthermore, among the most famous types of fish that cause many cases of HIS poisoning, due to the increase in the global rate of their consumption are those fish that belong to the families Scombridae and Scomberesocidae, and their examples are tuna, mackerel, bonito, and saury. As a result, it was called scombroid poisoning (Comas-Basté et al., 2019; Tortorella et al., 2014; WHO, 2013). Also, some other species cause histamine poisoning which is non-Scombroid fish, most notably the mahi-mahi, bluefish, and sardine (Taylor et al., 1989). Despite the high incidence of this type of poisoning, it can be treated through the use of antihistamine drugs (Kantaria & Gokani, 2011).

HIS can be eliminated through the body's metabolism process by two enzymes, the first: DAO; the second: histamine-*N*-methyltransferase (Maintz & Novak, 2007). Furthermore, because HIS is not impacted by heat or chemical treatment, it is difficult to decompose after it has been produced. Therefore, one of the most important food safety factors, on which the suitability of food for human consumption is determined, is the proportion of histamine in fish, as the shipment of fish is rejected if the fish contains the amount of HIS greater than or equal to 50 ppm (FDA, 2011). In contrast, Shalaby (1996) considered fish poisonous and unsafe for human consumption when the histamine content is greater than 100 mg/100 g.

Although HIS, CAD, and PUT are all produced through the degradation and fermentation of AAs such as histidine, lysine, and ornithine, respectively, by bacteria. However, the probability of the presence of both CAD and PUT increases in the case of poorly handled fish even in fish species that are not known to be the cause of scombroid fish poisoning, and their percentage can also be estimated as an indicator of fish spoilage. Some studies proved that CAD is formed and its percentage rises in spoiled fish before HIS rises (Pons-Sánchez-Cascado et al., 2005; Rossi et al., 2002). It was also found that CAD and PUT are HIS inducers, which explains the low toxicity of pure histamine (Peivasteh-Roudsar et al., 2020; WHO, 2013).

4 | BIOGENIC AMINES REDUCTION STRATEGIES

4.1 | Low temperature

There is a positive correlation between the reduction of HIS production rate and the temperature decrease. The decrease in HIS production rate and the drop in temperature has a favorable relationship. As a result, rapid cooling is one of the most significant elements to consider immediately after fishing and during handling and storing because it minimizes the microbial burden, lowering the proportion of HIS (FDA, 2011; Lehane & Olley, 2000). Keeping fish at 4°C reduces the growth rate of HIS-producing bacteria, and the best effect is obtained if the temperature is reduced to 0°C (WHO, 2013). In addition, cooling is done using various methods such as ice slurry or recirculating cooled seawater or brine, which are better than using ice alone to reduce space and increasethe rate of heat transfer. To achieve the finest outcome, the ratio between the cooling matter amount or cooling manner used and the amount of fish to be preserved must be taken into account (Köse, 2010). Furthermore, several studies have also proven that holding fish at a temperature below 4°C, achieves the highest inhibition of the production of BAs (Mendes et al., 1999; Veciana-Nogués et al., 1997; Yongsawatdigul et al., 2004). By inhibiting the growth of microorganisms responsible for forming them or by inhibiting the activity of the enzyme decarboxylase produced by these organisms (Naila et al., 2010). Also, some studies showed that temperature abuse increases the production of BAs due to temperature fluctuation, which is the most important factor for the formation of HIS (Economou et al., 2007).

Importantly, it was found that holding and storing fish by freezing (−18°C or less) will stop the growth of all bacteria, thus preventing HIS decarboxylase enzymes from producing HIS (WHO, 2013). As a result, freezing is more effective than cooling in preventing the production of BAs (Mendes et al., 1999; Naila et al., 2010). Furthermore, Economou et al. (2007) found that defrosting reduces the number of bacterial cells or causes sublethal damage to the bacterial cells, resulting in weak HIS production. Table 1 shows the effect of different temperatures on the production of BAs. It is noted from the table that storing fish by freezing (−30°C, −20°C, and − 18°C) had a significant role in preventing or reducing the formation of BAs. Also, it is noted that from the comparison of storage periods, it was found that increasing the period of freezing storage causes an increase in histamine formation.

TABLE 1 Effect of storage temperature on biogenic amines formation in fish and fish products

Fish type	Temperature (°C)	Biogenic amines formation	References
Tuna	0.4 and 17	Histidine exceeded the maximum permitted and reached 200 mg/kg at 17°C meanwhile, it recorded the maximal permitted within 20 days of storage at 4 and 0°C	Kerr et al. (2002)
Catla and rohu	5 and 30	The HIS level exceeded the maximum permitted level (200 mg/kg) after 18 h at 30°C and after 5 days at 5°C	Jeya Shakila (2002)
Indian anchovy	Storage in ice, 15 and 35	The HIS level in ice-stored fish was 19 mg/kg on day 15 of storage and at 15°C which, which increased to 190 mg/kg after 32 h and increased rapidly at 35°C to 254 mg/kg after 8 h	Rodtong et al. (2005)
Carp	3 ± 2 24 ± 1 −18 ± 1	HIS was not recorded at 3 ± 2°C during 7 days of storage period. While samples stored for 2 days at 24 ± 1°C reached the highest HIS value of 333.0 ± 100.0 mg/kg. Furthermore, it was also reported that samples stored at −18 ± 1°C for 3 months did not record any increase in the BAs values compared to the values recorded at zero time	Kordiovská et al. (2006)
Shanak Yellow Fin Fish	Storage in ice	The highest HIS value during 18 days of storage in ice was 34 mg/kg in all samples	Fathi et al. (2013)
Sardine	−30	Higher histidine content (>300 mg/kg) was reported in frozen sardine from Serbia	Petrovic et al. (2016)
Mackerel Indian mackerel	−20	Frozen mackerel recorded the highest free histidine content in fish reaching 732–1460 mg/kg HIS concentration in Indian mackerel was recorded at 363.5 mg/kg after 16 h at room temperature, while proper refrigeration effectively inhibited the production of HIS formation (8.31 mg/kg) after 16 days of storage	Biji et al. (2016) Chong et al. (2014)

4.2 | Evisceration

It is known that the quality and shelf life of many fish decreases if they are non-evisceration. During feeding periods, fish contains various bacteria in their digestive system. Also, fish produces powerful digestive enzymes, which can letter cause violent autolysis after death which can lead to a strong unpleasant flavor, especially in the abdominal area, and may cause a belly-burst eruption (Huss, 1995; Ikape & Cheikyula, 2017). On the other hand, evisceration means exposing the abdominal area and surfaces of cut to air, thus becoming more sensitive to oxidation and discoloration. In addition, many factors such as the age, type and amount of fat, area, and style of fishing, etc., should be considered before deciding whether to eviscerate (Huss, 1995).

The evisceration can affect the production of BAs positively or negatively. Ridding off the guts helps prevent contamination of fish meat with BAs-producing bacteria thus preventing BAs' formation. On the other hand, incorrect evisceration produces cross-contamination with BAs-producing bacteria, resulting in a rise in BAs. Ruiz-Capillas and Moral (2001) stored eviscerated hake fish in ice for 25 days. The CAD recorded the highest concentration (72.14 mg/kg) at the storage end compared with 13.47 mg/kg AGM. The researchers suggested that the production of CAD and AGM from the beginning of storage was likely more related to the endogenous enzymes than the microbial enzymes that started operating from day 12 of storage.

Similarly, Lakshmanan et al. (2002) found that the proportion of amine-forming halophilic bacteria in whole sardines was 19.98%, while was only 2.84% in gutted sardines. In the same way, Pons-Sánchez-Cascado et al. (2003) confirmed that delaying the evisceration of anchovy fish before ripening increased the production of AGM, TYR, CAD, HIS, and PUT, especially in fish in the ripening weeks before the fish reached the salt saturation stage. Also, the activity of microorganisms or bacterial enzymes was higher in non-eviscerated anchovies than in partially eviscerated fish (partial evisceration is commonly used because complete evisceration followed by complete rinsing delays ripening and the product does not acquire special flavor characteristics), which explains why some BAs are produced more.

In contrast to that mentioned above, Paleologos et al. (2004) found that PUT was the major amine produced and its amount was 12.64 mg/kg and 3.12 mg/kg at day 16 in whole eviscerated and non-eviscerated seabass, respectively, stored in ice that was resulted probably of cross-contamination during the evisceration. As well as the absence of HIS is expected in seabass because they do not contain or contain the little or free amino acid, histidine. Also, Baixas-Nogueras et al. (2009) found that the process of the evisceration of hake fish affected the growth of Enterobacteriaceae, *Shewanella putrefaciens*, and *Pseudomonas* during the storage by ice, which was higher in the eviscerated samples than the non-eviscerated, which reflected higher amounts of PUT, CAD, TYR, and HIS in the eviscerated samples.

Paleologos et al. (2004) reported that PUT was the predominant amine generated, with levels of 12.64 mg/kg and 3.12 mg/kg at day 16 in whole eviscerated and non-eviscerated seabass held on ice,

respectively, which was likely due to cross-contamination during the evisceration. In addition, the absence of HIS is expected in seabass since they lack or have a small amount of the free amino acid histidine. Furthermore, Baixas-Nogueras et al. (2009) discovered that the evisceration of hake fish affected the growth of Enterobacteriaceae, *S. putrefaciens*, and *Pseudomonas* during ice storage, which was higher in the eviscerated samples than the non-eviscerated samples, indicating higher amounts of PUT, CAD, TYR, and HIS in the eviscerated.

Fresh fish have a lot of histamine-producing bacteria in their guts, gills, and skin, so picking fish free of BAs-producing bacteria is not a choice.

Still, rapid removal of the guts and gills will delay the production of the dangerous levels of HIS. As well as the large eviscerated fish will allow the ice or ice-water mixture to reach the core, causing rapid overall cooling. However, during removing viscera and gills, care must be taken to reduce the prevalence of bacteria into muscle tissue (WHO, 2013). It is clear from the preceding that the evisceration process helps prevent contamination of fish meat with BA-producing bacteria and thus prevent the formation of BAs, but the evisceration process must be done correctly to avoid cross-contamination with BAs-producing bacteria.

4.3 | Food additives

Various types of food additives (FDs) are used in fish preservation combined with traditional preservation methods such as marinating, drying, smoking, and fermentation. Naila et al. (2010) reported that FDs such as potassium sorbate, sodium nitrites, glucono-delta-lactone, and glycine showed inhibition of the growth of HIS-producing bacteria and thus reduced HIS production. However, Bhutani et al. (2009) stated that different food seasonings be applied to obtain a similar effect, but the efficacy of FAs has not been sufficiently studied. In addition, the effect of FAs on sensory properties and consumer susceptibility to them in such products and potential negative effects must be taken into account. For example, curcumin can inhibit the growth of HIS-producing bacteria, inhibiting the enzyme DAO, which breaks down HIS.

Köse (2010) mentioned that NaCl is one of the most commonly FAs used. Also, it was mentioned that although some HIS-forming bacteria are halotolerant or halophilic, the effective dry salting process of fish products makes it unlikely that these bacteria can grow due to low water activity. Several studies were carried out to evaluate the ability of some food additives to reduce the formation of BAs in fish and fish products (Table 2).

The studies included in Table 2. show that spices, their essential oils, or their active compounds lead to a reduction in the formation of BAs in fish, as well as the use of glycine and sucrose also has the same effect. The use of NaCl has a role in inhibiting the formation of BAs in fish except for fermented fish, fesikh, which is not made from fresh, chilled fish, but rather fish is left at room temperature for several hours before being treated with salt, and this explains the increase in BAs during the ripening and storage periods.

4.4 | Starter cultures

Fermentation is defined as a general term that covers aerobic and non-aerobic changes caused by microorganisms (Srilakshmi, 2007). The starter cultures of fermented food are defined as the preparation of one or several systems of microorganisms that are applied to initiate the process of fermentation during food processing (Wigley, 1999). It includes the production of alcohols and acids and other similar interactions (Srilakshmi, 2007). The organisms involved in fermentation are of two types: bacteria and fungi. The bacteria in question include bacteria producing lactic acid, acetic acid, butyric acid, and other acids. Fungi involved in fermentation are yeasts (Srilakshmi, 2007).

Fermented food plays a major role in the food of many regions in Africa and Asia (Holzapfel, 2002) for reasons including (I) improving the flavor and texture of the product; (II) increasing nutrients such as vitamins B and C; (III) ease of digestion; (IV) low in pH, thus inhibits the growth of pathogenic microorganisms; (V) during fermentation, some harmful substances such as trypsin inhibitors and phytins decrease; and (VI) increasing the variety of meals (Srilakshmi, 2007).

The starters cultures used for fermented foods are either amine-negative, incapable of decarboxylation of AAs and converting them to BAs or amine-oxidizing bacteria, capable of oxidation of BAs to aldehydes, hydrogen peroxide, and ammonia (Naila et al., 2010). Fermented fish products rely on promoting the growth of specific bacteria to produce the desired product properties. Typical preparation of these foods requires storage at a certain temperature, promoting bacterial growth rather than inhibiting it. The bacteria themselves may contain histidine decarboxylase. Therefore, it is important to use decarboxylase-free bacterial starters for such products and in return, some bacteria produce enzymes such as DAO that break down BAs, which can be incorporated as part of the bacterial starters to provide further protection. In some cases, histamine-degrading bacteria or their enzymes can also be applied to remove pre-formed amines (WHO, 2013).

Through the studies listed in Table 3, it was noted that most of the bacterial starters recorded a decrease in BAs except the study conducted by Nie et al. (2014). Compared to the control, fermented silver carp sausage showed a significant drop in PUT and CAD while increasing TYR buildup, furthermore, HIS and SPD content was not affected.

The fermentation process can provide the conditions suitable for producing large amounts of BAs due to the availability of free AAs and decarboxylase-positive microorganisms and conditions that allow bacterial growth, decarboxylase synthesis, and decarboxylase activity (Petäjä et al., 2000). The microbiological application for amine oxidation in fermented food is limited due to conditions unsuitable for physiological enzyme activity such as low oxygen concentration, low pH value, presence of NaCl and glucose. Oxidation produces undesirable hydrogen peroxide because it can affect color and odor (Leuschner et al., 1998). Lactic acid bacteria have an important role in food fermentation due to their effect on flavor changes as a preservative and thus help enhance food safety by inhibiting the growth of pathogenic microorganisms (Devlieghere et al., 2004). Some lactic acid bacteria can also produce BAs (Spano et al., 2010).

TABLE 2 Effect of food additives on biogenic amines formation in fish and fish products

Fish type	Temperature (°C)	Food additive	Biogenic amines formation	References
Mackerel muscle broth	30	0.5% clove oil, (1–5%) NaCl, or a mixture of the two	Clove oil delayed the production of BAs meanwhile, the addition of NaCl with clove oil slowed the production of BAs	Wendakoon and Sakaguchi (1993)
Indian mackerel	5	10% of Curcumine, Capsaicin and piperine	All spices reduced BAs: HIS, CAD, PUT and TYR decreased from >200 to 13 ppm, about 200 to 100 ppm, approximately 100 to 25 ppm, and about 200 to <100 ppm, respectively over 8 days of storage	Jeya Shakila et al. (1996)
Salted mackerel	25	NaCl (5%–18.1%)	The 33 collected samples did not contain TRY and TYR and the content of CAD, 2-phenylamine, SPM, SPD, HIS, AGM was less than 30 ppm. Two samples obtained from southern Taiwan had higher HIS than the limit permitted by the FDA (70.1 and 120.0) ppm.	Tsai et al. (2005)
Sardine	25 ± 2	2% or 4% acetic acid with 15% NaCl	BAs were higher in the treated samples than the control samples during the seasoning process (24 h). This is explained by the fact that the acidic conditions caused the decomposition of proteins in fish tissues into amino acids	Gökoglu (2003)
Sardine fillets preserved under vacuum	3 ± 1	Mint extract 1% or Artemisia extract 1%	Samples treated for both extracts recorded lower content of HIS, TYR and CAD than control samples on 21 days of storage.	Houicher et al. (2015)
Rainbow trout	4 ± 1	Rose marry oil at 1,2 and 3%	The content of BAs decreases with the increase of essential oil concentration, especially PUT, CAD, TYR and HIS, which recorded an increase after 9 days of storage time, except for SPD, which was not affected by time	Peiretti et al. (2012)
Tuna	At room temperature	Ethyl acetate and methanol extract of Jatropha leaf 1%	HIS in tuna treated with water, ethyl acetate extract, and methanol extract was 17.73, 11.07, and 14.02 mg/kg, respectively, after 5 h of storage	Setha et al. (2014)
Mullet	At room temperature	NaCl at 1:3 (fish: salt, w: w)	The total concentration of BAs increased during the ripening period and after 60 days of storage. CAD was the main amine during ripening and storage	Mostafa and Salem (2015)

The composition of BA is strain-dependent and not specific to species (Deepika Priyadarshani & Rakshit, 2011; Garai et al., 2007).

4.5 | Canning

The effect of the canning process on the BAs content mainly depends on the quality of the raw material. Most of the histamine-producing bacteria are expected to be present as a result of fish contamination during fishing and improper handling in the canning factory. Therefore, strict control of temperature and time is required from fishing to canning to ensure the high safety of canned fish. The increase of HIS content is unexpected in tuna meat during the canning process (Lopez-Sabater et al., 1994). Furthermore, Ko (2006) studied histamine formation during the steps of canned tuna production; raw material reception and storage, defrosting, slaughtering/ evisceration, precooking, spraying, cleaning, trimming, cutting, weighing, packing, seaming, cooking/retorting, cooling, labeling, evaluation of the final product and storage. Spraying with water after the precooking had a remarkable effect on histamine formation in the pre-seaming stage. An increase in histamine appeared after 3.5 h from 15.9 ± 8.6 ppm at defrosting to 34.5 ± 8.5 ppm at the precooking. In the pre-seaming stage, the samples sprayed with water recorded a decrease in histamine level of 7.5 ppm. The main objective of spraying with water was to cool the tuna after its precooking. However, the water used at this stage with disinfectants such as chlorine (2 ppm) causes damage to the bacterial cells temporarily. Also, Shakila et al. (2005) examined changes in histamine in Tuna, Seerfish, and Sardine during the canning process at different stages; raw, precooked, and canned immediately and after a delay of 6 h at 30°C. The histamine content in fish kept for 6 h increased to 14.17 and 8 ppm in tuna and seerfish, respectively. In contrast, sardines did not exceed the maximum allowable limits of the FDA. In precooked and canned fish, histamine was lower than the raw samples which ranged between 1.6 and 8.0 ppm in precooked and 1.2 and 4.3 ppm in canned fish.

TABLE 3 Effect of starter cultures on biogenic amines formation in fish products

Fish product	Starter cultures	Biogenic amines hydrolysis	References
Rainbow trout	*Pediococcus* strain POHK, *Pokelferment* 77 Starter, *Pediococcus* Strain MLHK, *Pokelferment* 77 starter (MLHK) and CC- 430 Starter	The highest concentration of biogenic amines (HIS, CAD, TYR) was recorded in the control sample	Petäjä et al. (2000)
Fermented sardine	*Lactobacillus delbrueckii subsp. delbrueckii*	HIS did not exceed the maximum permitted level at the end of the fermentation period (22°C and 30°C/25 days) with the exception of control samples (not fermented)	Ndaw et al. (2007)
Canned Myeolchi-jeot, a salted and fermented anchovy	*Staphylococcus xylosus* No. 0538	Total BAs decreased by 16.0% compared to the control	Mah and Hwang (2009)
Minced grass carp slices	*L.casei*, *S. lactis*, *S.cerevisiae Hansen* and *M. anka*	The accumulation of BAs in muscle was effectively reduced by fermentation (During the 12 h fermentation at 30°C) using mixed starter cultures	Liu et al. (2010)
Bighead carp surimi	*Lactobacillus casei*, *Streptococcus lactis*, *Saccharomyces cerevisiae*, Hansen and *Monascus anka*	Prevent the buildup of HIS, TYR, SPM, and SPD	Zhong-Yi et al. (2010)
Fish sauce	*S. carnosus* FS19 and *B. amyloliquefaciens* FS05	After 120 days of fermentation at 35°C, the total BAs concentration was 15.9% and 12.5% which consider lower in the inoculated samples S. carnosus FS19 and B. amyloliquefaciens FS05, respectively, compared with the control samples	Zaman et al. (2011)
Fermented silver carp sausage	*Lactobacillus plantarum ZY40 and Saccharomyces*	A significant decrease in PUT and CAD was recorded while TYR accumulation was enhanced compared to control while HIS and SPD content was not affected	Nie et al. (2014)

TABLE 4 Histamine content in some commercial canned fish in different countries

Fish product	Country of study	Samples total number	Samples equal to permitted samples by FDA	Samples › permitted samples by FDA	References
Canned Mackerel, sardine and tuna	Morocco	248	238	10	Ababouch et al. (1986)
Canned Sardine	Libya Northwest of Mexico	50 9	46 9	4 –	Hassan and Sayed (1986) Pacheco-Aguilar et al. (1998)
Imported of Canned Mackerel and sardine	Poland	79	65	14	Windyga et al. (1992)
Tuna sandwiches	Southern Taiwan	43	42	1	(Kung et al., 2009)
Canned tuna	Brazil	54	53	1	Silva et al. (2011)
Canned tuna	Iran	40	30	10	Zarei et al. (2010)
Canned tuna	Egypt	90	30	60	Karmi (2014)
Canned tuna	Turkey	80	80	-	Er et al. (2014)

The researchers justified this for the following reasons: (I) The precooking conditions and subsequent processing temperatures significantly reduced the BAs. (II) The loss of BAs during precooking may be caused by exiting into the drained liquors.

A study in Iran conducted by Zarei et al. (2010) showed that 18.9% of canned tuna collected from the public market was above the permissible limit by FDA. The researchers concluded that using low-quality fish as raw material for canning and/or abuse handling fish during manufacturing is one of the main reasons for the high level of histamine. Also, Akbari-Adergani et al. (2012) studied the level of histamine in canned tuna collected in Iran. The level of histamine in 36.6% of the samples was above the permissible level of FDA and the levels of histamine differed according to the date of production and increased with the proximity of the expiration date.

Histamine levels can rise due to improper handling and storage of canned fish after opening. The Food and Environmental Hygiene Department (2005) preserved opened canned tuna samples under three different storage conditions (2°C, room temperature, 33°C). The highest levels of histamine sufficient to cause histamine poisoning were detected in tuna samples kept at room temperature for

24 h, or at 33°C/6–8 h. The study concluded that tuna sandwiches and open canned fish should be stored at 4°C or less and consumed as soon as possible. In a similar study, Kung et al. (2009) studied the content of BAs in 43 tuna sandwiches sold in Taiwan. The results showed that the content of all BAs (TRY, PHE, PUT, CAD, TYR, SPD, and SPM) was less than 3 mg/100 g, except one of them containing histamine at 5.21 mg/100 g, which is higher than 5 mg% the permissible limit of FDA. Contrary, in Libya, a study carried out by Hassan et al. (2017), histamine content found in 19 tuna sandwiches collected at break time during selling to pupils and students ranged between 0.052 and 0.485 mg%. The results were below the maximum allowed level in Libya, 10 mg% and FDA, 5 mg%.

Several studies were conducted to evaluate the safety of canned fish of histamine, Table 4. These studies showed that some canned fish contain histamine that exceeded the upper limit allowed by the FDA. In general, the results show that canned fish is safe for health.

4.6 | Packaging

The studies mainly focused on modified atmosphere packaging (MAP) and vacuum packaging (VP) and their effect on the formation of BAs. MAP is a packaging system in which air is removed from the package and replaced with a single gas or mixture of gases (Blakistone, 1998). VP means that the product is closed in a low gas permeability package after partial displacement of the air in the package as it produces changes in the atmosphere surrounding the package during storage due to the metabolism of the product and microorganisms as well as gas permeability (Phillips, 1996).

From Table 5, some studies reported that MAP and VP successfully inhibited the formation of BAs (Alak et al., 2011; Emborg et al., 2005; Křížek et al., 2004; Özogul et al., 2002a, 2002b; Özogul & Özogul, 2006). At the same time, other studies found that MAP

TABLE 5 Effect of packaging on biogenic amine formation in fish and fish products

Fish type	Packaging	Biogenic amines formation	References
Tuna	VP, Non-VP	VP did not show a beneficial effect in controlling HIS production (at 2°C, 10°C for 15 days). Cold storage was more effective than VP in controlling HIS production	Wei et al. (1990)
Hake	Storage under normal conditions (air), 60% CO_2: 25% N_2: 15% O_2, 40% CO_2: 40% N_2: 20% O_2	There was no effect for storage under MAP in BAs reducing compared with normal conditions	Ruiz-Capillas and Moral (2001)
Herring	Storage under normal conditions, VP, MAP using 60% CO_2 and 40% N_2	The amount of HIS reached 396 ppm, 284 ppm and 197 ppm after 16 days of storage at 2°C under normal, VP and MAP conditions, respectively	Özogul et al. (2002a)
Garfish	MAP using 40% CO_2 and 21% O_2	Pre-freezing of garfish with MAP caused prolonged shelf life and a significant decrease in histamine content. The highest histamine content was recorded in fresh fish (caught in spring) at 507 ± 95 ppm at 5°C for 9 days and the lowest content was recorded in frozen and defrosted fish (caught in autumn) at 5°C for >16 days	Özogul et al. (2002b)
Sardine	Storage under normal conditions, VP, MAP using 60% CO_2 and 40% N_2	BAs increased during storage at 4°C for 15 days, with HIS reaching 20.3 ± 1.3 mg/100 g, 14.0 ± 1.2 mg/100 g, and 10.5 ± 1.2 mg/100 g when packaged under normal conditions, VP and MAP, respectively	Özogul and Özogul (2006)
Sea bass	Ice, No icing, Aluminum Foil, Cling film	BAs (all samples stored at 4°C) were higher in samples coated with aluminum foil and cling film than those stored on ice. The research concluded that wrapping sea bass with aluminum foil or cling film is not beneficial in reducing the formation of BAs	Özogul et al. (2006)
Atlantic Bonito Fillets	Cling Film, 100% CO_2, VP, Chitosan Film	BAs increased during storage at 4°C for 15 days, where HIS reached 29.0 ± 6.00 mg/100 g, 28.07 ± 5.84 mg/100 g, 14.57 ± 4.00 mg/100 g, 4.60 ± 1.71 mg/100 g when packaged with cling film, VP, 100% CO_2 and chitosan Film., respectively	Alak et al. (2011)
Yellowfin tuna fillets	Polyethylene, vacuum packaging, MAP: 100% CO2 and chitosan film packaging during storage under controlled freezing-point temperature	BAs content increased in all treatments as the storage progressed. Obvious differences were found in the levels of cadaverine, tyramine, and histamine among the four treatments, Especially, chitosan film significantly inhibits histamine and cadaverine formation	Miaomiao et al. (2015)
Barramundi fillets	Packed in polyamide, polypropylene, and LDPE films and stored at 8°C for 20 days under MAP	Putrescine and cadaverine were the most abundant amines, meanwhile, the concentration of HIS ranged from less than 0.5 to 198.0, 264.3, and 308.5 mg/kg for polyamide, polypropylene, and LDPE films, respectively	Yassoralipour et al. (2016)

did not affect BAs production (Dalgaard et al., 2006; Ruiz-Capillas & Moral, 2001). In addition, it was found that VP and packaging using aluminum foil and cling film did not affect the formation of BAs (Özogul & Özogul, 2006). The chitosan is used as an edible packaging film (Jeon et al., 2002). Alak et al. (2011) showed that chitosan packaging was much more effective in reducing HIS formation than cling film, MAP (CO_2), and VP packaging due to its antimicrobial properties (Jeon et al., 2002).

4.7 | Irradiation

Numerous research and testing have carefully evaluated the toxicological innocuity, nutritional adequacy, and microbiological safety of irradiated food. These studies have resulted in support for the safety of irradiated food for consumption (Farkas, 2006). The Committee of Food Irradiation Experts (FAO/IAEA/WHO) concluded that irradiation of any food commodity to an average total dose of 10 KGy does not expose humans to toxicity risks and does not cause any nutritional or microbiological problems (WHO, 1994).

Food irradiation was used in many countries for purposes including inhibiting bacteria, destroying insects and parasites attached to food, delaying physiological ripening, extending shelf life, to inhibit bacteria, destroying insects and parasites attached to food, delaying physiological ripening, extending shelf life, or improve the technological properties of food (Thayer, 1994). Furthermore, irradiation is proven to be an excellent way for preventing pathogenic microorganisms in food products, as it significantly lowers bacteria and viruses (Radomyski et al., 1994). Furthermore, the irradiation technique in the recent experiments was applied to cause radiolysis to reduce the food content of toxic compounds such as nitrosamine, nitrite, and BAs (Ahn, Kim, et al., 2002; Ahn, Yook, et al., 2002; Kim et al., 2004).

Irradiation can control the presence of BAs in food by radiolysis of them or by reducing the number of bacteria responsible for BAs production (Table 6; Kim et al., 2003; Mbarki et al., 2009). In addition, it may be possible that the radiation inhibits the activity of the enzyme decarboxylase, but this requires more study (Kim et al., 2004).

Mbarki et al. (2008) evaluated the effect of different doses of gamma radiation (0, 1.5, 3, 4.5, 6, 7.5 KGy) on some quality aspects of bonito during chilled storage for 21 days. HIS content decreased after treatment by radiation, and this decrease strongly correlates with the applied dose level. Also, Cardozo et al. (2014) evaluated the effect of different doses of gamma rays in methanol solutions of three BAs (TRY, TYR, and PHE). TRY was more sensitive to radiation and it decreased to about 85%, 99%, and 100% at 1, 3,

TABLE 6 Effect of irradiation on biogenic amine formation in fish and fish products

Fish type	Irradiation dose (KGy)	Biogenic amines formation	References
Bonito	Gamma radiation (0, 1.5, 3, 4.5, 6, 7.5 KGy) + chilled storage for 21 days	HIS content decreased after treatment by radiation and this decrease strongly correlates with the applied dose level	Mbarki et al. (2008)
Sea bream (*Sparus aurata*)	Gamma radiation (2.5 and 5.0 kGy) + storage in ice for 19 days	Twelve types of biogenic amines were determined using HPLC: • 2-phenylethylamine, tyramine and histamine were not detected • The main amines formed in fish muscle were cadaverine, trimethylamine and putrescine • Dopamine, serotonin and spermidine concentration remained below the value of 0.6 mg/100 g and did not change significantly during the storage period • Irradiation causes a slight increase in agmatine, spermine and tryptamine concentrations during some storage periods	Özogul and Özden (2013)
Atlantic horse mackerel	Gamma radiation (1 and 3 kGy) + storage in ice for 23 days	The treatment has shown a positive effect on decreasing biogenic amine content	Mendes et al. (2005)
Tuna	Various doses of gamma radiation reached 2 kGy)	According to the findings, gamma irradiation may efficiently destroy histamine-producing bacteria such as *Klebsiella variicola*, which is particularly susceptible to gamma irradiation treatment and was eliminated at a dosage of 1.5 kGy	Reddy et al., 2020
Fillets of: • Grass carp (*Ctenopharyngodon idella*) • Bighead carp (*Hypophthalmichthys molitrix*)	The flesh of fish was treated by high-energy electron beam irradiation at low doses of 0.25 and 0.50 kGy then stored at 3.5°C for up to 70 days	Samples had good organoleptic characteristics, the amounts of the most toxicologically significant BA and histamine did not exceed 10 mg/kg, the same was discovered for tyramine	Křížek et al. (2017)

and 5 KGy, respectively. While, PHE decreased to 20%, 70%, and 85% at 1, 3, and 5 KGy, respectively. TYR showed less sensitivity to gamma rays, the decrease was only 20%, 50%, and 60% at 1, 3, and 5 KGy, respectively. The usage of gamma rays was beneficial in lowering the BAs examined in the study. Similarly, Kim et al. (2004) subjected histamine, cadaverine, putrescine, spermidine, spermine, tryptamine, tyramine, and agmatine, dissolved in distilled water at a concentration of 100 ppm to irradiation at 2.5, 5, 10, 20, and 25 KGy. The observed degradation of BAs was between 5 and 100%, and at 20 KGy the degradation was 95%.

In contrast, Mbarki et al. (2009) found the production of BAs in chub mackerel stored in cooling after irradiation followed by vacuum packaging. In addition, radiolytic products of BAs in irradiated food and their biological effects need to be studied (Kim et al., 2004). In addition, high levels of radiation require studies about sensory properties (Naila et al., 2010). Furthermore, there is an opposition of consumers to the use of radiation and this includes taste problems (Frewer et al., 2011; Mbarki et al., 2009).

5 | CONCLUSIONS

BAs are quality and safety indicators in fish and fish products, and their development is influenced by several factors such as the harvest process, vessel handling, post-catch contamination, insufficient cooling, and temperature abuse. Some strategies can be preventing the formation of BAs: (I) keeping fish at 0°C or -18°C or less; (II) proper evisceration of fish. (III) using essential oils and their active compounds, glycine, sucrose, and NaCl; (IV) using MAP, VP, and chitosan packaging may prevent BAs formation by inhibiting microbial growth; (V) using irradiation is a promise to degrade BAs, but their effects need more search and studying in terms of radiolytic products of BAs. In addition, using a bacterial starter that does not produce decarboxylase or bacteria that produce DAO is limited due to unavailable growth conditions in fermented fish and negative effects on sensory characteristics of fish products. As well as, to prevent BAs in canned fish, strict control of temperature and time is required from fishing to canning. In general, canned fish is very safe for human health in terms of BAs. Finally, with the help of current and emerging management strategies, adequate chilling is crucial to controlling the production of BAs in fish and fish products.

AUTHOR CONTRIBUTIONS

Thuraya A. Abuhlega: Conceptualization; writing – original draft; writing – review and editing. **Marwa R. Ali:** Visualization; writing – original draft; writing – review and editing.

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The authors have declared no conflicts of interest for this article.

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Research data are not shared.

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