ELSEVIER

Food Chemistry 82 (2003) 347–352

Food Chemistry

www.elsevier.com/locate/foodchem

Changes in histamine and volatile amines in six commercially important species of fish of the Thoothukkudi coast of Tamil Nadu, India stored at ambient temperature

R. Jeya Shakila*, K. Vijayalakshmi, G. Jeyasekaran

Department of Fish Processing Technology, Fisheries College and Research Institute, Tamil Nadu Veterinary and Animal Sciences University, Thoothukkudi, 628 008, India

Received 22 August 2002; received in revised form 13 November 2002; accepted 13 November 2002

Abstract

Six commercially important species of fish, i.e. mackerel (*Rastrelliger kanagurta*), sardine (*Sardinella fimbriata*), emperor bream (*Lethrinus miniatus*), threadfin bream (*Nemipterus japonicus*), trevally (*Carangoides armatus*) and barracuda (*Sphyraena barracuda*) of the Thoothukkudi coast of Tamil Nadu, India, were examined for changes in histamine and volatile amines (TVB-N and TMA-N) under ambient temperature storage (32±2 °C). Fish were organoleptically acceptable up to 15 h of storage, except emperor bream that spoiled after 12 h of storage. Histamine and volatile amines increased progressively on storage, but the rate of change varied with the species of fish. The TVB-N content of barracuda and emperor bream exceeded the acceptable limit of 35 mg/100 g after 15 h of storage while, in other fishes, their formation was slow. However, the TMA-N contents of all the fishes were above 10 mg/100 g after 15 h of storage. The TMA-N content of fish was found to correlate more closely with the sensory changes than the TVB-N content. With regard to the histamine toxicity, the histamine content was above the USFDA maximum allowable limit of 50 ppm in mackerel after 12 h, and, in sardine and trevally, after 15 h of storage. The histamine content did not show any correlation with the sensory changes or with the content of volatile amines. In trevally, it was noted that the histamine formation was very high and similar to that of mackerel. It is therefore concluded that the mackerel, sardine and trevally could cause histamine toxicity problems before they become organoleptically unacceptable.
© 2003 Elsevier Science Ltd. All rights reserved.

Keywords: Commercial fishes; Thoothukkudi coast; Storage; Ambient temperature; Histamine; Volatile amines

1. Introduction

Histamine poisoning is a chemical intoxication caused by the consumption of fish containing unusually high amounts of histamine in their muscle (Taylor, 1986). Histamine is formed mainly by the decarboxylation of the amino acid, histidine, through exogenous decarboxylase released from the microorganisms associated with fish or environment (Rawles, Flick, & Martin, 1996). Histamine is rarely found in fresh fish, but its level increases with the progress of fish decomposition (Frank, Yoshinaga, & Nip, 1981). Hence, it has been proposed as a chemical index of fish spoilage by a few authors (Lopez-Sabater, Rodriguez-Jerez, Hernandez-Herrero, Roig-Sagues, & Mora Ventura, 1994; Yoshinaga & Frank, 1981). Histamine is a chemical hazard monitored by the Food and Drug Administration of the USA for the safety of seafood products. The USFDA has recently established a guideline for histamine of 50 ppm (FDA, 1996) and fish with histamine above that level are prohibited from being sold for human consumption.

Despite the application of stringent hygienic standards and the establishment of the food regulations, the number of histamine toxicity outbreaks has continued to increase in most European countries (Lopez-Sabater, Rodriguez-Jerez, Hernandez-Herrero, Roig-Sagues, & Mora Ventura, 1996). This toxicity ranks as the second most frequent cause of foodborne disease associated with finfish consumption in most of the developed

* Corresponding author. Tel.: +91-461-322354; fax: +91-461-340574.

E-mail address: ttn_jerosh99@sancharnet.in (R.J. Shakila).

0308-8146/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0308-8146(02)00552-6

nations (Bean & Griffin, 1990; Sockett et al., 1993). A lack of relationship between histamine content and sensory attributes has been suggested to explain the high incidence. Histamine levels are also known to vary greatly, depending on the location and species of the fish (Arnold & Brown, 1978; Lerke, Werner, Taylor, & Guthertz, 1978; Lonberg, Movitz, & Scorach, 1980). Information is presently only available on the production of histamine and other biogenic amines in fish such as tuna (Mietz & Karmas, 1978), mackerel (Ritchie & Mackie, 1980; Wendakoon et al., 1990), sardine (Marrackchi et al., 1990), horse mackerel (Okuzumi, Fukumoto, & Fujii, 1990), anchovy (Veciana-Nogues, Vidal-Carou, & Marine-Font, 1990), mahi-mahi (Baranowski, Frank, Brast, Chongsiriwatana, & Premarathe, 1990) and flying fish (Vijayan, Jose, & Gopakumar, 1994). Furthermore, most work has been carried out on histamine formation in fish from temperate regions rather than from tropical regions.

Fish freshness is traditionally judged by sensory methods, but several chemical indices have also been proposed. One of them is trimethylamine (TMA), which is formed from trimethylamine oxide (TMAO) as a result of bacterial enzyme activity (Krzymien & Elias, 1990). In India, around 79.7% of the total fish catch is consumed fresh (Anon, 2001). The most frequently consumed fishes are from groups (lethrinids, clupeids, carangids, perches and mackerel) belonging to both scombroidae and non-scombroidae families. This work was conducted to investigate the formation of histamine and volatile amines in six commercially important species of fish of the Thoothukkudi coast of Tamil Nadu, India, held at ambient temperature (32±2 °C), to examine their relationship with the sensory attributes.

2. Materials and methods

Six commercially important species of fish, namely mackerel (*Rastrelliger kanagurta*), sardine (*Sardinella fimbriata*), emperor bream (*Lethrinus miniatus*), threadfin bream (*Nemipterus japonicus*), trevally (*Carangoides armatus*) and barracuda (*Sphyraena barracuda*), were procured fresh from the Fishing Harbour of Thoothukkudi, Tamil Nadu, India, and immediately brought to the laboratory in insulated boxes. The fishes were held at ambient temperature (32±2 °C) without any washing or evisceration. Samples were drawn from each fish for sensory evaluation, and for the determination of histamine and volatile amines at intervals of 3 h.

The quality of fish was examined based on the appearance of eyes, gills, skin and intestine, firmness of the muscle tissue, colour and odour of fillets. A panel of six experienced judges evaluated the overall quality of each fish on a 10-point scale. The scores were given in the decreasing order scale with 10–9 for very fresh; 8–6 for slight decomposition, but acceptable; 5–3 for definite decomposition and 2–1 for advanced decomposition. The mean of the scores given by the panel represented the overall sensory quality score (Baranowski et al., 1990).

The fish fillets were ground separately in the homogenizer. Histamine content was determined in triplicate by the standard AOAC fluorometric method (AOAC, 1990). Fish muscle (10 g) was homogenized with 50 ml of 0.4 N perchloric acid and filtered. The volume of the perchloric acid extract was adjusted to 100 ml in a volumetric flask. The filtrate was extracted with several portions of *n*-butane-1-ol under alkaline condition and finally with 0.1 N HCl. The acid-aqueous phase was collected and derivatized with *o*-phthalaldehyde. The fluorescent intensity was measured using a spectrofluorometer (ELICO, SL-174, India) at an excitation wavelength of 350 nm and emission wavelength of 444 nm.

The total volatile base nitrogen (TVB-N) and trimethylamine nitrogen (TMA-N) contents were determined by the micro-diffusion method of Conway (Cobb, Alanez, & Thompson, 1973).

Data were statistically interpreted by the analysis of variance (ANOVA). Mean difference was determined using the least significant difference (LSD) multiple range test (Snedecor & Cochran, 1967).

3. Results and discussion

The changes in the sensory characteristics of six fishes were monitored regularly and the scores given are shown in Table 1. The initial quality characteristics of the fishes were very fresh; seaweedy odours, firm texture and glossy appearance. The freshness was maintained in the fishes up to 6 h of storage and was graded with the score of above 8 points, except for emperor bream fish, which showed signs of slight decomposition. Loss in the freshness of fishes appeared after 9 h of storage with no slime, faded gill or body colour; eyes were slightly sunken and there was loss of texture. The progress of decomposition was faster from then onwards in

Table 1
Changes in the sensory scores of the six commercially important species of fish of the Thoothukkudi coast stored at ambient temperature

Fish	Storage time (h)								
	0	3	6	9	12	15	18	21	24
Mackerel	9.75	9.50	8.50	7.75	7.00	6.25	4.75	3.50	2.00
Sardine	9.50	9.75	8.00	7.25	6.25	5.00	3.50	2.50	1.00
Emperor bream	9.00	8.50	7.50	6.75	6.00	4.75	3.25	2.00	1.00
Threadfin bream	9.25	9.00	8.25	7.50	6.50	5.50	4.50	2.25	1.25
Trevally	10.00	9.25	8.75	8.00	7.25	6.50	3.75	3.00	1.50
Barracuda	9.25	8.25	7.75	7.00	6.75	5.25	4.00	2.75	1.75

emperor bream, which exhibited decomposed/off-odour after 12 h, followed by sardines after 13 h. The other fishes were at the slight decomposition stage, but no-off odour was detected. Threadfin bream and barracuda developed off-odour and loose texture after 15 h, followed by trevally and mackerel, which showed spoilage signs only after 16 h of storage. The sensory scores of emperor bream were found to differ statistically ($P < 0.05$) from those of mackerel and trevally. Thereafter, the spoilage was very rapid and advanced decomposition took place. The delay in the decomposition of mackerel was probably because of the presence of red meat in this fish. At the same time, the spoilage in emperor bream and barracuda was rapid, as these fishes contain a high proportion of light meat, which is readily available for spoilage by microorganisms. However, the sardines also spoiled faster, despite having high red meat and fat, because of the "belly burst" phenomenon.

Changes in the total volatile base nitrogen (TVB-N) levels of commercially important fishes held at ambient temperature are depicted in Fig. 1. The TVB-N contents of fresh fish were within 4–9 mg/100 g. The TVB-N of the fresh mackerel was found to be higher than that of other fishes. The TVB-N increased gradually until 9–12 h of storage; and thereafter increased rapidly with storage time. The increase in TVB-N may be due to the increase in the ammonia liberated by deamination of adenosine monophosphate (AMP) or histamine (Sakaguchi, Murato, & Kawai, 1984). Connell (1995) suggested that a TVB-N level of 30–35 mg/100 g indicates initial decomposition. This level was reached in barracuda at 12 h, in mackerel and emperor bream fish at 15 h, sardines at 18 h, threadfin bream at 21 h, but in trevally, even after advanced decomposition, such a high value was not detected. Although the TVB-N levels were above 30–35 mg/100 g in most of the fishes between 12 and 18 h, they did not correlate well with the sensory changes. Furthermore, the TVB-N formation differed with the species of fish. Very high levels of TVB-N was observed in emperor bream by the end of experiment with 103 mg/100 g, followed by barracuda. The TVB-N values of emperor bream differed statistically ($P < 0.05$) from those of mackerel, sardine, perch and trevally. Mendes (1999) has recorded higher TVB-N values (127–139 mg/100 g) in mackerel held at room temperature (20–23 °C) for 55 h. In trevally, the formation of TVB-N was very slow; also, sensorially, this species exhibited off-odour after 16–18 h of storage. The reason behind such differences in the TVB-N formation by fish could not be clearly elucidated. Mendes (1999) has also observed the same with the TVB-N contents of sardine and chub mackerel with relatively low levels (less than 35 mg/100 g) after complete putrefaction.

The changes in the TMA-N content of the fishes held at ambient temperature are shown in Fig. 2. The content of TMA-N was from 0.8 to 4 mg/100 g in fresh fishes. As noticed for TVB-N values, the TMA-N levels of fresh mackerel were found to be higher than in the other fishes. The increase in TMA-N values was observed throughout the time of storage. The increase was gradual up to 6–9 h of storage and thereafter it was rapid. Formation of TMA in the fish muscle is mainly by the bacterial action on the TMAO content and the presence of specific spoilage organisms in the fish (Huss, 1988). The level of 10–15 mg/100 g has been suggested as the maximum limit of acceptability by Connell (1995) to indicate fish freshness. This level was attained in mackerel and threadfin bream and barracuda after 9 h; emperor bream and trevally after 12 h and sardine after 15 h. The formation of TMA-N in sardines, emperor

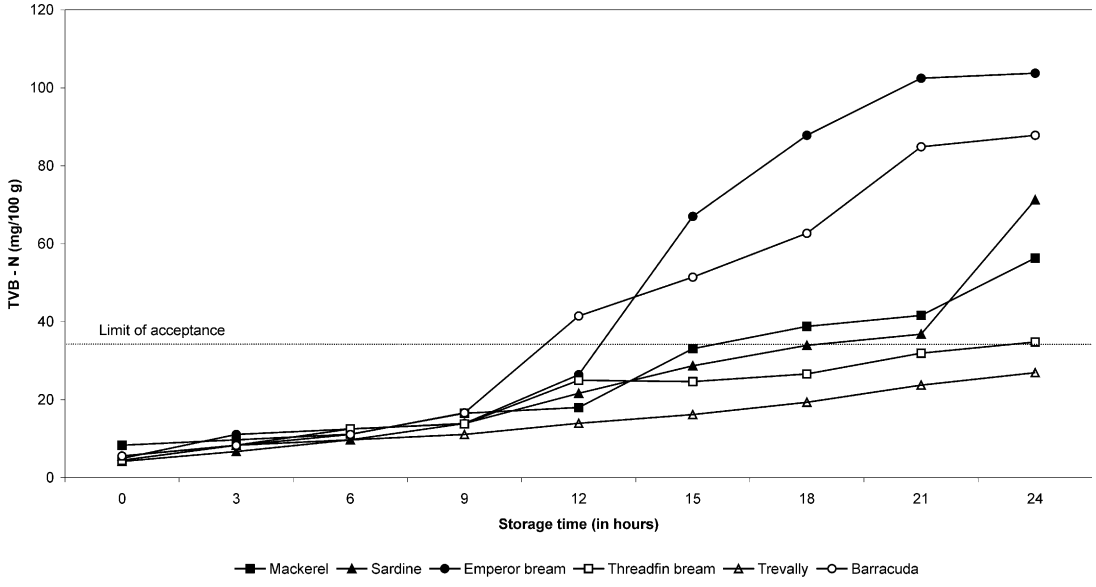

Fig. 1. Changes in TVB-N content of six commercially important species of fish of the Thoothukkudi coast stored at ambient temperature.

bream, threadfin bream and barracuda was not statistically significant ($P > 0.05$) at the end of storage. In mackerel, formation was greater and found to differ statistically ($P < 0.05$) from those of sardine, emperor bream and trevally. The differences in the formation of TMA-N in the fishes did not correlate with the formation of TVB-N. However, in trevally, the formation of both volatile amines, TMA-N and TVB-N, was comparatively lower than in other fishes. The reason behind such variation in the formation of volatile amines among different species of fish is not known. The changes in TMA-N values of fishes also did not show any correlation with the sensory changes as, in sardine and emperor fish, the TMA-N levels exceeded 15 mg/100 g after 15 h of storage, although they become sensorially unacceptable at 12 h of storage.

The changes in the histamine formation in the fishes held at ambient temperature (32±2 °C) are depicted in Fig. 3. Although fresh fish are known to contain varying amounts of histamine in their muscles, depending on their freshness, the fish analyzed did not initially contain any histamine. Some authors have also not detected histamine in fresh fishes, i.e. sardines, tuna and mackerel (Jeya Shakila, Vasundhara, & Kumudavally, 2001; Vieciena-Nogues, Marine-Font, & Vidal-Carou, 1997; Yatsunami & Echigo, 1993). However, there are a few

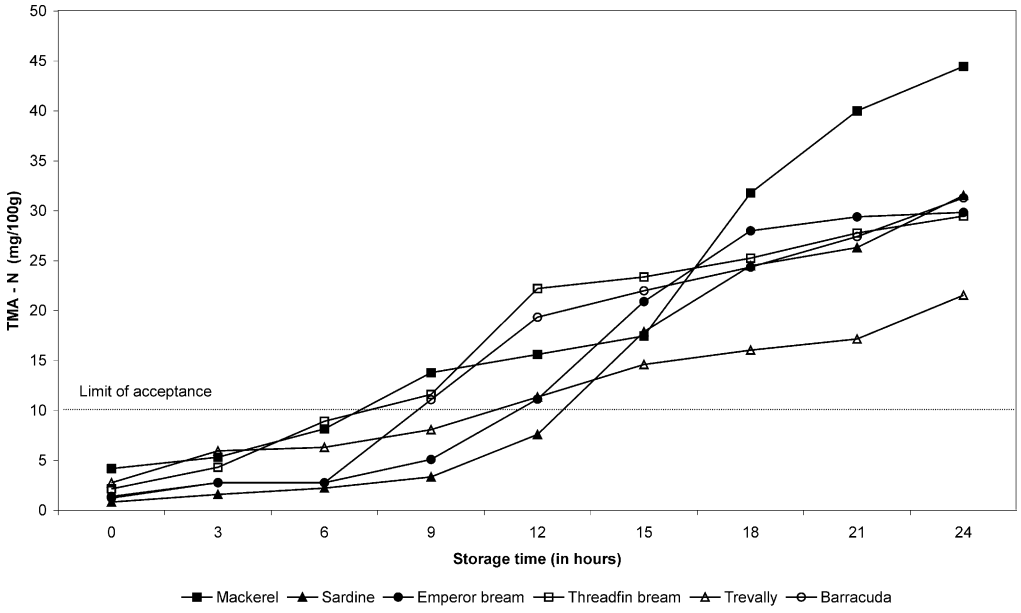

Fig. 2. Changes in the TMA-N content of six commercially important species of fish of the Thoothukkudi coast stored at ambient temperature.

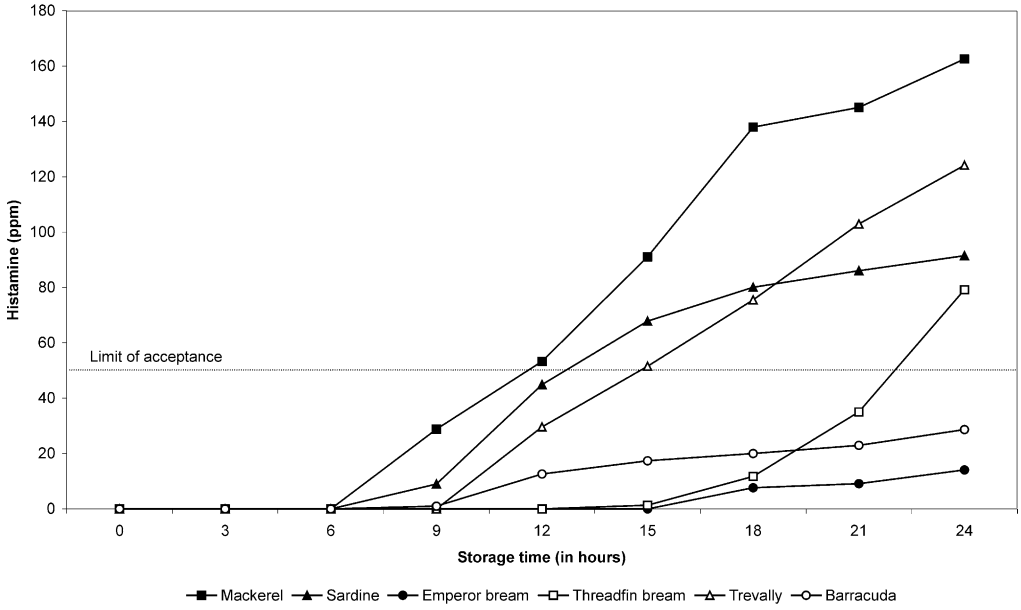

Fig. 3. Changes in the histamine content of six commercially important species of fish of the Thoothukkudi coast stored at ambient temperature.

reports that fresh fish do contain histamine up to a level of 5 ppm (Gopakumar, Surendran, & Vijayan, 1985; Vijayan et al., 1994). In this study, histamine formation appeared first in mackerel, sardine and barracuda only after 9 h of storage. The histamine content was higher (28 ppm) in mackerel than in the other two fishes, however, the fishes were considered organoleptically acceptable. Vijayan et al. (1996) have recorded 18 ppm of histamine in flying fish after 5 h storage, but such a high concentration was not detected in any of the fishes tested in this study. However, Ben-Gigirey, Craved, and An (1998) have found that the histamine formation was less than 4 ppm in tuna held on deck for 12 h at 15–33 °C. In trevally, histamine formation occurred after 12 h, but not in perch or emperor bream. At this stage, the histamine content of mackerel exceeded the permissible level of 50 ppm (FDA, 1996). Morii, Cann, and Taylor (1998) have noticed very high levels of histamine (260 ppm) in mackerel held at 30 °C for 10 h. The histamine formation continued to increase progressively on further storage in mackerel, sardine and trevally but not in barracuda.

Histamine formation appeared in threadfin bream and emperor bream after 15 and 18 h, respectively, although they exhibited spoilage at 15 h of storage. Mackerel and trevally had very high histamine concentrations at this stage, but did not exhibit off-flavour or off-odour. The histamine in sardine reached a maximum concentration of about 80–90 ppm at 18 h and thereafter remained more or less constant. The formation of histamine in emperor bream and barracuda marginally increased upon storage, but the increase was not significant ($P > 0.05$). High levels of histamine were formed in mackerel and trevally, reaching above 100 ppm at advanced stages of decomposition. Histamine formation continued to increase with the decomposition of mackerel, sardine and threadfin bream, but not with the other fishes. Large variations in the formation of histamine among the fish species were noticed. The histamine formation was higher in mackerel and differed significantly ($P < 0.05$) from emperor bream, perch and barracuda. Similarly, the histamine level of emperor bream was the lowest and it differed statistically ($P < 0.05$) from those of mackerel, sardine and trevally.

In the fish, mahi mahi, held at 32 °C, deterioration was observed after 12 h of incubation and the histamine level was only 20 ppm at this stage (Baranowski et al., 1990). In our study, at 12 h of incubation, histamine content of mackerel, sardine and trevally were above 25 ppm, but they were not totally spoiled. Very high levels of histamine of about 1555 ppm in flying fish held at 32 °C for 13 h (Vijayan et al., 1994), 2700 ppm in horse mackerel held at 30 °C for 15 h (Morii et al., 1998), 2350 ppm in sardine held at 28 °C for 24 h (Ababouch et al., 1991), 2500 ppm in mahimahi held at 32 °C for 24 h (Baranowski et al., 1990) and 4720 ppm in skipjack held at 37 °C for 26 h (Frank et al., 1981), were earlier recorded. In our study, such higher levels were not found in any of the fishes, even in advance stages of decomposition. The maximum histamine level observed was 162 ppm in Indian mackerel held at 32±2 °C for 24 h. However, Kim et al. (2001) have observed only 50 ppm of histamine in the mackerel held at 25 °C for 24 h, which is similar to our findings. Similarly, Ben-Gigirey et al. (1998) found that, in the tuna held on deck at 15–33 °C, the histamine content was found to be between 61 and 93 ppm, even after 4 days. In tuna held at 25 °C for 3 days, the histamine concentration was recorded as 120 ppm (Karmas & Meitz, 1978).

It has been found that there are variations in the formation of histamine in fishes belonging to the same species of different regions. There are also differences in the maximum level of histamine formation among the six fishes, with Indian mackerel showing the highest and emperor bream showing the lowest histamine content. The chemical composition of the fish, spoilage microflora and the climatic and storage conditions are certain parameters responsible for such differences in the histamine formation. However, the exact reason for such differences among the same fish species was not clearly known and hence needs to be explored further.

4. Conclusion

It is likely from this study that the commercially important fishes, mackerel, sardine and trevally, if consumed after prolonged exposure to ambient temperature, i.e. after 12–15 h, could cause histamine toxicity problems. Sensorial examination of mackerel, sardine and trevally exhibited putrid- and off-flavours, only when the histamine concentration exceeded 50 ppm. In the other fishes, i.e. threadfin bream, barracuda and emperor fish, the formation of histamine was very low and may not pose problems of histamine toxicity, when consumed within 12 h. There exists no relationship between the concentration of histamine and volatile amines.

Acknowledgements

The authors thank the Indian Council of Agricultural Research (ICAR), New Delhi, Government of India, for providing financial support to carry out this research project.

References

Ababouch, L., Aflial, M. E., Benabdeljelil, H., & Fusta, F. F. (1991). Quantitative changes in bacteria, amino acids and biogenic amines in sardine (*Sardina pilchardus*) stored at ambient temperature

(25–28 °C) and ice. *International Journal of Food Science Technology*, *26*, 297–306.

Anonymous. (2001). *Handbook of fisheries statistics—2000*. New Delhi: Government of India, Ministry of Agriculture.

AOAC. (1990). *Association of Official Analytical Chemists* (15th ed.). Washington, DC: AOAC.

Arnold, S. H., & Brown, W. D. (1978). Histamine (?) toxicity from fish products. *Advances in Food Research*, *24*, 113–154.

Baranowski, J. D., Frank, H. A., Brast, P. A., Chongsiriwatana, M., & Premarathe, R. J. (1990). Decomposition and histamine content in mahi-mahi (*Coryphaena hipparus*). *Journal of Food Protection*, *53*, 217–222.

Bean, N. H., & Griffin, P. M. (1990). Foodborne disease outbreaks in the United States, 1973–1987: pathogens, vehicles and trends. *Journal of Food Protection*, *53*, 801–817.

Ben-Gigirey, B., Craved, C., & An, H. (1998). Histamine formation in albacore muscle analyzed by AOAC and enzymatic methods. *Journal of Food Science*, *63*, 210–213.

Cobb, F., Alanez, I., & Thompson, C. (1973). Biochemical and microbial studies on shrimp: volatile nitrogen and amino nitrogen analysis. *Journal of Food Science*, *38*, 431–436.

Connell, J. J. (1995). *Control of fish quality*. England: Fishing News Books.

Food and Drug Administration (1996). Decomposition and histamine in raw, frozen tuna and mahi-mahi canned tuna; and related species.*Compliance Policy Guides* 7108.240, Sec. 540-525.

Frank, H. A., Yoshinaga, D. H., & Nip, W. K. (1981). Histamine formation and honeycombing during decomposition of skipjack (*Katsuwonus pelamis*) at elevated temperatures. *Marine Fisheries Review*, *43*, 9–14.

Gopakumar, K., Surendran, P. K., & Vijayan, P. K. (1985). Incidence of histamine decarboxylating bacteria and histamine levels in fish sold in retail markets. *FAO Fishery Reports*, *401*, 126–132.

Huss, H. H. (1988). *Fresh fish—quality and quality changes FAO fisheries series No. 29*. Rome: FAO Danish International Development Agency.

Karmas, E., & Mietz, J. L. (1978). Polyamine and histamine content of tuna fish and the relationship to decomposition. *Lebensmittel Wissenschaft and Technologie*, *11*, 333–337.

Kim, S. H., Field, K. G., Morrissey, M. T., Price, R. J., Wei, C. I., & An, H. (2001). Source and identification of histamine producing bacteria from fresh and temperature abused albacore. *Journal of Food Protection*, *64*, 1035–1044.

Krzymien, M. E., & Elias, L. (1990). Feasibility study on the determination of fish freshness by trimethylamine head space analysis. *Journal of Food Science*, *55*, 1228–1231.

Lerke, P. A., Werner, S. B., Taylor, S. L., & Guthertz, L. S. (1978). Scrombroid poisoning report of an out break. *Western Journal of Medicine*, *129*, 381–386.

Lopez-Sabater, E. I., Rodriguez-Jerez, J. J., Hernandez-Herrero, M., & Mora Ventura, M. A. T. (1994). Evaluation of histidine decarboxylase activity of bacteria isolated from sardine (*Sardina pilchardus*) by an enzymic method. *Letters in Applied Microbiology*, *19*, 70–75.

Lopez-Sabater, E. I., Rodriguez-Jerez, J. J., Hernandez-Herrero, M., Roig-Sagues, A. X., & Mora Ventura, M. A. T. (1996). Sensory quality and histamine formation during controlled decomposition of tuna (*Thunnus thynnus*). *Journal of Food Protection*, *59*, 167–174.

Longberg, E., Movitz, J., & Scorach, S. (1980). Histamine in tuna fish. *Var Foeda*, *32*, 114–123.

Marackchi, E. I., Bennour, A. M., Bouchritt, N., Hamnan, A., & Tagafait, H. (1990). Sensory, chemical and microbiological assessments of Moroccan sardines (*Sardina pilchardus*) stored in ice. *Journal of Food Protection*, *55*, 600–605.

Mendes, R. (1999). Changes in biogenic amines of major Portuguese bluefish species during storage at different temperatures. *Journal of Food Biochemistry*, *23*, 33–43.

Mietz, J. L., & Karmas, E. (1978). Polyamines and histamine content in rockfish, salmon, lobster and shrimp as an indicator of decomposition. *Journal of Association of Official Analytical Chemistry*, *61*, 139–145.

Morii, H., Cann, L. Y., & Taylor, L. (1988). Histamine formation by luminous bacteria in mackerel stored at low temperature. *Nippon Suisan Gakkaishi*, *54*, 299–305.

Okuzumi, M., Fukumoto, I., & Fujii, T. (1990). Changes in bacterial flora and polyamines contents during storage of horse mackerel meat. *Nippon Suisan Gakkaishi*, *56*, 1307–1312.

Rawles, D. D., Flick, G. J., & Martin, R. E. (1996). Biogenic amines in fish and shellfish. *Advances in Food Nutrition Research*, *39*, 329–364.

Ritchie, A. H., & Mackie, I. M. (1980). The formation of diamines and polyamines during storage of mackerel (*Scomber scrombrus*). In J. J. Connell (Ed.), *Advances in fish science and technology* (pp. 489–494). Farnham Surrey, England: Fishing News Books.

Sakaguchi, M., Murata, M., & Kawai, A. (1984). Changes in free amino acids contents in juvenile mackerel *Scomber japonicus* muscle during ice storage. *Bulletin of Japanese Society for Scientific Fisheries*, *50*, 323–329.

Shakila, R. J., & Vasundhara, T. S. (2001). Biogenic amines in fresh, canned and salt-dried fishery products of India. *Fishery Technology*, *38*, 92–96.

Sockett, P. N., Cowden, J. M., Le Baigne, S., Ross, D., Adak, G. K., & Evans, H. (1993). Foodborne disease surveillance in England and Wales: 1989–1991. *CDR Review*, *3*, 159–174.

Snedecor, G. D., & Cochran, W. G. (1967). *Statistical methods*. Ames: The Iowa State University Press.

Taylor, S. L. (1986). Histamine food poisoning: toxicology and clinical aspects. *CRC Critical Review of Toxicology*, *17*, 91–117.

Veciana-Nogues, M. T., Marine-Font, A., & Vidal-Carou, M. C. (1997). Biogenic amines as hygienic quality indicators of tuna relationship with microbial counts. ATP-related compounds, volatile amines, and organoleptic changes. *Journal of Agricultural Food Chemistry*, *45*, 1385–2041.

Veciana-Nogues, M. T. M., Vidal-Carou, M. C., & Marine-Font, A. (1990). Histamine and tyramine during storage and spoilage of anchovy, *Engraulis encrasicholus*: relationships with other fish spoilage indicators. *Journal of Food Sciences*, *55*, 1192–1193.

Vijayan, P. K., Joseph, J., & Gopakumar, K. (1994). Formation of histamine in flying fish (*Hirundichthys coramandelensis*) at ambient temperature and in ice. *Fishery Technology*, *31*(2), 142–147.

Wendakoon, C. N., Michiyo, M., & Sakaguchi, M. (1990). Compaison of non-volatile amine formation between the dark and white muscles of mackerel during storge. *Nippon Suisan Gakkaishi*, *56*, 809–818.

Yatsunami, K., & Echigo, T. (1993). Changes in the number of halotolerant histamine-forming bacteria and contents of non-volatile amines in sardine meat with addition of NaCl. *Nippon Suisan Gakkashi*, *59*, 123–127.

Yoshinaga, D. H., & Frank, H. A. (1982). Histamine producing bacteria in decomposing skipjack tuna (*Katsuwomus pelamis*). *Applied Environmental Microbiology*, *44*, 447–452.