Food Chemistry 119 (2010) 467–470

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Biogenic amine changes in barramundi (*Lates calcarifer*) slices stored at 0 °C and 4 °C

Jamilah Bakar *, Ali Yassoralipour, Fatimah Abu Bakar, Russly Abdul Rahman

Universiti Putra Malaysia, Faculty of Food Science and Technology, 43400 Serdang, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 21 February 2009
Received in revised form 22 May 2009
Accepted 23 June 2009

Keywords:
Biogenic amines
Barramundi
Refrigerated storage
Quality changes

ABSTRACT

The biogenic amines formation in barramundi (*Lates calcarifer*) slices kept for 15 days at 0 °C and 4 °C were investigated using nine biogenic amines, total plate counts and biogenic amines formers. Significant differences in biogenic amines concentrations of barramundi slices stored at 4 °C and at 0 °C after 3 days of storage were observed. All amines, except tryptamine, 2-phenylethylamine, tyramine and agmatine in the slices increased with time during storage at both temperatures. At the end of the storage period, histamine concentrations were 82 mg/kg and 275 mg/kg for samples kept at 0 °C and 4 °C, respectively. At day 15, the total plate count was approximately 8.6 log CFU/g for sample kept at 0 °C and 9.7 log CFU/g for samples kept at 4 °C. Histamine-forming bacteria (HFB) in all samples ranged from 5.4 to 6.1 log CFU/g at 0 °C and 4 °C, respectively. The observed shelf-life of barramundi slices were 6–9 days.

1. Introduction

Biogenic amines (BAs) in foods are formed by microbial decarboxylation of amino acids. Amines such as cadaverine and putrescine are very important in food, especially in fish and fish products, since they have been shown to potentiate the toxicity of histamine (Shalaby, 1996). Histamine, one of the biogenic amines, has been known as the contributory toxin of scombroid fish poisoning (Önal, 2007), however, histamine formation was reported to not be related to the activity of endogenous enzymes in fish, but due to histidine content in the fish muscle. Biogenic amines are produced at very low levels in fresh fish and their formation is related to bacterial spoilage (Özogul & Özogul, 2006). Spermine and spermidine are usually the major amines present in fresh muscle at concentration of less than 10 mg/kg flesh, but depending on the fish species, the free amino acids present in the tissue and the conditions of exposure to spoilage bacteria, other amines such as histamine in fish of mackerel and herring families (*Scombridae* and *Clupeidae*) can rise to 2000 mg/kg flesh (Clifford & Walker, 1992). They can be produced during the storage or processing of the products by thermal or bacterial enzymatic decarboxylation of free amino acids (Önal, 2007).

The most common fish associated with histamine fish poisoning or scombroid fish poisoning or scombrotoxicosis are scombroid fish including tuna, mackerel and saury, and non-scombroid fish including bluefish, mahi-mahi, sardine, anchovy, herring, and marlin (Flick, Oria, & Douglas, 2001). Different concentrations have been gazetted for the establishment of guidelines such as 'safe for consumption', or 'acceptance' for different fish species (Arnold & Brown, 1978). The Food and Drug Administration (FDA) of the United States of America had established a guidance level for histamine at 50 mg/kg for assuring the safe consumption of scombroid or scombroid-like fish. The FDA has also recommended the use of other data to judge fish freshness, such as the presence of other biogenic amines associated with fish decomposition (USFDA, 2002). A maximum histamine content of 200 mg/kg has been established in the European Community (EC) for acceptance of tuna and other fish belonging to the *Scombridae* and *Scomberesocidae* families (EC, 1991). The EC has suggested that in the future, a maximum of 300 mg/kg for total biogenic amines in fish and fish products may be an appropriate legal limit (EC, 1991).

The biogenic amine contents in several fish such as sardine, tuna and herring are quite abundant in the literature; however, none has been reported for Barramundi (*L. calcarifer*), a brackish water fish. It is a high value fish, which is cultured and also found wild in Malaysia. They are marketed live or in the fresh form on ice. Therefore, this study was carried out to investigate the formation of biogenic amines in barramundi slices kept at 0 °C and 4 °C. The findings from the study can contribute to the database on biogenic amines in farmed, tropical fish, which at present is negligible.

2. Materials and methods

2.1. Reagents

Standard amines, containing tryptamine hydrochloride (TRT), 2-phenylethylamine hydrochloride (PHE), putrescine dihydrochloride (PUT), cadaverine dihydrochloride (CAD), histamine

* Corresponding author. Tel.: +60 03 8946 8355; fax: +60 03 89423552.
E-mail address: jamilah@putra.upm.edu.my (J. Bakar).

0308-8146/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.foodchem.2009.06.041

dihydrochloride (HIS), spermidine trihydrochloride (SPD), spermine tetrahydrochloride (SPR), tyramine (TYR) and agmatine (AGM) were obtained from Sigma (St. Louis, MO, USA). All chemicals used were of analytical grade.

2.2. Sample preparation

Ten fresh barramundi (*L. calcarifer*) weighing approximately 1 kg and of 33 cm in length were purchased from a local wet market. The duration between catch and arrival of the fish at the laboratory was less than 15 h where they were always kept in ice. To ensure uniformity of the sample characteristics, all fish were bought from the same supplier and were treated in the same manner. Upon arrival, the whole fish were washed under running tap water, headed, gutted, filleted and rinsed. Then, they were cut to slices of approximately 1.3 cm thick. Slices were then randomly divided into homogenous groups of approximately 200 g each, then packed into two separate bags. One pack was analysed immediately and the data collected was labelled as the data for 0 day. The rest of the samples were then stored at two storage temperatures, 0 °C and 4 °C, for 15 days. The whole experiment was repeated twice within a space of a month.

2.3. Biogenic amine quantification

The sample preparation, benzoylation and determination were according to the procedure of Hwang, Chang, Shiua, and Chai (1997) Tryptamine hydrochloride (61.4 mg), putrescine dihydrochloride (91.5 mg), cadaverine dihydrochloride (85.5 mg), 2-phenylethylamine hydrochloride (65.1 mg), spermidine trihydrochloride (87.7 mg), spermine tetrahydrochloride (86.0 mg), histamine dihydrochloride (82.8 mg) tyramine hydrochloride (63.4 mg), agmatine sulphate (87.7 mg) were dissolved separately in 50 ml 0.1 N HCl. The final concentration of the free base for each amine was 1000 mg/kg solution. A series of dilutions were prepared from the standard stock solution and used to obtain the standard curve. The benzoyl derivatives of all biogenic amines were then prepared according to the prescribed procedure (Hwang et al., 1997).

2.4. Sample preparation and amine extraction

Samples were homogenised in a Waring blender (Model 32BL79, USA) for 3 min. Ground samples (5 g) were transferred to 50 ml centrifuge tubes and homogenised with 20 ml 6% TCA solution for 3 min. The homogenates were then centrifuged at 8000*g* for 10 min in a refrigerated high speed centrifuge (KUBOTA7800) and the supernatant was filtered through Whatman No. 1 filter paper (Whatman, Maidstone, UK). The filtrates were then placed in volumetric flasks and 6% TCA was added to a final volume of 50 ml. After which, an aliquot of each extract was derivatised with benzoyl chloride using the same procedure as the benzoylation of the standard amine solution.

2.5. HPLC parameters

Amines were determined using a Perkin Elmer liquid chromatograph (Perkin Elmer Series 200, USA) system which was equipped with a UV–Vis detector, LC Chromato-integrator and Vacuum Degasser. A Lichrospher 100 RP-18 reserved-phase column (5 μm, 150 × 4.6 mm I.D., Merck) was used for the peak separation which was detected at 254 nm. The gradient elution program was set at 0.8 ml/min, starting with a methanol–water mixture (50:50, v/v) for 0.5 min and the program preceded linearly to methanol–water (85:15, v/v) at a flow rate of 0.8 ml/min over 6.5 min. This was followed by the same composition and flow rate for 5 min, then a decrease over 2 min to methanol–water (50:50, v/v) at a flow rate of 0.8 ml/min.

2.6. Total plate count (TPC)

Twenty-five grams of fish slices were aseptically weighed and homogenised in stomacher bags (BAGMIXER® 400, Model P) with 225 ml sterile peptone water for 1 min. The homogenised sample was serially diluted using 9 ml peptone water. Further serial dilutions were made and 0.1 ml of each dilution was pipetted onto the surface of the plate count agar (Merck), in triplicates, after which they were incubated for 2 days at 30 °C (AOAC, 2002).

2.7. Histamine-forming bacteria (HFB)

The histamine-forming bacteria was carried out according to the procedure of Nivein's (Niven, Jeffreg, & Corlett, 1981). Ten grams of fish muscle was homogenised with 90 ml of peptone water in a stomacher bag (BAGMIXER® 400, Model P) for 1 min. Serial dilutions of each sample were prepared. Aliquots of 0.1 ml were spread in triplicate over the Niven's medium plates, which were then incubated for 72 h at 37 °C. Purple colonies (surrounded by a purple halo on a yellowish background) were counted for each plate using a colony counter.

2.8. Quality index and biogenic amines index

The quality index and the biogenic amine index were calculated according to the procedures described by Mietz and Karmas (1977) and Veciana-Nogues, Marine-Font, and Vidal-Carou (1997) respectively. The formulae used were as follows:

(i) $\text{Quality index(QI)} = \frac{(\text{histamine}+\text{putrescine}+\text{cadaverine})}{(1+\text{spermidine}+\text{spermine})}$

(ii) $\text{Biogenic amine index(BAI)} = (\text{histamine} + \text{putrescine} + \text{cadaverine} + \text{tyramine})$

2.9. Statistical analysis

Data collected were analysed by one-way analysis of variance (ANOVA). The one-way ANOVA was used to analyse the effect of days by different temperature on the fish slices. The Tukey's test was used for mean comparison when a significant variation was found by the ANOVA test. The significance of results was at $P < 0.05$. The software used was Minitab release 14 (2005). Pearson correlation was conducted to determine if there existed any relationship amongst the HFB, TPC, and histamine contents of the two samples tested.

3. Results and discussion

3.1. Biogenic amines analysis

The concentrations of the nine biogenic amines present in the muscle of barramundi stored at 0 °C and 4 °C for 15 days are given in Table 1. On the whole, samples stored at 0 °C had lower concentrations of the biogenic amines as compared to those stored at 4 °C. No amines were detected on the first day of storage for both temperatures.

For 0 °C storage, only two amines, i.e. putrescine and tryptamine were detected on the third day and six amines were detected on the sixth day of storage. However, for the same sampling day, the presence of eight and nine amines was detected, respectively, for samples kept at 4 °C. The first appearance of hista-

Table 1
Biogenic amines concentration[1] (mg/kg muscle) in barramundi slices stored at 0 and 4 °C.

Time (days)	PUT		CAD		TRT		PHE		SPD		SPR		HIS		TRY		AGM	
	0 °C	4 °C	0 °C	4 °C	0 °C	4 °C	0 °C	4 °C	0 °C	4 °C	0 °C	4 °C	0 °C	4 °C	0 °C	4 °C	0 °C	4 °C
0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	1.76 ± 0.65^{Ab}	29.58 ± 0.67^{Ab}	ND	ND	4.05 ± 0.14^{Aa}	8.4 ± 0.18^{A}	ND	ND	ND	19.03 ± 2.68^{A}	ND	ND	ND	34.21 ± 0.25^{A}	ND	7.91 ± 0.81^{A}	ND	9.33 ± 0.97^{A}
6	14.52 ± 3.53^{Aa}	45.41 ± 2.07^{Bb}	11.53 ± 0.63^{Aa}	44.37 ± 1.38^{Bb}	7.49 ± 1.70^{Aa}	18.32 ± 0.07^{Bb}	ND	37.19 ± 1.68^{A}	ND	25.10 ± 1.09^{B}	36.35 ± 5.40^{Aa}	75.94 ± 5.28^{Bb}	ND	14.82 ± 3.36^{A}	ND	54.19 ± 1.81^{Bb}	17.66 ± 1.60^{Aa}	13.48 ± 1.86^{Bb}
9	47.50 ± 6.59^{Ca}	142.03 ± 2.45^{Cb}	19.08 ± 2.35^{Ba}	207.09 ± 26.90^{Cb}	11.46 ± 0.83^{Ca}	28.72 ± 0.81^{Cb}	97.40 ± 2.20^{Aa}	48.09 ± 1.89^{Aa}	44.31 ± 1.50^{Cb}	47.50 ± 0.63^{Ba}	123.46 ± 8.86^{Cb}	43.14 ± 0.39^{Aa}	203.79 ± 0.95^{Bb}	40.78 ± 0.20^{Ba}	93.99 ± 1.55^{Cb}	149.91 ± 2.13^{Ba}	150.43 ± 2.92^{Cb}
12	149.25 ± 6.81^{Da}	276.50 ± 12.78^{Db}	38.29 ± 0.97^{Ca}	432.21 ± 15.26^{Db}	33.30 ± 2.42^{Da}	39.54 ± 4.26^{Db}	16.70 ± 0.14^{Ba}	100.54 ± 2.13^{Bb}	21.27 ± 1.33^{Ba}	86.32 ± 0.47^{Db}	106.67 ± 4.58^{Ca}	133.37 ± 14.97^{Cb}	62.38 ± 0.17^{Ba}	227.88 ± 1.37^{Cb}	29.54 ± 1.11^{Ca}	52.45 ± 0.75^{Db}	69.12 ± 2.40^{Ca}	138.89 ± 5.91^{Db}
15	362.46 ± 4.29^{Ea}	357.20 ± 4.35^{Da}	158.71 ± 11.09^{Da}	663.00 ± 4.57^{Eb}	30.50 ± 2.09^{Da}	17.22 ± 1.23^{Bb}	13.55 ± 1.62^{Ca}	44.12 ± 0.23^{Cb}	10.54 ± 1.25^{Ca}	80.71 ± 0.07^{Eb}	130.16 ± 17.41^{Ca}	165.38 ± 8.11^{Db}	82.21 ± 3.57^{Ca}	274.25 ± 0.42^{Db}	10.79 ± 1.48^{Da}	39.65 ± 0.30^{Eb}	45.06 ± 4.75^{Da}	50.83 ± 7.48^{Eb}

[a]Means within each column with different lower case are significantly ($P < 0.05$) different.
[A]Means within each column with different upper case are significantly ($P < 0.05$) different.
Abbreviations: PUT-putrescine, CAD-cadaverine, TRT-tryptamine, PHE-2-phenylethylamine, SPD-spermidine, SPD-spermine, HIS- histamine, TYR-tyramine, AGM-agmatine and ND-not detected.
[1] Means reported are the results of triplicate.

mine was detected on the ninth day of sampling. As storage time progressed, putrescine (362.4), cadaverine (158.7) and tryptamine (30.5) mg/kg muscle became the dominant amines in descending order. Valle, Malle, and Bouquelet (1996) found that when herring (*Clupea harengus*) was inedible, putrescine and cadaverine contents of the herring stored at 0 °C were at 10.1 and 23 mg/kg, respectively. They also reported that plaice (*Pleuronectes platessa*) and whiting (*Merlangius merlangus*) contained 15.7 and 58 mg/kg putrescine and 9.1 and 9.2 mg/kg cadaverine, respectively. Based on the EC acceptance of 200 mg/kg as the cut-off point for tuna and other fish belonging to the *Scombridae* and *Scomberesocidae* families, barramundi slices in this study could be considered acceptable until day 15 of storage at 0 °C. However, when the FDA Safe for consumption guidelines were referred to, the samples were only acceptable until day 9 of storage at 0 °C. Although spermidine, spermine, 2-phenylethylamine, tyramine and agmatine contents of barramundi showed fluctuations, they increased to 10.5, 130.1, 13.5, 10.7 and 45.1 mg/kg, respectively, at the end of the storage. These findings are generally in agreement with the amine values reported by Ritchie and Mackie (1979) for mackerel (*Scomber scombrus*).

A significant increase in histamine, putrescine and cadaverine were observed throughout the storage period of barramundi slices at 4 °C storage (Table 1). The concentration of histamine, putrescine and cadaverine increased during the storage period, reaching maximum levels of 274.2, 357.2 and 362.4 mg/kg on the 15th day, respectively.

Significant differences were found ($P < 0.05$) in the levels of cadaverine, putrescine and histamine for the different days. The level of histamine exceeded the 50 mg/kg fish after 9 days at 0 °C and after 6 days at 4 °C, legal limit for histamine set by the US Food and Drug Administration (FDA). Cadaverine and putrescine were highest in slices after 15 days of storage at 4 °C. Higher storage temperature seemed to produce a higher rate of formation for these two amines. Middlebrooks, Toom, Douglas, Harrison, and McDowell (1988) also reported that the levels of histamine, cadaverine, and putrescine and the time and temperature of decomposition in Spanish mackerel (*Scomberomorus maculatus*) showed a strong correlation.

Spermidine and Spermine, which are naturally found in foods, were identified in all the samples studied (Table 1). Spermidine concentrations in the samples for both temperatures were lower than that of spermine.

Tryptamine and 2-phenylethylamine were detected in all samples (Table 1). Tryptamine concentration increased after 6 days and reached a maximum on the ninth day and thereafter a decline was observed for both in the two studied temperatures. A similar trend was also obtained for agmatine. Significant differences in agmatine content between samples stored at 0 °C and 4 °C throughout the storage period were observed. Yamanaka, Shiomi, and Kikuchi (1987) indicated that agmatine may be used as an index of freshness since agmatine concentration increased during the early stage of fish spoilage but decreased in later stages. This was also observed in this study.

Table 2 shows the quality and biogenic amine indices of barramundi slices stored at 0 °C and 4 °C. An increase in the two indices with storage time, indicated that these indices could be used to determine the degree of spoilage of barramundi. The correlation between storage time and quality index at 0 °C and 4 °C ($r^2 = 0.82$, $r^2 = 0.95$) and biogenic amine index ($r^2 = 0.81$, $r^2 = 0.93$) were high compared to the values reported for tuna (*Thunnus thynnus*) ($r^2 = 0.34$; $r^2 = 0.63$) by Mietz and Karmas (1977) and by Veciana-Nogues et al. (1997), respectively. Therefore, storage at 0 °C managed to extend the shelf-life (approximately three days) of barramundi slices by inhibiting microbial growth compared to 4 °C (Fig. 1).

Table 2
Quality and biogenic amine indices and total biogenic amines of barramundi slices stored at 0 and 4 °C.

Time (days)	Quality index		Biogenic amine index		Total biogenic amine (mg/kg)	
	0 °C	4 °C	0 °C	4 °C	0 °C	4 °C
0	ND	ND	ND	ND	ND	ND
3	0.17	0.64	0.17	4.84	5.81	149.84
6	0.56	0.94	4.51	15.86	106.65	328.82
9	1.04	3.11	15.03	64.66	500.46	1420.45
12	1.81	4.07	27.92	98.89	527.52	1487.70
15	4.00	5.05	61.4	133.4	843.98	1692.36

Quality index = (histamine + putrescine + cadaverine)/(1 + spermidine + spermine).
Biogenic amine index (BAI) = (histamine + putrescine + cadaverine + tyramine).
ND-not detected.

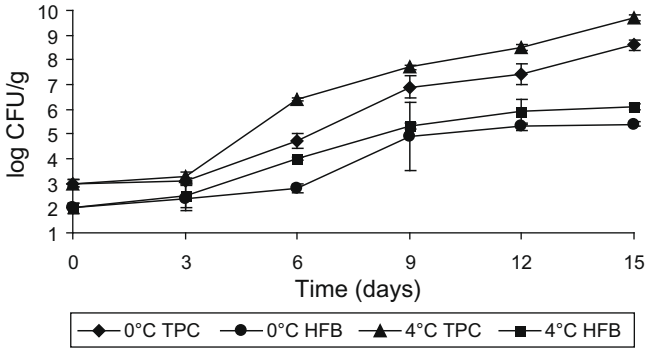

Fig. 1. Changes in total plate counts, histamine-forming bacteria of barramundi slices stored at 0 °C and 4 °C. Points represent mean values of six determinations ± standard deviation ($n = 2 \times 3$). TPC-total plate count, HFB-histamine-forming bacteria.

3.2. Total plate count (TPC) and histamine-forming bacteria (HFB)

Fig. 1 shows the total viable counts and histamine-forming bacteria in barramundi samples stored at 0 °C and 4 °C. Higher counts were observed at 4 °C as compared to the counts at 0 °C. At day 0, the initial aerobic colony counts were 3 log CFU/g. At day fifteenth the counts were to 8.6 and 9.8 log CFU/g for samples stored at 0 °C and 4 °C, respectively. If 6 log CFU/g is taken as the TPC limit of acceptability, therefore; the shelf-life of barramundi was approximately 9 and 6 days at 0 °C and 4 °C, respectively. There were significant differences ($P < 0.05$) in total viable count of fish stored at 0 °C and at 4 °C on fifteenth days. El Marrakchi, Bennour, Bouchaiti, Hamma, and Tagafait (1990) also reported that the total viable counts in sardines stored at ambient temperature exceeded the acceptable limit faster as compared to those kept on ice.

Fig. 1 also shows the changes in the histamine-forming bacteria of barramundi slices during storage at 0 °C and 4 °C. The histamine-forming bacteria grew faster in barramundi slices stored at 4 °C, as compared to at 0 °C. In this study, although histamine, putrescine and cadaverine and other biogenic amines were not found at the beginning of the storage, cadaverine increased faster than putrescine during storage. At the end of the experiment, when concentrations of histamine, cadaverine and putrescine reached a value of 274.2, 663, 357.2 for samples kept at 4 °C and 82.2, 158.7 and 362.4 mg/kg for samples kept 0 °C, the histamine-forming bacteria (HFB) corresponded to 5.4 log CFU/g and 6.1 log CFU/g, respectively. Therefore, this indicates that histamine-forming bacteria were naturally present at high levels in barramundi.

4. Conclusion

It can be concluded that strong positive correlations existed between HFB and histamine ($r = 0.98$, $r = 0.86$, $P < 0.05$), and TPC and histamine ($r = 0.96$, $r = 0.84$, $P < 0.05$) at 0 °C and 4 °C, respectively. The results of the present work also indicate that the concentrations of biogenic amines in barramundi slices increased drastically after 6 and 9 days of storage at 0 °C and 4 °C, respectively. The pattern of biogenic formation in this fish species is similar to that of marine species.

References

AOAC. (2002). *Official methods of analysis, standard methods for the examination* (17th ed.). Washington, DC: Association of Official Analytical Chemists, APHA.
Arnold, S. H., & Brown, W. D. (1978). Histamine toxicity from fish products. In: C.O. Chichester, E.M. Mark, G.F. Stewart (Eds.), Advances in Food Research (Vol. 24, pp. 113–154). New York: Academic Press.
Clifford, M. N., & Walker, R. (1992). The aetiology of scombrotoxicosis. *International Journal of Food Science and Technology, 27*(6), 721–724.
Council Directive 91/493/EEC of 22 July (1991). Laying down the health conditions for the production and the placing on the market of fishery products. *Official Journal of European Commission, L268*, 15–32.
El Marrakchi, A. E., Bennour, M., Bouchaiti, N., Hamma, A., & Tagafait, H. (1990). Sensory, chemical and microbiological assessment of Moroccan sardines (*Sardinas pilchardus*) stored in ice. *Journal of Food Protection, 53*, 600–605.
Flick, J. G., Oria, M. P., & Douglas, L. (2001). Potential hazards in cold-smoked fish: biogenic amines. *Journal of Food Science, 66*, 1088–1099.
Hwang, D. F., Chang, S. H., Shiua, C. Y., & Chai, T. J. (1997). High-performance liquid chromatographic determination of biogenic amines in fish implicated in food poisoning. *Journal of Chromatography B, 693*, 23–30.
Middlebrooks, B. L., Toom, P. M., Douglas, W. L., Harrison, R. E., & McDowell, S. (1988). Effects of storage time and temperature on the microflora and amine development in Spanish mackerel (*Scomberomorus maculatus*). *Journal of Food Science, 53*, 1024–1029.
Mietz, J. L., & Karmas, E. (1977). Chemical quality index of canned tuna as determined by high-pressure liquid chromatography. *Journal Food Science, 42*, 155–158.
Niven, C. F., Jeffreg, M. B., & Corlett, D. A. (1981). Differential plating medium for quantitative detection of histamine-producing bacteria. *Applied and Environmental Microbiology, 41*, 321–322.
Önal, A. (2007). A review: Current analytical methods for the determination of biogenic amines in foods. *Food Chemistry, 103*(4), 1475–1486.
Özogul, F., & Özogul, Y. (2006). Biogenic amine content and biogenic amine quality indices of sardines (*Sardina pilchardus*) stored in modified atmosphere packaging and vacuum packaging. *Food Chemistry, 99*(3), 574–578.
Ritchie, A. H., & Mackie, I. M. (1979). The formation of diamines and polyamines during storage of mackerel (*Scomber scombrus*). In J.J. Connell (Ed.), *Advances in fish science and technology* (pp. 489–494). Surrey, UK: Fishing News Books.
Shalaby, A. R. (1996). Significance of biogenic amines to food safety and human health. *Food Research International, 29*, 675–690.
USFDA (US Food and Drug Administration). (2002). Scombrotoxin (histamine) formation, fish and fishery products hazards and controls guide (3rd ed. pp. 73–93). Washington, DC: Department of Health and Human Services, Public Health Service, Food and Drug Administration, Center for Food Safety and Applied Nutrition, Office of Seafood.
Valle, M., Malle, P., & Bouquelet, S. (1996). Liquid chromatographic determination of fish decomposition indexes from analyses of plaice, whiting and herring. *Journal of AOAC International, 79*(5), 1134–1140.
Veciana-Nogues, M. T., Marine-Font, A., & Vidal-Carou, M. C. (1997). Biogenic amines as hygienic quality indicators of tuna. Relationships with microbial counts, ATP-related compounds, volatile amines, and organoleptic changes. *Journal of Agriculture and Food Chemistry, 45*(6), 2036–2041.
Yamanaka, H., Shiomi, K., & Kikuchi, T. P. Y. (1987). Agmatine as a potential index for freshness of common squid (*Todarodes pacificus*). *Journal of Food Science, 52*, 936–938.