

Preservation practices and safety of fresh shrimp (*Penaeus notialis*) sold in Beninese markets

Yénoukounmè Euloge Kpoclou^{1,2} · Victor Bienvenu Anihouvi² · Paulin Azokpota² · Mohamed Mansourou Soumanou³ · Caroline Douny⁴ · Ahmed Igout⁵ · Charis M. Galanakis^{6,7,8} · Marie-Louise Scippo⁴ · Djidjoho Joseph Hounhouigan²

Received: 2 December 2022 / Accepted: 8 February 2023

Published online: 23 February 2023

© The Author(s) 2023 [OPEN](#)

Abstract

The microbiological characteristics of fresh shrimps during storage in ice (FSPI) (1–4.5 °C) and at ambient temperature (FSKAT) (27.5–29.5 °C) was evaluated in Beninese selling market conditions to assess hygiene and shrimp safety in artisanal preservation practices. Furthermore, samples of FSPI and FSKAT sold at the retail markets were collected and analyzed using bacteriological and physicochemical methods. The acceptable limits for aerobic mesophilic bacteria (AMB) [7.0 Log₁₀ (CFU/g)] and trimethylamine (TMA) (5 mg/100 g) were exceeded after 12 days (FSPI) and 9 h (FSKAT). Most market samples (75% FSPI, 92% FSKAT) were non-compliant with the acceptable limit for AMB. The maximal limits specified were exceeded regarding *Enterobacteriaceae*, *E. coli*, and *Salmonella*, up to 75%, 92%, and 42%, respectively (FSKAT) and 33%, 67%, and 75% (FSPI). About 33% (FSPI) and 58% (FSKAT) samples were non-compliant with the TMA limit. All the samples were within the acceptable limits of histamine and tyramine. However, training stakeholders in good handling and hygienic practices is necessary.

Keywords Ice · Hygiene · Spoilage · Biogenic amines · Quality

1 Introduction

Shrimp is a perishable product. Enzymatic and microbiological changes greatly influence its quality and safety during post-capture storage. According to Aitken et al. [1] and Shamshad et al. [2], shellfish spoil more rapidly than fish for some reasons. First, shellfish are smaller, and small fish spoil more quickly than larger ones. Second (and more critical), the gut is usually not removed immediately after capture; however, post-mortem autolytic changes occur fast. A third reason is that the chemical composition of shellfish tissue is different, and it contains a lot of non-protein nitrogenous compounds that contribute to more rapid spoilage. Finally, black spots, or melanosis, a discoloration indicative of spoilage, always

✉ Yénoukounmè Euloge Kpoclou, euloge.kpoclou@gmail.com | ¹Ecole des Sciences et Techniques de Conservation et de Transformation des Produits Agricoles, Université Nationale d'Agriculture, BP 114 Sakété, Benin. ²School of Nutrition and Food Sciences and Technology, Faculty of Agronomic Sciences, University of Abomey-Calavi, Jericho, 03 BP 2819 Cotonou, Benin. ³Polytechnic School of Abomey-Calavi, University of Abomey-Calavi, 01 BP 2009 Cotonou, Benin. ⁴Department of Food Science, Faculty of Veterinary Medicine, University of Liège, Quartier Vallée 2, Avenue de Cureghem 10, 4000 Liège, Belgium. ⁵Department of Preclinical and Biomedical Sciences, Faculty of Medicine, Quartier Hôpital, University of Liège, Avenue Hippocrate 13, 4000 Liège, Belgium. ⁶Department of Research & Innovation, Galanakis Laboratories, Skalidi 34, 73131 Chania, Greece. ⁷Department of Biology, College of Science, Taif University, Taif, Saudi Arabia. ⁸Food Waste Recovery Group, ISEKI Food Association, Vienna, Austria.



occur in shrimp [3]. Therefore, the shrimp processing industry must develop a storage method to maintain shrimp's high quality and freshness.

In Benin, shrimp fishing plays a significant socio-economical role. This activity occupies about 21000 fishermen living in more than 200 villages in the country's south, who catch wild shrimps in the brackish waters of lake Ahémé, lake Nokoué, and Lagoon of Porto-Novo [4]. The annual production of fresh shrimp in Benin, estimated to be approximately 3000 tons, concerns mainly the *Penaeidae*, of which *Penaeus notialis* and *P. monodon* constitute the major species [5]. More than 75% of this production is intended for the artisanal sector [6]. In 2005, the government self-banned shrimp export to Europe in reaction to the shortcomings noted by the Food and Veterinary Office (FVO) of the European Commission in the legislative and sanitary arrangements for the export-oriented shrimp sector in Benin [7]. Since then, all the national shrimp collection has been directed towards the artisanal sector. In artisanal conditions known as unclean, fresh shrimps are preserved in ice for 3 to 7 days or kept at ambient temperature (about 30 °C) to be sold in local markets [8]. This study aims at evaluating hygiene in preservation practices and shrimp safety in selling conditions in Beninese markets.

2 Materials and methods

2.1 Fresh shrimp storage experiment as practiced by stakeholders

Wild shrimps (*Penaeus notialis*) with a size of 55 to 60 shrimp/kg, fished from lake Nokoué, were purchased from fishermen at wharves in Cotonou Township, Benin. Shrimps have washed thrice in tap water to remove slime and other extraneous material and divided into two batches. One batch was kept in ice in a plastic basket with a shrimp/ice ratio of 1:2 (w/w). The basket was heightened on PVC pipes and enclosed in an icebox. As sellers used to, flake ice was added twice daily at 8 a.m. and 5 p.m. (experiment 1). The second batch was kept in another plastic basket without ice at ambient temperature (experiment 2). These two experiments were performed, each in 3 trials, with a fresh shrimp seller in markets of Saint Michel (ambient temperature) and Ganhi (preservation in ice), following their customary practices. The temperature was monitored in the mass of the product undergoing the storage conditions using a thermocouple (TSTEMP 10 K, Oakton, Singapore). Samples were withdrawn for analysis at 2-day intervals for experiment 1 and 3-h intervals for experiment 2.

2.2 Sampling of fresh shrimp as sold in retail markets

Twenty-four (24) samples comprising 12 samples of fresh shrimp preserved in ice and 12 other samples of fresh shrimp kept at ambient temperature were randomly purchased from retail markets of Ganhi and Saint Michel (Cotonou), Comè (Comè city center) and Ahouangbo (Porto-Novo) (Table 1). Samples were collected in sterile stomacher bags, kept in ice, and transported to the laboratory within 2 h for immediate microbiological analysis and pH determination or stored at – 20 °C until other chemical analyses.

2.3 Microbiological analyses

Ten (10) shrimps (random selection) of each sample were ground in a sterile stomacher bag using a laboratory blender (Stomacher Lab-Blender 400, model N BA 6021, Seward, London, UK). Twenty-five grams (25 g) of ground samples were suspended in 225 ml of buffer peptone water (Oxoid CM0509B, Basingstoke, Hampshire, England) and homogenized for 2 min in the laboratory blender. Serial decimal dilutions were prepared in buffer peptone water as described by ISO 6887–3 [9] and inoculated in different media to enumerate aerobic mesophilic bacteria (Plate count agar, Oxoid

Table 1 Fresh shrimp collected from retail markets for analysis

Retail markets	FSIS	FSATS	Total
Ganhi (Cotonou)	3	3	6
Saint Michel (Cotonou)	3	3	6
Comè (Comè city center)	3	3	6
Ahouangbo (Porto-Novo)	3	3	6
Total	12	12	24

FSIS Fresh shrimps preserved in ice for selling; FSATS Fresh shrimp kept at ambient temperature for selling

CM0463B), *Staphylococcus aureus* (Baird-Parker agar, Oxoid CM0275B), *Enterobacteriaceae* (Violet Red Bile Glucose Agar, Oxoid CM0485B), *Escherichia coli* (TBX, Oxoid CM0945B), *Pseudomonas* spp. (*Pseudomonas* agar, CM0559 and *Salmonella* (Rappaport–Vassiliadis broth, Oxoid CM0669B; Muller Koffman broth, Oxoid CM0343B; X.L.D, Oxoid CM0469B; *Salmonella*, *Shigella* Agar (Oxoid CM0099B), as described by Kpoclou et al. [10].

2.4 Physicochemical analyses

2.4.1 Moisture content and pH determination

The pH of the samples was determined as described by Goulas and Kontomina [11] using a digital pH meter (Inolab pH 730 WTW 82362 Wellheim, Germany). The dry matter content was determined by oven drying 5 g of ground samples at 105 °C until a constant weight was reached [12].

2.4.2 Total volatile basic nitrogen (TVBN) and trimethylamine (TMA) determination

Total volatile bases of nitrogen (mg N/100 g) were determined in trichloroacetic acid (TCA) extracts of whole peeled shrimp, as described by Malle and Poumeyrol [13] using steam distiller (Büchi distillation Unit K-350, Switzerland). Briefly, 100 g of whole peeled shrimp sample was weighed and blended with 200 ml of 7.5% aqueous TCA (Trichloroacetic acid). The blend was then centrifuged at 400 × g for 5 min and the supernatant liquid was filtered (Whatman N 3 filter paper). Twenty-five milliliters (25 ml) of filtrate were loaded into the distillation tube followed by 5 ml of 10% NaOH. Steam distillation was carried out using Kjeldahl-type distillatory (VELP mark, model UDK-6, Milan, Italy). A beaker containing 10 ml of a 4% boric acid solution to which three to five drops of the indicator solution, Tashiro Mixed Indicator (2 g Methyl-red and 1 g Methylene-blue are dissolved in 1000 ml 95% ethanol) have been added, was placed at the end of the condenser. Distillation was continued until a final volume of 50 ml was obtained in the beaker. The contents of the collection beaker were titrated from green to a pale pink end point. A procedural blank was done using 200 ml Trichloroacetic acid with no sample and titrated as before. The concentration of trimethylamine (TMA) was determined by modification of the TVBN method adding 35 ml of formaldehyde to 25 ml of filtrate. Steam distillation was then performed as for TVBN determination. The concentrations of TVBN and TMA were determined as follows:

$$\text{TVB} - \text{N (mg/100g)} = 14 \text{ mg/mol} \times a \times b \times 2 \times 300 / 25 \text{ ml}$$

$$\text{TMA (mg/100g)} = 14 \text{ mg/mol} \times c \times b \times 2 \times 300 / 25 \text{ ml}$$

where: a and c = ml of sulphuric acid. b = molarity of sulphuric acid.

2.4.3 Biogenic amines

2.4.3.1 Standard solutions Putrescine, cadaverine, histamine, spermine, spermidine, tyramine, tryptamine, 2-phenylethylamine, and 1,7-diaminoheptane were obtained from Sigma (St. Louis, MO, USA). Individual stock solutions (10 mg/mL) were prepared by dissolving each biogenic amine standard in a 5% trichloroacetic acid (TCA) solution. A working solution of 1,7-diaminoheptane (1.5 mg/ml) obtained by diluting 10 mg/ml stock solution with TCA 5% was used as an internal standard. A pool of the 8 other biogenic amines was obtained by mixing 100–1000 µL of each stock solution with TCA 5% to 10 ml. All the standard solutions were kept for 6 months at 4 °C.

2.4.3.2 Sample preparation Five grams of fresh shrimps were mixed with 100 µL internal standard working solution into a 50 ml Falcon tube (Becton Dickinson Labware (NJ, USA)). Then, 20 ml of trichloroacetic acid (TCA) 5% was added; the mixture was vortexed and let stand for 10 min. Homogenization was realized with an UltraTurrax mixer (T25 basic) (IKA®-Werke, Staufen, Germany) for 30 secs. Next, the solution was filtered through a paper filter (MN 640 M ¼, diameter 150 mm, Macherey–Nagel, Düren, Germany) into another 50 ml Falcon tube, and TCA 5% was added to 50 ml. One milliliter of the extract was poured into a 15 ml Falcon tube. Three hundred µL NaHCO₃ saturated, and 250 µL NaOH 2N was added. The dansylation was realized by adding 1 ml dansyl chloride (20 mg/ml in acetone) and incubating the tubes at 70 °C for 20 min. After dansylation, 1 ml glycine (30 mg/ml in water) was added to bind to the dansyl chloride in excess, and the tubes were incubated at 70 °C for 20 min. Then acetone was evaporated under a nitrogen stream, and 2 ml

water was added. Next, biogenic amine derivatives were extracted with 4×1 ml of diethyl ether followed by evaporation of the solvent to dryness in a Savant™ Universal SpeedVac™ Vacuum System (Thermo Fisher Scientific, Waltham, Massachusetts, USA) and the addition of 500 μ L of acetonitrile/water (50:50, v:v). Finally, the solution was filtered through an Acrodisc® filter (GHP Acrodisc® 13 mm syringe filters with 0.2 μ m GHP membrane, Pall Life Sciences, MI, USA) and transferred into an injection vial.

2.4.3.3 UPLC-Fluorescence analysis Amines were analyzed on a UPLC Acquity system integrated autosampler (Acquity Sample Manager FTN), solvent delivery system (Acquity QSM H Class), and column heater coupled to an Acquity Fluorescence detector, all from Waters Corporation (Milford, MA, USA). The column used was an Acquity UPLC BEH C18 (2.1 \times 100 mm, 1.7 μ m), with a UPLC BEH C18 VanGuard pre-column (2.1 \times 5 mm, 1.7 μ m), both from Waters Corporation. The mobile phase was acetonitrile (solvent A) and water (solvent B). The gradient elution conditions were: 50% of solvent A maintained for 1.75 min, from 50 to 60% of solvent A within 6.75 min, from 60 to 85% within 1.80 min, and from 85 to 100% within 2.40 min; then, conditions were held for 0.30 min, and the contribution of solvent A was decreased to 50% over 0.30 min and maintained for 2.40 min. The oven temperature was set at 40 °C, and the injection volume was 5 μ L. The flow rate was 0.6 ml/min.

The peaks were identified by comparing their retention times with the corresponding standards. The fluorescence detection was applied at 300 nm for excitation and 480 nm for emission. Results were calculated using Empower 3 software (Waters). The limits of quantification (LOQ) of the method were 5.9 mg kg⁻¹ for tryptamine and 2-phenylethylamine and 5.9, 4.5, 2.5, 14.9, 10.2, 2.0, and 0.8 mg kg⁻¹ for putrescine, cadaverine, histamine, tyramine, spermidine, and spermine, respectively. The recovery of extraction was ranging between 95.4 and 104.8% for all biogenic amines.

2.5 Data analysis

Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS, version 16). Data are presented as mean with standard deviation; the significant differences were set at $p < 0.05$. One-way ANOVA and SNK (Student, Newman, and Keuls) range tests were used. In addition, correlation analyses between physicochemical and microbiological parameters were studied.

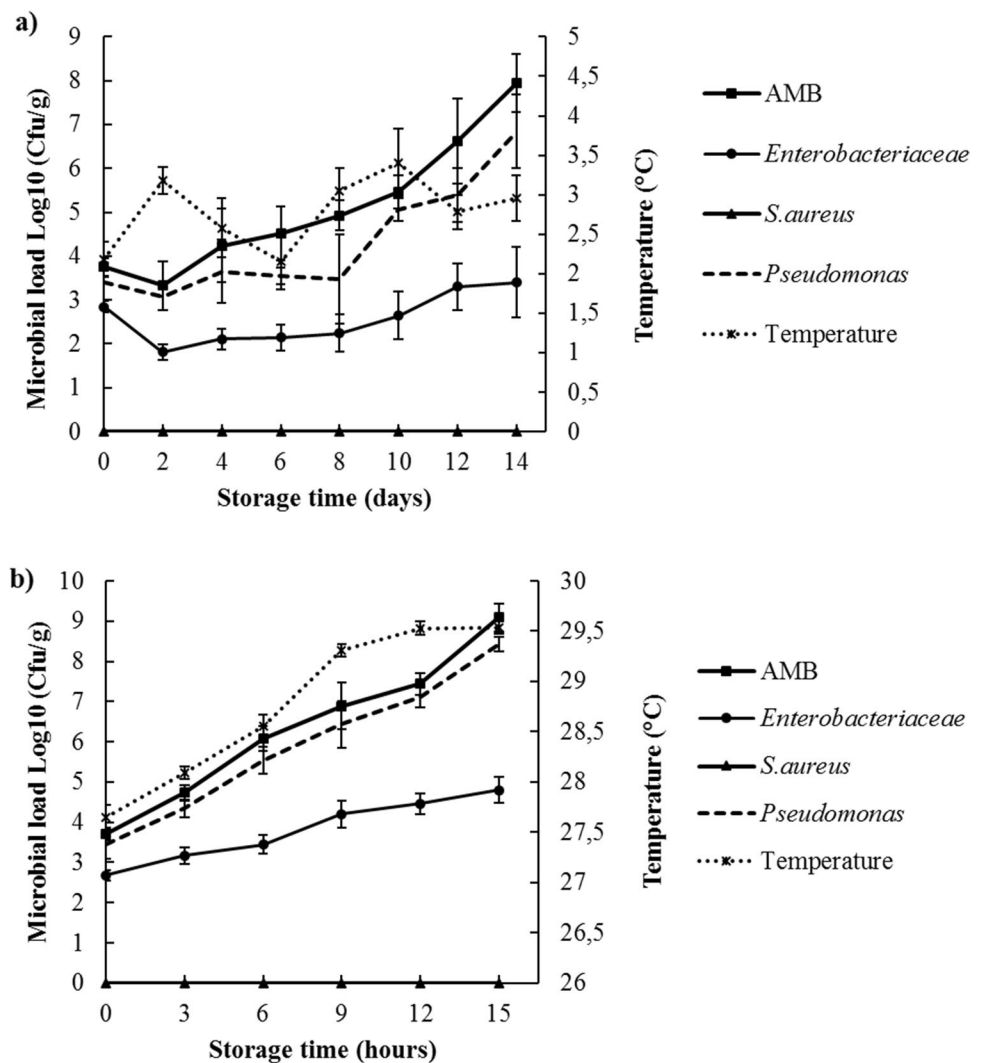
3 Results and discussion

3.1 Microbiological characteristics of shrimps

3.1.1 Fresh shrimps during storage in ice and at ambient temperature

The microbial loads of fresh shrimp during storage in ice and at ambient temperature are shown in Fig. 1. It appears that during storage in ice, the temperature in the mass of shrimps oscillates between 1 and 4.5 °C. During 14 days, the aerobic mesophilic bacteria (AMB) load and *Pseudomonas* load increase progressively from 3.8 Log₁₀ (CFU/g) to 8.0 Log₁₀ (CFU/g) and from 3.4 Log₁₀ (CFU/g) to 6.8 Log₁₀ (CFU/g), respectively. The load of *Enterobacteriaceae* wavered between 2.8 Log₁₀ (CFU/g) and 3.4 Log₁₀ (CFU/g), while *S. aureus* was absent throughout the experimentation. When shrimps are stored at ambient temperature (27.5–29.5 °C), AMB, *Pseudomonas* and *Enterobacteriaceae* increased from 3.7 Log₁₀ (CFU/g), 3.5 Log₁₀ (CFU/g), and 2.7 Log₁₀ (CFU/g) to 9.1 Log₁₀ (CFU/g), 8.4 Log₁₀ (CFU/g) and 4.8 Log₁₀ (CFU/g), respectively within 15 h. Therefore, keeping at an ambient temperature (27.5–29.5 °C) is favorable for microbial development in fresh shrimp. This testifies to the preservative effect of ice. AMB load superposes *Pseudomonas* load either during storage in ice or keeping at ambient temperature; this indexes *Pseudomonas* as dominant microorganisms of the aerobic mesophilic flora. The same tendency was observed for similar storage conditions (0 °C and 28 °C) in a previous study on fresh shrimp (*Penaeus notialis*) collected from the same lake (Nokoue) in Benin by Dabade et al. [14]. These authors showed the progressive growth of total viable count (TVC), *Pseudomonas* spp., and *Enterobacteriaceae*, with *Pseudomonas* spp. as the dominant microorganism group in shrimp storage at 0 °C. At 28 °C storage, they identified *Pseudomonas* spp. among the dominant bacteria groups (H₂S-producing bacteria, *Pseudomonas* spp., and Lactic acid bacteria). In our study, only *Pseudomonas* spp. have been enumerated in these groups. Ray and Bhunia [15] reported that Gram-negative aerobic rods, such as *Pseudomonas* spp. and several Gram-negative rods are the major shrimp spoilage bacteria. However, because of the relatively shorter generation time, spoilage by psychrotrophic *Pseudomonas* spp. predominates under aerobic storage at

Fig. 1 Changes in microbial loads during fresh shrimps storage in ice (a) and at ambient temperature (b)



both refrigerated and slightly higher temperatures. Other previous studies have identified *Pseudomonas* as the main flora in the deterioration of shrimps from tropical waters [16–19]. The International Commission on Microbiological Specifications for Foods [20] set up maximum limits of 7.0 Log₁₀ (CFU/g), 4.0 Log₁₀ (CFU/g), 2.0 Log₁₀ (CFU/g), and absence in 25 g for AMB, *S. aureus*, *E. coli*, and *Salmonella* respectively in raw crustaceans. Furthermore, the German Society for Hygiene and Microbiology [21] recommended 5.0 Log₁₀ (CFU/g) for *Enterobacteriaceae* for raw shrimp. In this study, the maximal limit of AMB was exceeded after 12 days and 9 h of storage in ice and at ambient temperature, respectively (Fig. 1). This agrees with data reported by Dabade et al. [14], in which TVC attained the limit of 7.0 Log₁₀ (CFU/g) after 12 days of storage at 0 °C and 28 °C respectively. Based on a sensory analysis, these authors identified the rejection times of 8–10 h and 10–12 days at 28 °C and 0 °C.

3.1.2 Fresh shrimp collected from retail markets

AMB count was up to 9.0 Log₁₀ (CFU/g) and 8.5 Log₁₀ (CFU/g) in FSPI and FSKAT, respectively (Table 2). Most of the FSKAT samples (75%) were contaminated with *S. aureus*, and none of them complied with the maximal limit set by the ICMSF [20]. Except for *Salmonella* tests, FSKAT was less safe than FSPI (Table 2) for all microbiological criteria. This could be due to the preservative role of ice, as reported by Dabade et al. [14] in a comparative study of shrimp storage at 28 °C, 7 °C and 0 °C.

Many FSPI and FSKAT were non-compliant with *Enterobacteriaceae*, *Salmonella*, and *E. coli*. This points out the possibility of human or animal fecal sources of contamination (often correlated with contamination by digestive pathogens) of shrimp, even in the environment, they are caught from or during post-harvest handling. Indeed, raw shrimps used for

Table 2 Microbial loads (Log_{10} (CFU/g)) and status of fresh shrimps collected from retail markets

Samples	Tests	Mean	SD ^a	Minimum	Maximum	Standards	No-compliant samples (%)
FSPI (n = 12)	AMB	6.8	1.6	5.2	9.0	7.0	42
	<i>S. aureus</i> ^b	3.8	–	3.8	3.8	4.0	0
	<i>E. coli</i>	4.1	0.7	3.3	4.9	2.0	67
	<i>Enterobacteriaceae</i>	4.7	1.30	3.3	6.8	5.0	33
	<i>Pseudomonas</i>	6.6	1.3	4.7	8.3	–	–
	<i>Salmonella</i> ^c	–	–	–	–	Absence	75
FSKAT (n = 12)	AMB	7.5	0.5	6.7	8.5	7.0	83
	<i>S. aureus</i>	4.4	2.0	4.0	5.6	4.0	75
	<i>E. coli</i>	4.3	1.1	1.8	5.7	2.0	92
	<i>Enterobacteriaceae</i>	5.2	1.0	3.3	6.2	5.0	75
	<i>Pseudomonas</i>	6.8	0.5	6.1	7.4	–	–
	<i>Salmonella</i>	–	–	–	–	Absence	42

FSPI fresh shrimps stored in ice; FSKAT fresh shrimps stored at ambient temperature; AMB Aerobic Mesophilic Bacteria; CFU colony forming unit; n number of samples; Standard ICMSF [20]

^aSD standard deviation

^bcoagulase-positive staphylococci

^cPresence/absence test in 25 g of sample

experiments with sellers were initially contaminated with *Enterobacteriaceae*, a group of microorganisms including *E. coli* and *Salmonella*, but were not infected with *S. aureus* (Fig. 1). The non-compliance of FSPI and FSKAT for *Enterobacteriaceae*, *Salmonella*, and *E. coli*. Could be associated with microorganisms growth during the shelf-life at market before they were collected. Indeed, Dabade et al. [14] reported growth of shrimp during storage at 28 °C, 7 °C and 0 °C. FSKAT exceeded the microbiological specifications in storage experiments with sellers after 9 h. Furthermore, all the samples of this shrimp collected in retail markets for analysis were non-compliant at more than 75% for all microbiological criteria, except for *Salmonella* (42%). Fresh shrimps stored at ambient temperature at the sale points present more risk for consumers' health.

3.2 Physico-chemical characteristics of shrimps

The results showed that pH, TMA, and TVBN increased significantly ($p < 0.05$) during storage both in ice (1–4.5 °C) and at ambient temperature (27.5–29.5 °C) (Table 3). The initial value of TVBN and TMA was 17.34 mg/100 g and 1.39 mg/100 g, respectively (FSPI) and 17.64 mg/100 g and 1.39 mg/100 g, respectively (FSKAT). These values are lower than those (30.1 mg/100 g and 2.5 mg/100 g, respectively) reported by Dabade et al. [14]. As argued by these authors, the difference would be due to the shrimp's non-protein nitrogen content, which depends on feeding; catching season; size, age, sex, microbial activity, and the methods used for determination. In this study, TVBN and TMA determination were achieved on an extract of ground tissue of peeled shrimp by several authors [22–26], while Dabade et al. [14] measured these data on whole fresh shrimp. Heu et al. [27]. reported TVBN values up to 9.8 mg/100 g and 5.6 mg/100 g in processing by-products (heads, shells, and tails) of Northern pink shrimp (*Pandalus borealis*) and spotted shrimp (*Trachypenaeus curvirostris*) respectively while 12.6 mgN/100 g and 11.9 mg/100 g were reported in muscles. Limam et al. [28] wrote for caramote prawns (*Penaeus kerathurus*), 10.3 mg/100 g (muscle) and 12.4 mg/100 g (by-product).

Changes in pH, TMA, TVBN, and biogenic amines could be due to post-mortem microbial and biochemical reactions of shrimps' spoilage. Indeed, previous studies [22, 29–31] have shown that shrimp spoilage started due to endogenous enzymes and microorganism reactions after death. They result in basic nitrogen such as urea, ammonia, and trimethylamine inducing pH change [22, 29–31]. Our study's pH increases significantly from 6.86 to 7.52 (FSPI) and from 6.89 to 7.62 (FSKAT). Furthermore, in this study, data showed that pH is positively correlated with TMA, TVBN, and AMB: 0.92, 0.86, and 0.87, respectively, for storage in ice and 0.96, 0.93, and 0.86 for storage at ambient temperature (Table 4).

Gram-negative bacteria dominate microbial flora in shrimp. These microorganisms initially metabolize the non-proteinic nitrogen (NPN) compounds by decay (oxidation), followed by putrefaction to produce different types of volatile

Table 3 Physicochemical characteristics of fresh shrimp during storage in ice and at ambient temperature

Time	pH	TMA (mg/100 g)	TVBN (mg/100 g)	Dry matter (%)	
Shrimp storage in ice (1–4.5 °C; n = 3)					
Time (days)	0	6.86 ± 0.05 ^a	1.39 ± 0.16 ^a	17.43 ± 0.73 ^a	20.23 ± 0.12 ^a
	2	7.01 ± 0.03 ^b	1.64 ± 0.16 ^a	20.58 ± 0.84 ^{ab}	20.08 ± 0.09 ^a
	4	7.15 ± 0.03 ^c	2.35 ± 0.31 ^{ab}	22.68 ± 2.17 ^b	19.27 ± 0.36 ^a
	6	7.28 ± 0.05 ^d	2.94 ± 0.48 ^b	27.72 ± 2.15 ^c	18.79 ± 0.07 ^{ab}
	8	7.33 ± 0.01 ^e	3.07 ± 0.44 ^b	32.76 ± 1.97 ^d	17.87 ± 0.05 ^{bc}
	10	7.37 ± 0.02 ^f	4.33 ± 0.85 ^c	39.48 ± 2.17 ^e	17.18 ± 0.02 ^{cd}
	12	7.42 ± 0.01 ^g	4.70 ± 0.90 ^c	56.28 ± 4.00 ^f	17.11 ± 0.03 ^{cd}
	14	7.52 ± 0.04 ^h	6.43 ± 1.33 ^d	70.98 ± 3.73 ^g	16.27 ± 0.06 ^d
Shrimp storage at ambient temperature (27.5–29.5 °C; n = 3)					
Time (hours)	0	6.89 ± 0.05 ^a	1.39 ± 0.16 ^a	17.64 ± 0.97 ^a	22.87 ± 0.52 ^a
	3	7.05 ± 0.04 ^b	2.73 ± 0.69 ^b	19.61 ± 0.84 ^a	22.75 ± 0.41 ^a
	6	7.20 ± 0.02 ^c	3.61 ± 0.52 ^c	22.09 ± 0.89 ^a	22.62 ± 0.28 ^a
	9	7.39 ± 0.02 ^d	4.58 ± 4.58 ^d	40.19 ± 0.16 ^b	22.45 ± 0.19 ^a
	12	7.51 ± 0.01 ^e	6.97 ± 0.40 ^e	65.39 ± 5.77 ^c	22.36 ± 0.52 ^a
	15	7.62 ± 0.01 ^f	9.16 ± 0.81 ^f	83.87 ± 3.83 ^d	22.17 ± 0.31 ^a

Data expressed as mean ± standard deviation (n = 3)

n number of trials

a, b, c, d, e, f, g, h values in the same column followed by the same letter are not significantly different (p > 0.05)

Table 4 Linear correlation between physicochemical and microbiological parameters for quality assessment during shrimp storage in ice (1–4.5 °C)

	pH	TMA	TVBN	Dry matter	AMB	<i>Enterobacteriaceae</i>	<i>S. aureus</i>
Storage in ice (1–4.5 °C)							
TMA	0.92						
TVBN	0.86	0.98					
Dry matter	– 0.96	– 0.96	– 0.92				
AMB	0.87	0.98	0.99	– 0.94			
<i>Enterobacteriaceae</i>	0.48	0.73	0.80	– 0.67	0.82		
<i>S. aureus</i>	–	–	–	–	–	–	
<i>Pseudomonas</i>	0.77	0.96	0.96	– 0.88	0.96	0.84	–
Storage at ambient temperature (27.5–29.5 °C)							
TMA	0.96						
TVBN	0.93	0.90					
Dry matter	– 0.99	– 0.98	– 0.95				
AMB	0.86	0.97	0.92	– 0.99			
<i>Enterobacteriaceae</i>	0.98	0.96	0.93	– 0.99	0.98		
<i>S. aureus</i>	–	–	–	–	–	–	
<i>Pseudomonas</i>	0.99	0.98	0.93	– 0.99	0.99	0.99	–

TMA trimethylamine, TVBN Total volatile basic nitrogen, AMB Aerobic mesophilic bacteria

compounds such as NH₃, trimethylamine, histamine, putrescine, and cadaverine [15]. In this study, AMB and Gram-negative bacteria such as *Pseudomonas* and *Enterobacteriaceae* are positively correlated with TMA (0.96 and 0.48 respectively for FSPI; 0.98 and 0.96 for FSKAT) and TVBN (0.96 and 0.80 respectively for FSPI; 0.93 and 0.93 for FSKAT) (Table 4). Dry matter decreasing during storage in ice could be due to meltwater absorption or protein degradation in shrimp (Table 3). In this study, dry matter is negatively correlated with pH, TMA, TVBN, and AMB during the two storage trials (– 0.96; – 0.96; – 0.92 and – 0.94, respectively, for FSPI and – 0.99; – 0.98; – 0.95 and – 0.99 for FSKAT) (Table 4).

Nitrogen basic compounds such as TMA and TVBN are indexed as indicators for shrimp spoilage [24, 32, 33]. Chinivasagam et al. [34] suggested 30 mgTVBN/100 g, while Cobb et al. [22] reported 5 mg TMA/100 g and 30 mg TVBN/100 g as limits of acceptability used for raw shrimp in some regions of the world. However, Zeng et al. [25] indicated that the TVBN limit might be questionable for shrimp because higher levels have been found even in fresh shrimp. Indeed, several authors reported TVBN values above 30 mg/100 g in freshly caught shrimp. The initial TVBN values of 38.2 mg/100 g, 34 mg/100 g, 33.5 mg/100 g, and 30 mg/100 g have been reported respectively by Cob et al. [23] in white shrimps (*Penaeus setiferus* and *P. aztecus*), Chinivasagam et al. [34] in white shrimp (*Penaeus merguensis*), Zeng et al. [25] in northern shrimp (*Pandalus borealis*) and Lopez et al. [35] in pink shrimp (*Parapenaeus longirostris*). Dabade et al. [14] reported 30.1 mg/100 g in freshly caught shrimp (*Penaeus notialis*) from the origin (lake Nokoué) as those used in the present study. Regarding the TMA as a freshness indicator, the acceptability limit was exceeded after 12 days and 9 h, respectively, in FSPI and FSKAT, as shown in the AMB count (Fig. 1). Gram et al. [36] and Gram and Huss [17] indexed TMA as a product of bacterial spoilage. Regarding the marketed shrimps, data show that the mean value of TMA was lower than the acceptability limit (5 mg TMA/100 g) (Table 5). However, considering samples individually, 33% and 58% of FSPI and FSKAT collected from retail markets were non-compliant with the TMA acceptability limit (Table 5). The odds are that a consumer buys non-compliant shrimp. Therefore, fresh shrimp, sold in Beninese markets (open-air, 1–4.5 °C or 27.5 °C–29.5 °C), is not of the required quality. Guidance documents must be developed to help stakeholders with good handling and hygienic practices.

3.3 Biogenic amines in shrimps

During both storage in ice (1–4.5 °C) and at ambient temperature (27.5–29.5 °C), tryptamine, 2-phenylethylamine, histamine, and tyramine were not detected beyond their limit of quantification value of 5.9, 5.9, 14.9 and 10.2 mg kg⁻¹ respectively, except that tyramine appeared after 15 h of storage at ambient temperature, up to 530.4 and 272.2 mg kg⁻¹ for both trials (Tables 6 and 7). However, until the 12th day and the 9th hour for which FSPI and FSKAT, respectively, exceeded the TMA acceptable limit, putrescine, cadaverine spermidine, and spermine were detected with maximal values of 117.9, 2.6, 2.2, and < 0.8 mg kg⁻¹ respectively for storage in ice and 31.5; 74.4; 4.3 and 7.1 mg kg⁻¹ for storage at ambient temperature.

Biogenic amine formation results in amino acid decarboxylation from protein degradation by the metabolism of alternative microorganisms [37]. They are non-volatile low-molecular weight nitrogenous organic bases that may represent a health threat for humans if ingested at certain levels. Among them, histamine is the most frequently implied in seafood poisoning, whose symptoms include skin flushing, hypotension, and diarrhea [38]. Nout [39] suggested Toxic levels of 50–100 mg of histamine/kg and 100–800 mg of tyramine/kg of food. Likewise, according to the scientific opinion published by the European Food Safety Authority [40], histamine concentrations between 50 and 200 mg/kg may cause adverse health effects, and levels above 200 mg/kg histamine are reported to cause toxic effects in humans. In this study, histamine and tyramine were not detected beyond respective LOQ values of 14.9, and 10.2 mg kg⁻¹ before the maximal limits for TMA were attained during storage trials (Tables 6 and 7). Likewise, both FSPI and FSKAT collected from retail markets agreed with this recommendation on biogenic amines (Table 8). Putrescine and cadaverine are known to enhance the toxicity of histamine and tyramine [41]. In this study, these amines were detected, but no maximal limit value was recommended.

Table 5 Physicochemical characteristics of fresh shrimp collected from sellers in retail markets

Parameters	FSPI (n = 12)			FSKAT (n = 12)			Status (No-compliant samples)			
	Mean	Minimum	Maximum	Mean	Minimum	Maximum	FSPI	FSKAT	Limit value	Reference
pH	7.32	7.12	7.50	7.39	7.21	7.54	–	–	–	–
TMA (mg/100 g)	3.96	2.23	6.12	4.12	3.01	6.02	33%	58%	5	Cobb et al. [22]
TVBN (mg/100 g)	26.99	19.24	33.42	29.84	23.02	33.24	–	–	–	

FSPI fresh shrimp preserved in ice, FSKAT fresh shrimp, kept at ambient temperature, TMA trimethylamine, TVBN Total volatile basic nitrogen; n number of samples; Limit value limit of acceptability

Table 6 Change in biogenic amines (mg kg^{-1}) during shrimp storage in ice (1–4.5 °C) ($n=2$)

	Trial	LOQ	Storage time (days)						
			0	2	4	6	10	12	14
Tryptamine	1	5.9	nd	nd	nd	nd	nd	nd	nd
	2		nd	nd	nd	nd	nd	nd	nd
2-Phenylethylamine	1	5.9	nd	nd	nd	nd	nd	nd	nd
	2		nd	nd	nd	nd	nd	nd	nd
Putrescine	1	4.5	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	2		4.8	7.0	10.5	6.5	109.6	117.9	99.5
Cadaverine	1	2.5	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ	<LOQ
	2		9.9	27.6	15.9	4.2	3.0	2.6	<LOQ
Histamine	1	14.9	nd	nd	nd	nd	nd	nd	nd
	2		nd	nd	nd	nd	<LOQ	nd	nd
Tyramine	1	10.2	nd	nd	nd	nd	nd	nd	nd
	2		<LOQ	nd	<LOQ	<LOQ	<LOQ	<LOQ	11.9
Spermidine	1	2.0	<LOQ	2.8	3.4	2.3	2.6	2.2	<LOQ
	2		6.0	2.9	3.1	<LOQ	<LOQ	nd	nd
Spermine	1	0.8	nd	4.3	4.6	<LOQ	2.8	<LOQ	1.5
	2		2.0	1.3	<LOQ	9.3	8.4	nd	10.8

LOQ limit of quantification; n number of trials; *nd* not detected

Table 7 Change in biogenic amines (mg kg^{-1}) during shrimp storage at ambient temperature (27.5–29.5 °C) ($n=2$)

	Trial	LOQ	Storage time (hours)					
			0	3	6	9	12	15
Tryptamine	1	5.9	nd	nd	nd	nd	nd	nd
	2		nd	nd	nd	nd	nd	nd
2-Phenylethylamine	1	5.9	nd	nd	nd	nd	nd	nd
	2		nd	nd	nd	nd	nd	<LOQ
Putrescine	1	4.5	<LOQ	4.9	6.5	31.5	119.4	165.5
	2		<LOQ	<LOQ	6.3	30.4	87.2	134.7
Cadaverine	1	2.5	<LOQ	<LOQ	16.9	74.4	124.3	373.7
	2		<LOQ	<LOQ	14.7	62.2	124.4	353.6
Histamine	1	14.9	<LOQ	nd	<LOQ	<LOQ	nd	nd
	2		<LOQ	<LOQ	<LOQ	<LOQ	nd	<LOQ
Tyramine	1	10.2	nd	nd	nd	nd	nd	530.4
	2		nd	nd	nd	nd	<LOQ	272.2
Spermidine	1	2.0	3.0	3.6	3.3	4.3	2.7	7.1
	2		2.3	3.4	3.9	2.8	2.1	2.7
Spermine	1	0.8	2.8	4.3	6.0	4.3	7.2	1.0
	2		6.5	6.2	6.8	7.1	7.4	1.1

LOQ limit of quantification; n number of trials; *nd* not detected

4 Conclusion

This study revealed that, as preserved by sellers in markets, fresh shrimp becomes stale after 12 days of preservation in ice (1–4.5 °C) (shrimp/ice ratio, 1:2) and 9 h of storage at ambient temperature (27.5–29.5 °C). As sold in retail markets, fresh shrimps are safe from toxic biogenic amines (histamine and tyramine). However, they are of poor hygienic quality from the physicochemical and microbiological points of view. In addition, most samples collected from markets were non-compliant with the TMA limit specified and limits specified for microorganisms of fecal

Table 8 Biogenic amines content (mg kg⁻¹) of fresh shrimp collected from retail markets

Biogenic amines	LOQ	FSPI (n = 12)			FSKAT (n = 12)		
		Minimum	Maximum	Median	Minimum	Maximum	Median
Tryptamine	5.9	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ
2-Phenylethylamine	5.9	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ	< LOQ
Putrescine	4.5	< LOQ	146.6	6.4	< LOQ	9.9	< LOQ
Cadaverine	2.5	< LOQ	287.1	27.9	5.4	56.4	15.0
Histamine	14.9	< LOQ	< LOQ	< LOQ	< LOQ	27.6	< LOQ
Tyramine	10.2	< LOQ	35.4	< LOQ	< LOQ	< LOQ	< LOQ
Spermidine	2.0	< LOQ	4.7	< LOQ	< LOQ	7.3	4.1
Spermine	0.8	< LOQ	17.2	8.9	3.5	21.5	9.0

FSPI fresh shrimp stored in ice; FSKAT fresh shrimp stored at ambient temperature; LOQ Limit of quantification; n number of samples

contamination, such as *E. coli*, *Enterobacteriaceae* and *Salmonella*. Therefore, developing guidance documents and training stakeholders for good handling and hygienic practices is necessary.

Acknowledgements The authors thank CUD (Commission Universitaire Belge pour le Développement) for financial support through the UAC01 project.

Author contributions Yénoukounmè Euloge KPOCLOU: Study design; data collection; original draft writing Victor Bienvenu Anihouvi: Study design, original draft writing, validation Paulin AZOKPOTA: draft review, validation Mohamed Mansourou SOUMANOU: study design, draft review Caroline Douny, Data collection, original draft writing Ahmed Igout: draft review Charis M. Galanakis: draft review Marie-Louise Scippo: study design, draft review, validation Djidjoho Joseph Hounhouigan: study design, draft review, validation. All authors read and approved the final manuscript.

Data availability The dataset generated for this study are available on request to the corresponding author.

Declarations

Competing interests The author declares no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

1. Duanquan Lin D, Sun LC, Chen YL, Liu GM, Miao S, Cao MJ. Shrimp spoilage mechanisms and functional films/coatings used to maintain and monitor its quality during storage. *Trends Food Sci Technol.* 2022;129:25–37.
2. Deng S, Lutema PC, Gwekwe B, Li Y, Akida JS, Pang Z, Huang Y, Dang Y, Wang S, Chen M, Miao W, Lin H, Wang L, Cheng L. Bitter peptides increase engulf of phagocytes in vitro and inhibit oxidation of myofibrillar protein in peeled shrimp (*Litopenaeus vannamei*) during chilled storage. *Aquac Rep.* 2019;15:e100234.
3. Li Y, Lei Y, Tan Y, Zhang J, Hong H, Luo Y. Efficacy of freeze-chilled storage combined with tea polyphenol for controlling melanosis, quality deterioration, and spoilage bacterial growth of Pacific white shrimp (*Litopenaeus vannamei*). *Food Chem.* 2022;370:130924.
4. Gnimadi A, Gbaguidi A, Kakpo GL, Gnimadi CC, Latifou L, Salifou LL, Sohoul ZL, Tossou CE. Base de données sur les activités de pêche dans les lagunes du Bénin (lac Ahémé, lac Nokoué et lagune de Porto-Novu). Résultats du recensement. Programme pour des Moyens d'Existence Durable dans la Pêche (PMEDP), rapport de mission. 2006.
5. Raux J. Diagnostic de la filière crevette au Bénin. Développement du secteur privé au Bénin et l'identification d'un projet de compétitivité et de croissance sous le 10e FED, rapport de consultation, CE/FINEUROPE. 2009.
6. Degnon GR, Dahouenon-Ahoussi E, Adjou SE, Sohounhloou KCD. Transformation artisanale des crevettes (*Penaeus spp*) au sud du Bénin: évaluation des performances techniques des équipements et procédés de fumage. *Nat Technol.* 2013;8:23–31.
7. Dabadé DS, Den Besten HMW, Azokpota P, Nout MRJ, Hounhouigan DJ, Zwietering MH. Quality perceptions of stakeholders in Beninese export-oriented shrimp chain. *J Food Prot.* 2014;77:1642–8.

8. Kpoclou YE, Anihouvi BV, Scippo ML, Hounhouigan DJ. Preservation practices and quality perception of shrimps along the local merchandizing chain in Benin. *Afr J Agric Res.* 2013;8:3405–14. <https://doi.org/10.5897/AJAR12.2014>.
9. ISO 6887–3. Microbiology of food and animal feeding stuffs – Preparation of test samples, initial suspension and decimal dilutions for microbiological examination – Part 3: Specific rules for the preparation of fish and fishery products. 2004.
10. Kpoclou YE, Anihouvi BV, Azokpota P, Soumanou MM, Daube G, Douny C, Brose F, Scippo ML, Hounhouigan JD. Microbiological and physicochemical quality of smoked shrimp, an expanding food condiment in Beninese local markets. *Food and Public Health.* 2013;3:277–83.
11. Goulas AE, Kontominas MG. Effect of salting and smoking method on the keeping quality of chub mackerel (*Scomber japonicus*): biochemical and sensory attributes. *Food Chem.* 2005;93:511–20. <https://doi.org/10.1016/j.foodchem.2004.09.040>.
12. Ozdemir Z, Zannou O, Koca I. Assessment of the aluminium contents of black tea and black tea infusions. *Discov Food.* 2022;2:13. <https://doi.org/10.1007/s44187-022-00014-8>.
13. Malle P, Poumeyrol M. A new chemical criterion for the quality control of fish: trimethylamine/total volatile basic nitrogen (%). *J Food Prot.* 1989;52:419–23. <https://doi.org/10.4315/0362-028x-52.6.419>.
14. Dabade DS, den Besten HMW, Azokpota P, Nout MJR, Hounhouigan DJ, Zwietering MH. Spoilage evaluation, shelf-life prediction, and potential spoilage organisms of tropical brackish water shrimp (*Penaeus notialis*) at different storage temperatures. *Food Microbiol.* 2015;48:8–16. <https://doi.org/10.1016/j.fm.2014.11.005>.
15. Ray B, Bhunia A. *Fundamental food microbiology*. 4th ed. Taylor & Francis Group. USA: RC Press; 2008.
16. Gram L, Wedell-Neergaard C, Huss HH. The bacteriology of fresh and spoiling lake Victorian Nile perch (*Lates niloticus*). *Int J Food Microbiol.* 1990;10:303–16. [https://doi.org/10.1016/0168-1605\(90\)90077-i](https://doi.org/10.1016/0168-1605(90)90077-i).
17. Gram L, Huss HH. Microbiological spoilage of fish and fish products. *Int J Food Microbiol.* 1996;33:121–37. [https://doi.org/10.1016/0168-1605\(96\)01134-8](https://doi.org/10.1016/0168-1605(96)01134-8).
18. Chinivasagam HN, Bremner HA, Wood AF, Nottingham SM. Volatile components associated with bacterial spoilage of tropical prawns. *Int J Food Microbiol.* 1998;42:45–55. [https://doi.org/10.1016/s0168-1605\(98\)00057-9](https://doi.org/10.1016/s0168-1605(98)00057-9).
19. Reynisson E, Lauzon HL, Magnússon H, Ólafsdóttir Jónsdóttir R, G, Marteinsson V, Hreggviðsson GO. Bacterial composition and succession during storage of North-Atlantic cod (*Gadus morhua*) at superchilled temperatures. *BMC Microbiol.* 2009;9:250. <https://doi.org/10.1186/1471-2180-9-250>.
20. ICMSF (International Commission on Microbiological Specification for Foods). *Microorganisms in Foods. 2. Sampling for microbiological analysis: principles and specific applications*. 2nd ed. Buffalo: University of Toronto Press; 1986.
21. DGHM (Deutsche Gesellschaft für Hygiene und Mikrobiologie). *Veröffentlichte mikrobiologische Richt- und Warnwerte für die Beurteilung von Lebensmitteln*. Bonn: Institut für Lebensmittel- und Ernährungswissenschaften. 2007. <http://www.lm-mibi.uni-bonn.de/DGHM.html>
22. Cobb BF, Vanderzant C, Thompson CA, Custer CS. Chemical characteristics, bacterial counts and potential shelf-life of shrimp from various locations on the northwestern Gulf of Mexico. *J Milk Food Technol.* 1973;36:463–8. <https://doi.org/10.4315/0022-2747-36.9.463>.
23. Cobb BF, Vanderzant C, Hanna MO, Yeh CPS. Effect of ice storage on microbiological and chemical changes in shrimp and melting ice in a model system. *J Food Sci.* 1976;41:29–34. <https://doi.org/10.1111/j.1365-2621.1976.tb01094.x>.
24. Kamal M, Rahman MM, Yasmin L, Islam MN, Nurullah M, Mazid MA. Studies on the post-mortem changes in shrimp and prawn during ice storage: II. Biochemical aspects of quality changes. *Bangladesh. Fish Res.* 2000;4:91–6.
25. Zeng QZ, Thorarinsdóttir KA, Ólafsdóttir G. Quality changes of shrimp (*Pandalus borealis*) stored under different cooling conditions. *J Food Sci.* 2005;70:S459–66. <https://doi.org/10.1111/j.1365-2621.2005.tb11493.x>.
26. Ali MY, Sharif MI, Adhikari RK, Faruque O. Post mortem variation in total volatile basic nitrogen and trimethylamine nitrogen between Galda (*Macrobrachium rosenbergii*) and Bagda (*Penaeus monodon*). *Univ J Zool Rajshahi Univ.* 2010;28:07–10.
27. Heu MS, Kima JS, Shahidi F. Components and nutritional quality of shrimp processing by-products. *Food chem.* 2003;82:235–42. [https://doi.org/10.1016/S0308-8146\(02\)00519-8](https://doi.org/10.1016/S0308-8146(02)00519-8).
28. Limam Z, Sadok S, El Abed A. Etude de la composition biochimique de la chair et des coproduits de la crevette royale *Penaeus kerathurus* du Nord et Sud de la Tunisie. *Bull Inst Natn Scien Tech Mer de Salammbô.* 2010;37:75–81.
29. Bailley ME, Fieger EA, Norvak AF. Objective tests applicable to quality studies of ice-stored shrimp. *Food Res.* 1956;21:611–20. <https://doi.org/10.1111/j.1365-2621.1956.tb16965.x>.
30. Bethea S, Ambrose ME. Comparison of pH, trimethylamine content and picric acid turbidity as indices of iced shrimp quality. *Comm Fish Rev.* 1962;24(3):7.
31. Vanderzant C, Nickelson R. Comparison of extract-release volume, pH, and agar plate count of shrimp. *J Milk Food Technol.* 1971;34:115.
32. Oehlenschläger J. Volatile amines as freshness/spoilage indicators. A literature review. In: *Seafood from Producer to Consumer, Integrated Approach to Quality. Proceedings of the International Seafood Conference*, Ed- J.B. Luten, T. Borrensens., J. Oehlenschläger, Elsevier - Developments in Food Science. 1997; 38: 571–586.
33. Oehlenschläger J. Suitability of ammonia-N, dimethylamine-N, trimethylamine-N, trimethylamine oxide-N and total volatile basic nitrogen as freshness indicators in seafood. In: Ólafsdóttir G, Luten J, Dalgaard P, Careche M, Verrez-Bagnis V, Martinsdóttir E, Heia K, editors. *Methods to determine the freshness of fish in research and industry. Evaluation of fish freshness*. Paris: Institut International du Froid; 1998. p. 92–9.
34. Chinivasagam HN, Bremner HA, Thrower SJ, Nottingham SM. Spoilage pattern of five species of Australian prawns: deterioration is influenced by environment of capture and mode of storage. *J Aquatic Food Prod Technol.* 1996;5:25–50.
35. Lopez-Caballero ME, Martinez-Alvarez O, Gomez-Guillen MC, Montero P. Quality of thawed deepwater pink shrimp (*Parapenaeus longirostris*) treated with melanosis-inhibiting formulations during chilled storage. *Int J Food Sci Technol.* 2007;42:1029–38.
36. Gram L, Trolle G, Huss HH. Detection of specific spoilage bacteria from fish stored at low (0°C) and high (20°C) temperatures. *Int J Food Microbiol.* 1987;4:65–72.
37. Jayasinghe GDTM, Jinadasa BKKK, Pohl P, et al. Critical review on microextraction techniques used in determination of histamine in food samples. *Discov Food.* 2022;2:8. <https://doi.org/10.1007/s44187-022-00008-6>.
38. Belleggia L, Milanović V, Cesaro C, Cardinali F, Garofalo C, Aquilanti L, Osimani a. Exploratory study on histamine content and histidine decarboxylase genes of gram-positive bacteria in Hákarl. *J Aquat Food Prod Technol.* 2021;30:907–13.
39. Nout MJR. Fermented foods and food safety. *Food Res Int.* 1994;27:291–8.

40. European Food Safety Authority. Scientific opinion on risk-based control of biogenic amine formation in fermented foods, EFSA panel on biological hazards (BIOHAZ). *EFSA J.* 2011;9:2393.
41. Hernandez-Jover T, Izquierdo-Pulido MM, Veciana-Nogues T, Marine-Font A, Vidal-Carou MC. Biogenic amine and polyamine contents in meat and meat products. *J Agric Food Chem.* 1997;45:2098–102.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.