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Introduction to Seafood Processing – Assuring Quality and Safety of Seafood

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1.1 Introduction

Demand for seafood has consistently increased during recent years with fish protein being the major animal protein consumed in many parts of the world. According to the Food and Agriculture Organization (FAO, 2012), fresh seafood represents 40.5% of the world's seafood production, while processed products (frozen, cured, canned, etc.) represent 45.9%. To assure the quality of raw material used for processing, fish has to be treated carefully before and after harvest. Often fish and shellfish undergo some type of handling or primary processing (washing, gutting, filleting, shucking, etc.), before the main processing occurs, to assure their quality and safety, as well as to produce new, convenient and added-value products (e.g. packed fish fillets instead of unpacked, whole ungutted fish).

Processing of seafood mainly inhibits and/or inactivates bacteria and enzymes which results in shelf-life extension and also assures food safety. While the main role of processing is preservation, processing not only extends shelf life but also creates a new range of products.

Seafood processing uses almost all the processing methods available to the food industry. The most widely used methods to preserve fish involve the application of low temperatures (chilling, super-chilling, freezing). Improvements in packaging technology (modified atmosphere packaging, MAP) and the application of chilling maximise quality retention as well as extending shelf life. Heating inactivates bacterial pathogens and spoilage microorganisms, which contributes to the stability and safety of the products. Irradiation is a well-established, non-thermal method, while high-pressure processing of

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seafood is being continuously increased. Traditional methods of preservation (curing, fermentation, etc.) are also used in the production of a variety of products.

1.2 Seafood spoilage

Seafood deteriorates very quickly due to various spoilage mechanisms. Spoilage can be caused by the metabolic activity of microorganisms, endogenous enzymatic activity (such as autolysis and the enzymatic browning of crustaceans shells) and by the chemical oxidation of lipids (Ashie *et al*., 1996; Gram and Huss, 1996; Huis in't Veld, 1996).

Seafood flesh has a high amount of non-protein nitrogenous (NPN) compounds and a low acidity ($pH > 6$), which support the fast growth of microorganisms that are the main cause of spoilage. The growth and metabolic activity of the spoilage microorganisms, especially specific spoilage organisms (SSOs), result in the production of metabolites that affect the organoleptic properties of the product (Ashie *et al*., 1996; Gram and Huss, 1996). Briefly, SSOs may initially represent only a small proportion of the microbiota (indigenous and exogenous); however, they subsequently proliferate to become the part of the dominant microbiota that has spoilage potential (the qualitative ability to produce off-odours) and spoilage activity (the quantitative ability to produce metabolites) (Gram and Dalgaard, 2002). Inhibiting the growth of SSOs increases the shelf life of seafood. *Pseudomonas* and *Shewanella* species spoil marine fish and crustaceans stored aerobically at low temperatures, while *Photobacterium phosphoreum*, various lactic acid bacteria and *Brochothrix thermosphacta* usually predominate in spoilage associated with MAP (Gram and Huss, 1996; Dalgaard, 2000).

Immediately following death, autolysis resulting from the action of endogenous enzymes, initially causes loss of the characteristic fresh odour and taste of fish and then softens the flesh (Huss, 1995; Ashie *et al*., 1996). The main changes that take place are initially the enzymatic degradation of adenosine triphosphate (ATP) and related products and subsequently the action of proteolytic enzymes. Enzymes are also responsible for colour changes. After microbial growth, enzymatic browning is the most important spoilage mechanism of crustaceans (Ashie *et al*., 1996; Boziaris *et al*., 2011). Browning of the crustacean shell is the result of the action of polyphenol oxidase on tyrosine and its derivatives such as tyramine (Martinez-Alvarez *et al*., 2007). Inhibition or inactivation of polyphenol oxidase by various means (heating, additives, etc.) as well as oxygen reduction or exclusion can prevent the loss of the original colour of the crustacean shell.

Chemical oxidation of lipids (oxidative rancidity) is one of the most important spoilage mechanisms, especially in fatty fish. Oxygen is necessary for the development of oxidative rancidity; hence, oxygen reduction or exclusion limits the oxidation reaction (Ashie *et al*., 1996).

All these mechanisms advance almost simultaneously contributing to the spoilage; however, fresh and lightly preserved seafood spoils mainly due to the action of microorganisms. For products in which microbial growth is retarded or inhibited, non-microbial mechanisms play a more determinative role.

1.3 Seafood hazards

Contamination of seafood by chemicals, marine toxins and microbiological hazards can be high. Various bacterial pathogens present in aquatic environments – either naturally (pathogenic *Vibrio, Clostridium botulinum, Aeromonas hydrophilla*), or as contaminants (*Salmonella* spp., pathogenic *Escherichia coli*) – can contaminate seafood, while contamination with other bacteria such as *Listeria monocytogenes, Staphylococcus aureus*, etc., can occur during processing (Feldhusen, 2000; Huss *et al*., 2000). Seafood can also be contaminated by viruses (such as hepatitis A virus, Norwalk-like viruses, Astrovirus, etc.), marine biotoxins (which cause several diseases such as diarrhoeic shellfish poisoning (DSP), paralytic shellfish poisoning (PSP), neurotoxic shellfish poisoning (NSP), amnesic shellfish poisoning (ASP) and fish ciguatera poisoning) and chemical contaminants (such as heavy metals) (Huss, 1994). Generally, processing mainly controls microbiological hazards but leaves chemical hazards or biotoxins virtually unaffected. Effective control of chemical hazards and biotoxins has to be applied mostly during primary production and the pre-harvest stages.

From a safety point of view, seafood can be classified in to seven groups according to the risk of microbial contamination and the processing method (Huss *et al*., 2000). Molluscs, especially those that are to be eaten without cooking, belong to the group with the highest risk. The second group contains the fish and crustaceans that will be consumed after cooking. The third and fourth groups contain lightly preserved (NaCl $<$ 6% w/v in aqueous phase, pH $>$ 5) and semi-preserved (NaCl $>$ 6% w/v in aqueous phase, pH $<$ 5) products, respectively. The fifth group contains the mild-heated products, such as pasteurized and hot-smoked seafood, while the sixth contains the heat processed products. Finally dried, dry-salted and smoke-dried seafood products have the lowest risk.

1.4 Getting the optimum quality of the raw material

Pre-harvest and post-harvest handling of fish affects its quality. A number of biochemical changes start immediately following the death of the fish. The most important change is the onset of rigor mortis, during which the initially relaxed and elastic muscles become hard and stiff. At the end of rigor mortis the muscles relax again but are no longer elastic. The mechanism of rigor mortis is described in Chapter 3. The significance of rigor mortis is important in post-mortem processing. Filleting fish in rigor may produce fillets with gaping and give lower yields, while whole fish and fillets frozen before the onset of rigor can give better products (Huss, 1995). The onset of rigor mortis and its duration depend on various factors such as the size of the fish, the temperature and the physical condition of the fish, including stress (Huss, 1995). For instance, in either starved or stressed fish the glycogen reserves are depleted and rigor mortis starts immediately. Rapid chilling of fish is important not only to inhibit bacterial growth but also for managing the onset and duration of rigor. Abe and Okuma (1991) suggested that the onset of rigor mortis depends on the difference between the sea temperature and the storage temperature. When this difference is high, the onset of rigor is fast and *vice versa*.

1.4.1 Pre-mortem handling

Handling of fish before death affects rigor mortis. It is important in wild fish to use methods of capture that do not stress and exhaust fish, while in farmed fish, pre-harvest starvation, harvesting and slaughtering practices that do not stress fish are essential to maximise seafood quality and shelf life (Bagni *et al*., 2007; Borderias and Sanchez-Alonso, 2011). The digestive tract contains a high bacterial population that produces digestive enzymes that result in intense post-mortem autolysis giving strong off-odours in the abdominal area (Huss, 1995). Starvation reduces the amount of faeces in the intestines and delays spoilage. In general, the starvation period is 1–3 days. Harvesting, stunning and killing methods greatly affect post-mortem changes and subsequent fish quality. When fish are rapidly killed, stress can be reduced, improving quality (Ottera *et al*., 2001; Bagni *et al*., 2007). Many methods can be used for stunning and killing fish, such as asphyxiation, live chilling in ice slurry, electrical stunning and electrocution, carbon dioxide narcosis, knocking or spiking. Asphyxiated and electrically stunned fish are more stressed than spiked, knocked and live-chilled fish (Poli *et al*., 2005). Knocking on the head is reported as the optimal killing method for obtaining the best quality flesh in turbot (Roth *et al*., 2007).

For shellfish, suitable pre- and post-harvest handling is required to achieve a safe seafood product. Shellfish are filter-feeders and can concentrate contaminants from the aquatic environment. Preventive measures are required to deter the accumulation of pathogenic microorganisms, biological toxins and chemical contaminants. Water quality is one of the most important factors, while treatments such as depuration and subsequent suitable handling and processing are essential (see Chapter 2).

Regarding the handling of crustaceans, such as lobsters and crabs, considerably fewer studies have been published compared to finfish and molluscan shellfish. The quality and prolonged shelf life of lobsters and crabs can be maintained by keeping them alive as long as possible. Norway lobster and crab individuals stored at chilling temperature or in ice spoil rapidly mainly due to microbial growth, which occurs after their death (Robson *et al*., 2007; Boziaris *et al*., 2011). The effect of post-harvest handling on the quality of crustaceans has been recently reviewed (Neil, 2012).

1.4.2 Post-mortem handling

After killing and chilling fish, minimal processing such as washing, gutting or filleting can take place. The results of the effect of gutting on the quality and shelf life of fish are contradictory. Microbial counts in ungutted sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) were found to be slightly lower compared to gutted fish while the quality and shelf life assessed by sensory and chemical methods was found to be the same (Cakli *et al*., 2006). Erkan (2007) reported that the shelf life of gutted and ungutted sea bream was similar. On the other hand, Papadopoulos *et al*. (2003) found that gutted sea bass have a shorter shelf life compared to their ungutted counterparts.

Fish are filleted to produce value-added products. In general the practice of filleting in rigor is avoided because the yield is low and may cause gaping. Filleting is usually performed before or after rigor with various advantages and disadvantages in each case. Pre-rigor fillets of Atlantic salmon had lower bacterial numbers, the odour-flavour scores were higher, the gaping was lower, but the water loss was higher compared to post-rigor fillets (Rosnes *et al*., 2003).

1.5 Seafood processing

Processing imposes hurdles to the actions of microorganisms (Leistner and Gorris, 1995), hence inhibiting or inactivating them, which results in the prevention of spoilage and the extension of shelf life. Additionally, processing can also retard or inhibit non-microbial spoilage mechanisms (Table 1.1). From the safety point of view, processing can remove or eliminate pathogenic bacteria making seafood safer for consumption.

Table 1.1 Current food and seafood processing methods

Process	Hurdle	Objective
Chilling	Low temperature	Inhibition of microbial growth
Chilling and packaging under modified atmosphere	Low temperature, reduced O_2, elevated CO_2	Inhibition of microbial growth, slowing down chemical oxidations
Freezing	Low temperature	Inhibition of microbial growth, slowing down enzymatic activity and chemical oxidations
Freezing and glazing or vacuum packaging	Low temperature, reduced O_2	Inhibition of microbial growth, oxidative rancidity and enzymatic browning
Heating	High temperature	Inactivation of microorganisms and enzymes
Irradiation	Ionizing radiation	Inactivation of microorganisms and enzymes
Salting	Low a_w	Inhibition of microbial growth
Marination	Low pH, organic acids,	Inhibition and/or inactivation of microorganisms
Drying	Low a_w	Inhibition of microbial growth
Smoking	Low a_w, high temperature (in hot smoking), antimicrobial substances from smoke	Inhibition of microbial growth
Curing (combination of salting, smoking, acidification, drying)	Low a_w and pH, high temperature (in hot smoking), antimicrobial substances from the smoke	Inhibition of microbial growth
Fermentation	Low pH, organic acids, bacteriocins, bacterial antagonism	Inhibition of microbial growth

A range of processing methods can be used to preserve seafood. Processing methods can be applied either singly or in combination (Table 1.1). Cold storage is the simplest way to preserve seafood. Chilling of whole fish in ice takes place after harvesting and killing, while packed gutted or filleted fish are refrigerated. Fish shelf life can be extended by superchilling, where fish is stored a few degrees below 0 °C (see Chapter 3). Packaging under reduced O_2 and elevated CO_2 (modified atmosphere packaging, MAP) in combination with cold storage (0–2 °C) can extend the shelf life of various seafoods (see Chapter 10). Freezing is also one of the most widely used preservation methods for seafood (see Chapter 3).

Heat processing remains one of the major methods for extending the shelf life of seafood because as well as giving a long shelf life it also gives a high level of safety and convenience (see Chapter 4). Irradiation is a widely used non-thermal process for preserving fish and seafood. Irradiation guarantees the safety of the product and also increases its shelf life, despite the lack of trust for this method by consumers. It is a very effective method for inactivating microorganisms without considerably decreasing foodstuff quality (see Chapter 5).

Traditional methods of preservation such salting, smoking, marination, drying and fermentation (see Chapters 6, 7 and 8) are widely used throughout the world. Traditionally preserved fish is highly appreciated, mainly due to its excellent stability during storage, special organoleptic characteristics and nutritional value.

Quite considerable amounts of fish are used for surimi production. Surimi is a fish protein concentrate with gelling abilities that has become an important intermediate raw material for food production all over the world. Surimi is further processed into surimi-based products such as *kamaboko* and crab-meat analogues (see Chapter 10).

The seafood industry consumes a lot of energy and produces a considerable amount of waste. Methods to treat fish waste and to convert it into useful products such as feed, natural pigments and other products have been developed (see Chapter 11). The sustainable operation of fish processing plants, which involves not only waste treatment and disposal as well as the recovery of by-products, but also energy efficiency and water usage, are also of concern (see Chapter 12).

1.6 Quality, safety and authenticity assurance

Freshness and quality of seafood is assessed using sensory, microbiological and chemical methods (Olafsdottir *et al*., 1997). Sensory assessment is subjective and requires highly trained personnel to be reliable, hence it is unattractive for routine examination, while microbiological results are retrospective, thus the determination of the chemical spoilage parameters related to microbial growth, is more practical for routine use (Dainty, 1996). Total volatile base-nitrogen (TVB-N) and trimethylamine-nitrogen (TMA-N) are the main chemical parameters related to the microbial growth of microorganisms such as *Pseudomonas* spp., *Shewanella putrefaciens* and *Photobacterium phosphoreum* (Gram and Huss, 1996; Gram and Dalgaard, 2002). However, the most used parameter, TVB-N, is considered as a poor indicator of teleostean fish freshness (Castro *et al*., 2006). Current research is focusing on other metabolites produced during the storage of aquatic products, such as volatiles other than nitrogenous compounds (Duflos *et al*., 2006; Soncin *et al*., 2008). Additionally, a range of physical and automated instrumental methods that can give fast reliable measurements a without destruction of the sample are being developed, such as VIS/NIR spectroscopy, electronic nose, etc. (see Chapter 14).

A variety of microbiological parameters are also examined to assess the microbiological quality and safety of seafood. Despite the disadvantages of traditional culture techniques, they are still considered standard methods. However, advances in molecular microbiology and automated rapid methods offer alternative tools for quick and reliable analysis (see Chapter 15).

To protect consumers and prevent fraud in the marketing of fishery and aquaculture products, fast and reliable methods for species identification, even for processed products, are required. Recent developments in molecular biology and polymerase chain reaction (PCR)-based techniques, as well as the use of molecular markers and databases have greatly contributed to this field of study (see Chapter 16).

Finally, in the past two decades the concept of risk assessment has greatly improved the way that seafood hazards are evaluated and controlled, leading towards to an integrated approach of food/seafood safety. The presentation of the four elements of risk assessment (hazard identification, exposure assessment, hazard characterization and risk characterization) are analysed in Chapter 17.

1.7 Future trends

Current processing technologies are quickly evolving (modified atmosphere packaging, minimal heat processing, rapid freezing, etc.), while emerging technologies such as high pressure processing (HPP), radio-frequency heating, flexible retort packaging, and pH-shift processing, etc., will be applied extensively in seafood processing. HPP is currently applied mostly in oysters. Pressure severs the adductor muscle from the shell, which results essentially in a shucked oyster while inactivation of pathogenic *Vibrios* and other microorganisms occurs (see Chapter 2). HPP will soon extend its applications to various seafood products.

Value-added seafood products are becoming increasingly important in satisfying consumer demands for safe, high-quality, convenient, healthy and nutritious seafood throughout the world (see Chapter 13). Market requirements and the new technologies in seafood processing will soon be the driving force for many innovations in seafood processing.

References

Abe, H. and Okuma, E. (1991). *Rigor mortis* progress of carp acclimated to different water temperatures, *Nippon Suisan Gakkaishi*, 57, 2095–2100.

Ashie, I.N.A., Smith, J.P. and Simpson, B.K. (1996). Spoilage and shelf-life extension of fresh fish and shellfish. *Critical Reviews in Food Science and Nutrition*, 36, 87–121.

Bagni, M., Civitareale, C., Priori, A. *et al*. (2007). Pre-slaughter crowding stress and killing procedures affecting quality and welfare in sea bass (*Dicentrarchus labrax*) and sea bream (*Sparus aurata*). *Aquaculture*, 263, 52–60.

Borderias, A.J. and Sanchez-Alonso, I. (2011). First processing steps and the quality of wild and farmed fish. *Journal of Food Science*, 76, R1–R5.

Boziaris, I.S., Kordila, A. and Neofitou, C. (2011). Microbial spoilage analysis and its effect on chemical changes and shelf-life of Norway lobster (*Nephrops norvegicus*) stored in air at various temperatures. *International Journal of Food Science and Technology*, 46, 887–895.

Cakli, S., Kilinc, B., Cadun, A., Dincer, T. and Tolasa, S. (2006). Effects of gutting and ungutting on microbiological, chemical, and sensory properties of aquacultured sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) stored in ice. *Critical Reviews in Food Science and Nutrition*, 46, 519–527.

Castro, P., Padron, J.C.P., Cansino, M.J.C., Velazquez, E.S. and De Larriva, R.M. (2006). Total volatile base nitrogen and its use to assess freshness in European sea bass stored in ice. *Food Control*, 17, 245–248.

Dainty, R.H. (1996). Chemical/biochemical detection of spoilage. *International Journal of Food Microbiology*, 33, 19–33.

Dalgaard, P. (2000). Fresh and lightly preserved seafood, in *Shelf-Life Evaluation of Foods* (eds C.M.D. Man, and A.A. Jones), Aspen Publishers, London, pp. 110–139.

Duflos, G., Coin, V. M., Cornu, M., Antinelli, J.F. and Malle, P. (2006). Determination of volatile compounds to characterize fish spoilage using headspace/mass spectrometry and solid-phase microextraction/gas chromatography/mass spectrometry. *Journal of the Science of Food and Agriculture* 86, 600–611.

Erkan, N. (2007). Sensory, Chemical, and Microbiological Attributes of Sea Bream (*Sparus aurata*): Effect of Washing and Ice Storage. *International Journal of Food Properties*, 421–434.

FAO (2012). *The State of the World Fisheries and Aquaculture*. Food and Agriculture Organization, Rome, Italy. http://www.fao.org/docrep/016/i2727e/i2727e00.htm [accessed 30 May 2013].

Feldhusen, F. (2000). The role of seafood in bacterial foodborne diseases. *Microbes and Infections*, 2 (13), 1651–1660.

Gram, L. and Dalgaard, P. (2002). Fish spoilage bacteria – problems and solutions. *Current Opinion in Biotechnology*, 13, 262–266.

Gram, L. and Huss, H. H. (1996). Microbiological spoilage of fish and fish products. *International Journal of Food Microbiology*, 33, 121–137.

Huis in't Veld, J.H.J. (1996). Microbial and biochemical spoilage of foods: an overview. *International Journal of Food Microbiology*, 33, 1–18.

Huss, H.H. (1994). Assurance of seafood quality. FAO Fisheries Technical Paper – 334. FAO Press. Rome.

Huss, H.H. (1995). Quality and quality changes in fresh fish. FAO Fisheries Technical Paper – 348. FAO Press, Rome.

Huss, H.H., Reilly, A. and Karim Ben Embarek, P. (2000). Prevention and control of hazards in seafood. *Food Control*, 11, 149–156.

Leistner, L. and Gorris, L.G.M. (1995). Food preservation by hurdle technology. *Trends in Food Science and Technology*, 6, 41–46.

Martinez-Alvarez, O., Lopez-Caballero, M.E., Montero, P. and Gomez-Guillen, M.C. (2007). Spraying of 4-hexylresorcinol based formulations to prevent enzymatic browning in Norway lobsters (*Nephrops norvegicus*) during chilled storage. *Food Chemistry*, 100, 147–155.

Neil, D.M. (2012) Ensuring crustacean product quality in the post-harvest phase. *Journal of Invertebrate Pathology*, 110, 267–275.

Olafsdottir, G., Martinsdottir, E., Oehlenschläger, J. *et al*. (1997). Methods to evaluate freshness in research and industry. *Trends in Food Science and Technology*, 8, 258–265.

Ottera, H., Roth, B. and Torrissen, O.J. (2001). Do killing methods affect the quality of Atlantic salmon? in *Farmed Fish Quality* (eds S.C. Kestin and P.D. Warriss), Blackwell Science Ltd, Oxford, pp. 398–399.

Papadopoulos, V., Chouliara, I., Badeka, A., Savvaidis, I.N., Kontominas, M.G. (2003). Effect of gutting on microbiological, chemical, and sensory properties of aquacultured sea bass (*Dicentrarchus labrax*) stored in ice. *Food Microbiology*, 20, 411–420.

Poli, B.M., Parisi, G., Scappini, F. and Zampacavallo, G. (2005). Fish welfare quality as affected by pre-slaughter and slaughter management. *Aquaculture International*, 13, 29–49.

Robson, A.A., Kelly, M.S. and Latchford, J.W. (2007). Effect of temperature on the spoilage rate of whole, unprocessed crabs: *Carcinus maenas, Necora puber* and *Cancer pagurus*. *Food Microbiology*, 24, 419–424.

Rosnes, J.T., Vorre, A., Folkvord, L. *et al*. (2003). Effects of pre-, in-, and post-rigor filleted Atlantic salmon (*Salmo salar*) on microbial spoilage and quality characteristics during chilled storage. *Journal of Aquatic Food Product Technology*, 12, 17–31.

Roth, B., Imsland, A., Gunnarsson, S., Foss, A. and Schelvis-Smith R. (2007). Slaughter quality and rigor contraction in farmed turbot (*Scophthalmus maximus*): a comparison between different stunning methods. *Aquaculture*, 272, 754–61.

Soncin, S., Chiesa, M., L., Panseri S., Biondi, P. and Cantoni, C. (2008). Determination of volatile compounds of precooked prawn (*Penaeus vannamei*) and cultured gilthead sea bream (*Sparus aurata*) stored in ice as possible spoilage markers using solid phasemicroextraction and gas chromatography/mass spectrometry. *Journal of the Science of Food and Agriculture* 89, 436–442.