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A review of captures and treatments of sea food, post mortem biochemical degradations of macro-molecules and impacts of certain factors on the quality of the fish

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Abstract
Sea food in overall and particularly fish constitute a worldwide nutritional wealth. The current review describes the different responses of *post mortem* biochemical degradations of macro-molecules and the impact of certain factors on the organoleptic and nutritional quality of the fish. The exhaustion of energy (ATP: Adenosine Triphosphate) in relation to capture and treatment processes is a source of rapid degradation of proteins, glucides and lipids. They are responsible to the odor and the taste of spoiled fish. Knowledge and mastery of these processes towards treatments will definitely enhance technological, organoleptic and nutritional qualities of the fish for the whole consumers.

Keywords: Sea food, fish, macro-molecules, biochemical degradation

1. Introduction

Algae, shrimps, crabs, crayfish, gastropods and fishes are sea food coming from fishery and aquaculture. They play a key role in the improvement of human food security and nutrition and increasingly important in fighting hunger [1]. In 2016, aquaculture supplied 96.5% of wild or cultured aquatic plants [1]. In addition, aquatic plants production largely dominated by algae, passed from 13.5 million tons in 1995 to average 30 million tons in 2016. Production of shrimps, crabs, crayfishes, gastropods are respectively and sensitively equal to 350, 1250, 320 and 175 thousand tons in 2016 [1]. However, aquaculture produces 51.4 million tons of food fish, either 64.2% of world farmed fish production against 57.9% in 2000 [1]. Fish farming is still dominating continental aquaculture with 92.5% (47.5 million tons) of the total production [1]. Fishery and aquaculture constitute the way out face the current population increase [2, 3, 4]. Besides, sea foods are excellent high quality protein sources. The bio-availability of proteins coming from fish is higher average 5 to 15% than vegetal proteins [5]. Sea food in general and particularly fish constitute a source of essential nutrients able to ensure all the human nutritional and sanitary needs [6]. By the same way, according to Micha (2006) [7], 100g of fresh fish contains 25 to 30 g of dry matters, 16 to 24 g of proteins, 0.5 to 3 g of lipids with 20 to 50% of polyunsaturated fatty acids and supply 500 to 600 kJ of energy necessary to every *Homo sapiens*. So, the worldwide food fish supply in these latter fifty years has increased higher than the world demography [8]. By the same way, fish is an important source of nutritive elements and animal proteins for a big part of the world population though consumption is the double (either 3.2%) of the demographic growth [8]. Sea foods are part of basic foodstuffs most traded in the world and the biggest worldwide fish exportations comes from developing countries, representing 10% of the total agricultural exportations and 1% of world trade with a 13% increase for 34 years [8]. So, according to FAO [8] (2012), 88% of fish production is reserved for direct human consumption. The major part of Africans consume smoked or dried fish and frequently fresh [9]. However, fish is a high spoilable product after capture compared to other foods and so becomes inedible and dangerous to consumers' health due to microbes proliferation on the one hand and an endogenous enzymatic degradation tied to a series of biochemical reactions of ATP (Adenosine Triphosphate) in the muscles of the fish during *post mortem* storage [10]. So, it's to ensure a sustainable preservation of the fish that certain transformation technics are used with variability according to countries and feeding habits [11].

According to this author, among these preservation and transformation methods, we can quote freezing, refrigeration, over-freezing, drying, smoking, frying, boiling and fermentation etc… The high fish demand in the world is followed by quality requirement and certification of sea foods [12]. That's the reason why, respect of some criteria for good preservation of sea foods becomes mandatory. However, some intrinsic and extrinsic factors to the fish can influence its transformation and preservation. The current manuscript is a review on food fish production, mechanisms of *post mortem* biochemical degradation of macro-molecules and the impacts of certain factors on the fish quality.

2. Sea food coming from fishery and aquaculture for human consumption and treatment.

According to FAO (2014; 2016; 2018) [12, 13, 1], fish and fishery products play a fundamental role in term of nutrition and food security in the world because they constitute a precious source of micro and macro nutrients that are highly important for safe and diversified food diets. Fish contains several essential amino-acids for human health such as lysine and methionine. Many fish species (particularly fat fishes) supply omega 3 fatty acids with long chain that participate to visual and cognitive development [14]. Besides, fish provides essential minerals such as calcium, phosphorus, zinc, iron, selenium and iodine also vitamins A, D and B that help reduce risks of malnutrition [15]. So, consumption of sea foods in general and particularly fish *per capita* passed from 9.0 kg to 20.2 kg, either an increase of average 1.5% per year for fifty four years [16]. Estimations of the forthcoming years reveal respectively an increase of 20.3 kg and 20.5 kg (Table 1; Figure 2). The progression of the consumption can be explained not only by the increase of production but also the association of several factors especially wasting reduction, a most complete utilization, the improvement of distribution channels and the crescent demand that is tied to the increasing demography, the increase of revenue and urbanization (Table 2) [2, 3, 4, 1].

Table 1: Worldwide fish production and consumption from 2014 to 2018.

	CF	Aq	T_pF	HC	NFU	FFPC (kg)
Continental (in million tons)	11.6	51.4	171	151.2	19.7	20.3
Marine (in million tons)	79.3	28.7				

Source: (FAO, 2014, 2016; 2018) [11, 13, 1].

CF: Capture fishery, Aq: Aquaculture, TpF: Total production of Fish, HC: Human Consumption, NFU: Non Food Usage, FFPC: Food Fish *Per Capita* (kg).

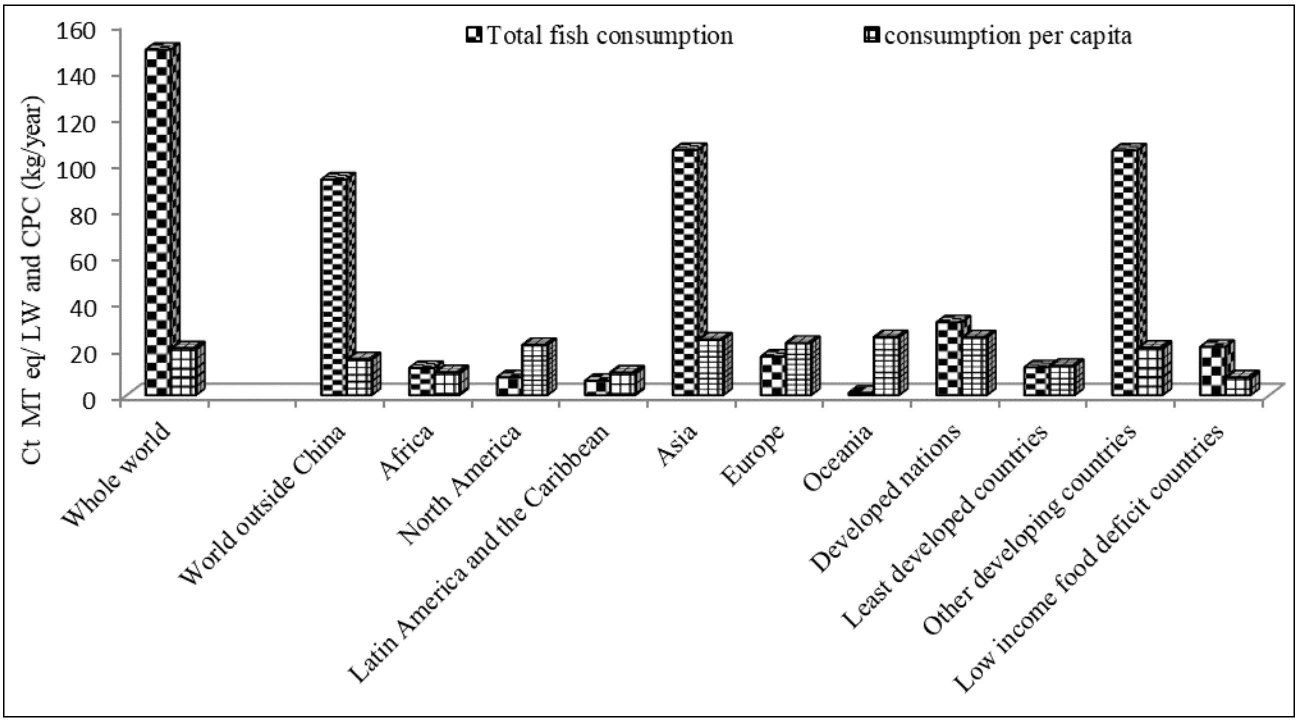

Fig 1: Region, total apparent fish consumption and *per capita*. Source: (FAO, 2016; 2018 [13, 1] data treated this work). Ct MT eq/ LW: Consumption in million tons equivalent to live weight, CPC (kg /an): Consumption per capita.

Globally, sea food coming from fishery and aquaculture constitute survival means for 10 to 12 % of the world population [12]. Fishing boat through the world (from small and engineless to the big modern and industrial boats) was estimated to average 4.6 million in 2016, though 75 % of worldwide fleet are from Asian continent [1]. By the same way, statistical analysis of capture and fishery data classifies China ahead with 49.7% of the total worldwide fish production [1]. With notice from this analysis that sea foods are envied and become indispensable for human survival and development. Indeed, due to its biochemical composition and nutritive values, fish constitutes a protein source appreciated by a large number of individual contrary to other protein sources such as pork, poultry, beef etc.

3. Sea food treatment

Fresh products would be spoiled when canned food will be consumable for longtime. Fish is one of fresh products rapidly spoilable and was for longtime a problem for producers and consumers. Preservation of spoilable foodstuffs has always

been an issue. We remarked empirically that after a certain time foodstuffs degraded till provoke an illness in the individual who consume them at this stage [17, 18].
Thus, treatment technologies have been developed in order to provide solution to consumers. Indeed, *treatment <<the word took in its current context>> is all the transformation and preservation processes enabling to achieve a longtime storage of sea foods.* This will enable to use the excess of sea food in lack period. On the other hand, preservation enables expensive out of season sales than during the harvest period. According to FAO (2018) [1], the worldwide fish production has been consumed frozen (31%), prepared and canned (12%), smoked, salted, pickled in brine or fermented (12%) and the remaining as live, fresh or refrigerated (45%). The different transformation and preservation technics have been object of several works [11, 6].

4. Post mortem biochemical degradations of macro-molecules

Components such as water, proteins and lipids represent average 98% of the fish filet; glucides, vitamins and minerals are the remaining components [19]. They are the most important during reactions of synthesis and/or degradation of ATP (Adenosine Triphosphate: source of energy) but also indispensable in the determination of the fish quality [20]. The fish will enter in *rigor mortis* few times after its death. Indeed, the *rigor mortis* is a process through which the fish loses its flexibility due to the stiffness of its muscle (lack of myosin and actine bridges dissociation) due to the exhaustion of the ATP [21]. Indeed, ATPase pumps close and concentrations of calcium (Ca^{2+}) and sodium (Na^{+}) released in the sarcoplasm remain intact, consequence, the muscle remains contracted due to the *post mortem* dropping of ATP. This phenomenon is called *post mortem* rigidity or *rigor mortis* [22, 23]. The increase of the muscular tension during the beginning of the *rigor mortis* is correlated to a decrease of components tied to ATP. An important degradation of ATP will begin 5 to 6 hours after capture if fishes are exposed to high ambient temperatures [24]. According to Mairesse (2005) [25], the quality of a fish depends on *ante mortem* rearing conditions but considering consumers, this quality depends mainly on *peri-mortem* and *post-mortem* conditions (capture conditions, stocking duration, type of transformation etc…). Indeed, the *post-mortem* musculature of fishes is generally susceptible to undergo numerous biochemical modifications, leading to unusual and undesirable texture changes such a soft or pasty texture. The stress level of all the fish efforts will influence the available quantity of glycogen and consequently on the definitive *post-mortem* pH. In addition, the ATP degradation is part of the *post-mortem* changes processes in fishes [20]. Indeed, during *post-mortem* storage of fishes, the ATP in muscle tissues degrades after a package of biochemical reactions generally represented by Figure 2.

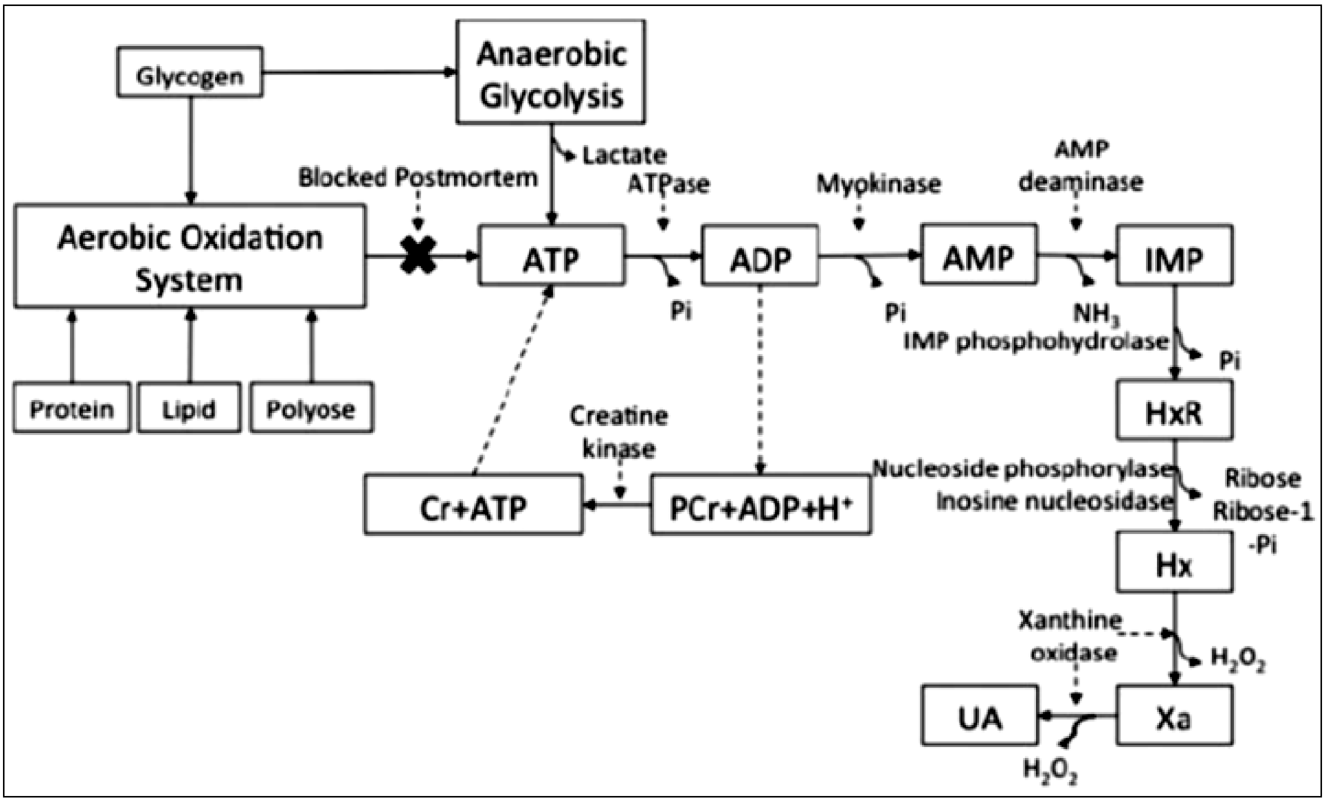

Fig 2: *Post mortem* metabolism of ATP in the muscle of the fish (modified by Huss, 1995) [26].

Indeed, there are two ways for a *post mortem* muscle to produce ATP: the way of phosphate creatine (PCr) and/or the way of anaerobic glycolysis. The PCr way uses creatine kinase (CK) in the muscle of the fish to transform ADP and PCr into ATP and Cr (Figure 2) [21]. One of the degradation products of ATP tied to the good taste of the fish is Inosine monophosphate (IMP). In the food industry, IMP and salts are largely used as taste enhancers. The glycogen of the muscle is degraded and metabolized by glycolysis into pyruvate that will be reduced into lactic acid by dehydrogenase in the absence of oxygen. According to Massa *et al.* (2005) [27], IMP can be synthetized from small molecules of ADP in the presence of aldenylkinase and accumulate in the *post mortem* muscles of the different fish species. And then, IMP degrades into Ino and the disappearance of the IMP characterizes the loss of freshness in fishes [28]. In contrary, products coming from IMP degradation are essentially hypoxanthine, xantine, uric acid and other products by the action of nucleoside phosphorylase provoking the breaking up of development cycle of microbes.

Essential organic components of fish muscles, proteins occupy average 60 to 70% of dry weight of these tissues, either 18 to 22% of fresh weight [29, 30, 31, 32].

Table 2: Different types of proteins and their proportions in the muscle of the fish.

Types of proteins	Examples	Proportion	Authors
Proteins of structure	Myofibril proteins : actine, myosine, tropomyosines, troponines, desmine, titine, nebuline, α-actinine	70 to 90%	Ladrat *et al*, 2003 [33].
Sarcoplasmic proteins	myoglobine, globuline and enzymes	10 à 30%	Hernandez-Herrero *et al.*, 2003; Haard, 1992; Borresen, 1995 [34, 29, 35].
Proteins of conjunctive tissue	essentially elastine and collagen	3 to 10%	Haard, 1992 [29] Borresen, 1995 [35]

Proteins of structure occupy an important proportion following by sarcoplasmic proteins and proteins of conjunctive tissue. This important protein proportion undergoes an immediate degradation after the fish death under the effect of the different factors. Fish proteins have an important biological value containing all the essential amino-acids such as lysine, tryptophan, histidine, phenylalanine, leucine, isoleucine, threonine, methionine, cysteine and valine [36]. In addition, proteins are important sources of lysine and sulphureted amino-acids (methionine and cysteine). Besides, in certain fishes, ammoniac and trimethylamine oxide, creatinine, free amino-acids, nucleotides and puric bases and urea are volatile bases constituting the largest part of non proteinic nitrogen components. According to Huss (1988) [37], in most of fishes, free amino-acids vary in relation to species despite taurine, alanine, glycine and amino-acids with imidazole kernel such as histidine are major. Certain authors such as Shewan *et al.* (1957) [38], Wojtowicz *et al.* (1972) [39], Herbert *et al.* (1976) [40], reported that biochemical reactions in the fish are low in nucleotides of proteins and are not mandatory for the beginning of the microbial degradation. However, Castell *et al.* (1973) [41], Mackie (1974) [42] mentioned that the muscles of certain fishes contain enzymes able to degrade non proteinic nitrogen components essentially oxide of trimetylamine (OTMA) into Dimethylamine (DMA) and Formaldehyde (FA), even though bacteria degrade rapidly OTMA into Trimethylamine (TMA) in refrigerated fishes. Concerning freezing, there is also inhibition of microbial actions and it's during this time that DMA and FA are important in the fish by provoking modification of the texture and an important water loss due to its low retention capacity of water [43]. Love (1980) [44] reported that the decrease of pH after the fish death can accelerate synthesis and digestive enzymatic activity that weaken the resistance and accelerate degradation of conjunctive tissues.

It results from these information that proteins as major components of fish filet in lack of good treatment condition undergo rapid degradation. Indeed, a relatively low rate of ATP after the fish death exhausts rapidly making the fish filet protein vulnerable to microbial agents. In addition, proteins degradation is correlated with the decrease of pH.

Lipids

In fishes, all lipid classes are present and gathered in two types: neutral lipids (triglycerides) and polar lipids (phospholipids). This lipid richness is due to the energy transfer by the food web of the fish. Indeed, fish consuming inferior organisms of the trophic web such as phytoplankton made of average 40% n-3 PUFA (poly-unsaturated fatty acids) and zooplankton 15 to 20%, enrich in poly-unsaturated fatty acids. Energetic reserves of the fish are mainly triglycerides though phospholipids as major components of cells membrane are structure lipids. Lipids concentration and fatty acids composition are submitted to many variation factors in fishes [45]. Lipids degradation mainly happens by oxidative reactions (chemical) but also by tissue or bacterial enzymatic hydrolysis though main products are free fatty acids and glycerol (Figure 3).

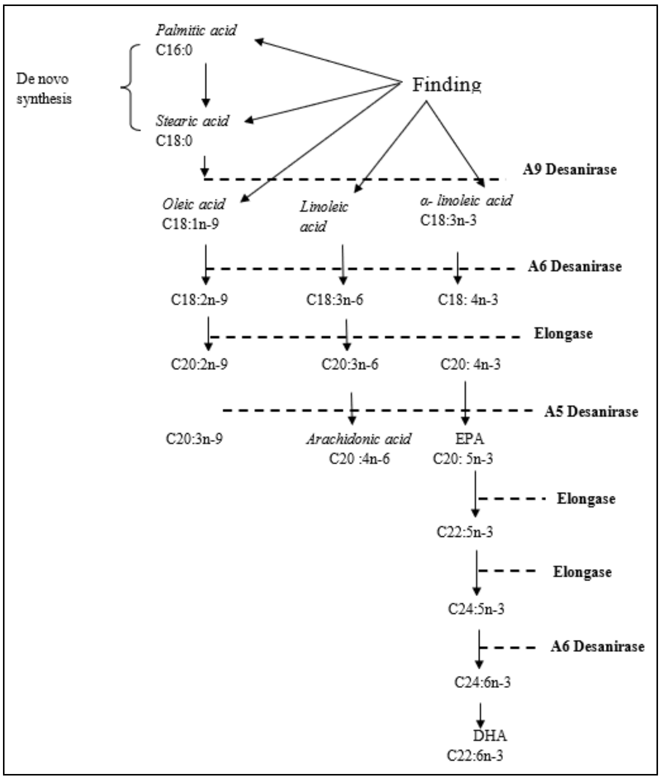

Fig 3: Diagram of lipid metabolism ways (adapted from Sargent *et al.* (2002) and Opsahl-Ferstad *et al.* (2003)) [46, 47].

Besides, lipase (endogenous or microbial) transforms triglycerides into glycerol and free fatty acids [37]. When fishes are eviscerated (viscera rich in lipolytic enzymes), at low temperature, hydrolysis reactions reduce [37]. In micro-organisms having lipoxydases, free fatty acids can react with molecular oxygen to form aldehydes or ketones though rancid taste id characteristic of spoiled fish [48]. Otherwise, it's crucial to mention that during transformation and preservation of the fish by the wood smoke, certain substances coming from the wood penetrate through external stratum till fatty matters to preserve the smoked fish from rancidity [37, 49]. Indeed, lipids alteration leads to the production of a series of substances though certain have rancid taste and odor. Fat fishes are too sensitive to lipids degradation which can create serious quality issues even at preservation temperature lower than 0 °C.

As other macro-molecules in fish, the biochemical degradation of lipids also helps to determine the fish quality. In addition, if fish is a source of protein desired throughout the world, it's due to the role of those poly-unsaturated fatty acids. It's the reason why emergency measures of pre or post preservation worth to be taken in order to keep the major part of these molecules intact before consumption.

5. Factors impacting the pre or post mortem quality of the fish

5.1 Stress

Stress is defined as all non-specific responses of the body to environmental stimulus and which perturb the homeostasis [50]. According to Lowe *et al.* (1993) [51] and Nakayama *et al.* (1992) [52] the *rigor mortis* (RM) is a *pre-mortem* stress indicator in both duration and intensity. There is also the *pre-mortem* neutral stress that has no effect (positive or negative) on the organism [53]. According to Barton (2002) [54]. stress factors are summarized in (Table 3). By the same way, corresponding physiological responses are also three such: (1) the primary stress that includes mainly endocrine changes showing high levels of catecholamine and corticosteroid, (2) secondary stress affects metabolism, water-salt balance and functions of the cardiovascular, respiratory and immune systems, and (3) the tertiary stress is associated to changes in the growth, resistance to illnesses and behavior of fishes, and can occur resulting from primary and secondary responses [54, 53]. According to Reid *et al.* (1998) [55] and Flik *et al.* (2006) [56], these physiological responses provoke the release of some hormones, adrenaline and noradrenaline (called catecholamines) by chromaffine cells located in the anterior part of fishes and adrenocorticotropic (ACTH) by kidney cells and in the fish head. Besides, Tort *et al.* (2004) [57] reported that the stress duration influences considerably physiological changes in the fish. Indeed, physiological changes of metabolism would provoke an increase of glucides catabolism following by high levels of glucose and lactate and then hepatic enzyme releasing, free amino-acids provoking a rapid proteolysis [58]. Elongated stress is so harmful and provokes the fish death in a critical status and is forbidden by the Council Welfare Animal Farmed [59, 60]. Certain free air exposition, transport practices, different killing methods of the fish play mainly a role as acute stress factors. Also, over-population or high stocking density is a chronic stress factor. That's the main target of the results of Bolasina (2011) [61] on *Paralichthys orbignyanus* submitted to a high stocking density. These hormones released during the fish death under stress effect, could be on the base of rapid deterioration process of the fish that becomes inedible.

Table 3: Different stimulus groups of stress factors.

Stimulus	Stress factors
sight	Presence of predator
Physical	Handling, transport etc.
Chemical	Low oxygen concentration, high concentration of acid, etc.

Source: (Barton, 2002) [54]

5.2 pH

Hydrogen potential is an important factor in the degradation process of the fish after death. pH is an evaluation indicator of the deterioration level of fishes [62]. According to Akter *et al.* (2014) [62], the pH of fresh fish after death is close to neutral (pH=7). The decrease of pH value is due to the making up of lactic acid in the fish filet [63]. Indeed, the inhibition of glycolytic enzymes due to the decrease of pH is essentially due to the accumulation of lactic acid in the muscles of the fish [64, 65]. In addition, the hydrolysis of ATP in the fish muscle tissues is associated to the release of protons leading to a supplementary decrease of pH (pH comprises between 4.5 and 5.5). This acidification leads to a decrease of water retention capacity by proteins. However, Hamm (1977) [66]. reported that 10% of the *post mortem* total decrease of pH is due to released protons. Stocked energy as ATP prior undergoes a package of biochemical dephosphorylating and deamination reaction to provide inosine monophosphate (IMP) (absence of taste) that transforms in three products such as ionosine (HxR), hypoxanthine (Hx) (bitter taste) and Ribose (R).

Table 4: Different pH of some fishes.

Fish species	pH	Authors
Maquerella	5.8 to 6.0	Tomlinson *et al.*, (1963) [67]
Red Tuna	5.4 to 5.6	
Tinca tinca	6.07	Gasco *et al.*, (2014) [60]
Solea senegalensis	6.4 to 6.9	Ribas *et al.*, (2007) [68]
Channa striata	6.7 to 6.95	Treesa *et al.*, (2016) [69]

From the analysis of these data, it results that muscles pH of fishes varies according to species and are under the limit pH (Table 4). According to Wongwichian *et al.* (2013) [70], pH variation is tied to the different attacks of micro-organisms in the muscle tissues, to glycolysis rate and to the tampon power that differs in relation to fish species. As pH is an appreciating parameter of the fish quality, certain authors indicate that the acceptable pH limit in fishes after death varies between 6.8 and 7 and beyond 7 the fish is considered as spoiled [71- 73]. It results that the *post mortem* progression of pH has a noteworthy consequence on degradation, organoleptic and sensorial quality of the fish.

5.3 Temperature

The role of temperature is crucial in preservation and for a good quality of the fish. For fish that are poikilothermic, temperature is a primordial factor for regulation of metabolic reactions and lipid metabolism. According to Henderson *et al.* (1987) [74], temperature influences indirectly lipid components that are tied to the natural food and feeding in rearing condition. In addition, the increase of the concentration of eicosapentaenoic acids (EPA) and docosahexaenoic (DHA) in the muscle of the fish occurs with the decrease of temperature [75]. Hwang and Lin, (2002) [76]; Hsieh *et al.* (2003) [77] and Stillwell *et al.* (2003) [78], demonstrate that the decrease of temperature induces a reduction of saturated fatty acid though we notice an increase of unsaturated fatty acids ensuring membrane fluidity mainly viewable in phospholipid fatty acids [79, 80]. Besides, temperature influences definitely pH by the time. The same trend is notified by Hwang and Lin, (2002) [76] on *Oreochromis shiranus* exposed to ambient temperature from 27 °C to 30 °C, during which they noticed a rapid progression of pH in 12 hours. Low temperature progression recorded -20 °C, -12 °C, 4 °C and 12 °C respectively on *Channa striata Argyrosomus regius*, *Pangasianodon hypophthalmus et Mystus seenghala* induce low pH progression with good sea foods preservation [81, 82]. Besides, psychotropic bacteria are able to develop at temperature comprises between 0 and 25 °C. However, psychrophilic (liking cold) have growth temperature average 20 °C. Mesophyll concern fishes from most warm waters. We notice from this analysis that there is a close link between degradation temperature and lipids membrane function. In addition, a very low temperature prevents or slows down bacteria multiplication responsible to degradation of alkaline molecules which are responsible to pH increase enabling a good preservation of the fish.

5.4 Salinity

This factor concerns mainly marine fishes. Salinity has no effect on the total lipid concentration but influences fatty acids composition especially phospholipids [79]. Salinity makes vary enzymatic activities happening in the lipid and proteins metabolism inducing changes in the fatty acids composition enabling the maintenance of permeability and fluidity properties of the cells membranes as observed in temperature [83, 84]. Besides, in *Dicentrarchus labrax*, Cordier *et al.* (2002) [85] found a negative correlation between the water salinity and the percentage of docosahexaenoic (DHA) in phospholipids of the fish muscle.

5.5 Handling

Different fights of capture and killing of the fish will accelerate the degradation of components tied to ATP. Indeed, Fraser *et al.* (2004) [86] showed that partial exhaustion of muscular ATP reserves during sailing is sufficient to stimulate dephosphorylating and deamination of nucleotide components. By the same way, Scherer *et al.* (2005) [87] also remarked that fishes killed by electric current presented more rapid initial rate of ATP degradation and early entered in *rigor mortis*. Indeed, glycogen consumption during and after killing depends on the fishing technic and killing method. Glycogen reserves in the muscle can be almost exhausted (intensive muscle activity during capture) before the fish death which will provoke acceleration of ATP degradation.

5.6 Seasons

Hwang *et al.* (2002) [88] determined that the levels of inosine monophosphate (IMP) and adenosine monophosphate (AMP) were higher in the muscle of globe-fishes (*Takifugu rubripes*) sampled from July to January in relation to the other period of the year. Fluctuation of nucleotides of these fishes during the different seasons could be due to different environmental and nutritional conditions. This fluctuation of nucleotides in the muscle of fishes during seasons could expose them to the different microbes and accelerate degradation.

5.7 Micro-organisms

Micro-organisms are on all the external surface (skin and gills) and internal (intestines) of live fishes with in low amount. There is a large amount of micro-organisms of the fish that differs according to media. The main micro-organisms are: Mesophyll Anaerobic Germs (MAG), Total Coliforms (TC), Fecal Coliforms (FC), Anaerobic-Sulfite Reducers (ASR), Staphylococcus, Salmonella are favored by the different above-mentioned factors [89, 90, 11]. In addition, according to Løvdal (2015) [89], these micro-organisms can appear on transformed or preserved (evisceration, smoking, frying etc...) fishes when hygiene conditions are not maintained.

6. Conclusion

Sea food in general and particularly fish play a fundamental role in term of worldwide nutrition and food security. Fish is so a nutritional wealth. However, it undergoes a rapid alteration, becomes spoiled and inedible. The degradation process of sea food is essentially tied to biochemical degradation of macro-molecules favored by certain factors such as low pH, low oxygen concentration, stress etc… facilitating development of micro-organisms.

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