Effects of refrigerated storage on the microstructure and quality of Grouper (*Epinephelus coioides*) fillets

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Revised: 13 September 2011 / Accepted: 8 November 2011 / Published online: 18 November 2011
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Abstract Refrigerated storage is the simplest method of preserving for short time handling and storage of fish. The objective of this study was to investigate the effects of refrigerated storage on the microstructure, physicochemical (proximate composition, pH, TVB-N, LHC), microbial (total mesophilic count, TMC and total psychrotrophic count, TPC) and sensory changes of grouper (*Epinephelus coioides*) fillets during a 14-day period at +4 °C. The estimated TVB-N value was significantly different in all days of storage. TPC value reached to a limiting level for human consumption (10^7 micro-organism/g) after the 10th day of storage while TMC remained under the limited acceptability until 14 days. Cellular tissue damage was observed after 7 days of storage. The shelf life of grouper was approximately ~8–9 days according to the results of sensory, chemical and microbial analysis.

Keywords Grouper · Microstructure · Quality · Refrigerated storage · Shelf life

Introduction

The eating quality of fish is one of the important attributes that influence the acceptability of fish as food to the

consumer. Freshness is one of the most important aspects of fish, and because of consumer preferences, there is a strong tendency to select very fresh fish (Luten and Martinsdottir 1997). Quality of fish, which depends on the nature of fish species and on the handling and storage conditions (Chotimarkorn 2011; Erkan 2007; Whittle et al. 1990), changes after catch due to chemical reaction and microbiological spoilage (Sharifian et al. 2011). During handling and storage, quality deterioration of fresh fish occurs rapidly and limits the shelf life of the product. Spoilage of fish and shellfish results from changes caused by three major mechanisms (i) the breakdown of tissue by the fish's own enzymes (autolysis of cells), (ii) growth of microorganisms, and (iii) oxidative reactions. The muscle of fish has a very particular organization compared to meat, because it consists of the alternation of muscular sheets called myotomes separated and maintained by the connective tissue. Moreover, myotomes are composed of a large number of individual muscle fibres in a collagen matrix (Chéret et al. 2005). It is a fact that fresh fish that has been well handled and kept at low temperatures exhibits reduced bacterial growth and other spoilage factors. With the aim of reducing loss in freshness, different preservative methods, such as flake ice (Sharifian et al. 2011), slurry ice (Losada et al. 2005) and chemical addition (Fan et al. 2008) have been employed. Refrigerated storage is possibly the simplest method of preserving for short time handling and storage of fish caught. It is widely employed to retain fish properties before consuming or employing in other technological processes. Grouper (*Epinephelus coioides*), also known Hammor in countries around the Persian Gulf, is one of the main marine fish species in these area. *E. coioides* is dominant species of groupers in Persian Gulf and mainly is captured by the trap that is named locally Gargoor. In Iran, demand for fresh grouper has been

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constantly increasing over the past 15 years owing to its high nutritional quality and excellent organoleptic properties. Some research have been done about quality, quality and structure changes of other fish during chilled storage (Özogul et al. 2006, 2008; Ofstad et al. 2006; Pons-Sánchez-Cascado et al. 2006; Rodríguez et al. 2004; Alasalvar et al. 2001), but limited information were about grouper (*E. coioides*) during refrigerated storage. Therefore, the aims of this study are to determine (1) quality changes (2) changes in microstructure and (3) shelf life of grouper (*E. coioides*) fillets during refrigerated storage.

Materials and methods

Sample preparation Grouper is selected for this study because of its wide consumption and nutrition value. Experiments were carried out with fresh grouper (*Epinephelus coioides*), which were caught near the Bandarabbas coast located in southern Iran (March, 2009). They were transported in isothermal iceboxes to the laboratory 5 h after catching. Fresh grouper of similar weight (0.5–0.6 kg) were selected for each experiment. The fishes were cleaned and filleted. The samples were placed in moisture-impermeable plastic bags (oxygen permeability: 60 cc/m²/24), stored in refrigerator (+4 °C) and taken for analysis on 0, 4, 7, 10, and 14 days. For chemical analysis, the fillets were minced/mixed by passing three times through a meat grinder with 4 mm diameter holes. All analyses were performed in triplicate.

Sensory analysis The attributes of raw fish fillet were evaluated by a panel of five experienced judges (4 males and 1 female, 26–40 years old) on each day of sampling. Sensory evaluation was conducted in individual booths under controlled conditions of light, temperature and humidity. Sensory analysis was performed according to a scheme from Liu et al. (2010) with some modification for grouper. A 5-point scoring scale was used for quantitative evaluation of overall acceptability (excellent, 5; good, 4; moderately good or acceptable, 3; poor, 2; very poor, 1; putrid, 0). On each sampling day, three random fillets were individually presented to the panel. They were firstly asked to evaluate the odour, appearance and texture of raw fillets in the trays and subsequently tasted the cooked samples after cooking in boiling water for 2 min and finally judged the overall acceptability. Newly-caught grouper was used as reference for sensory analysis each time. The shelf life was defined as the average total sensory score below 2.

Physicochemical analysis

Proximate composition Moisture content was determined by air-drying of a given sample in a thermostat oven

(Gallenkamp, HOTBOX, Model OVB-306) at 105 °C for 24 h until constant weight. Ash content was determined by igniting the sample in a muffle furnace at a temperature of 550 °C for 6 h. Crude protein was determined by the Macro Kjeldahl method, as described by Reza et al. (2008). Total lipid was determined by Soxhalet method (AOAC 1995).

Total Volatile Base Nitrogen (TVB-N) and pH TVB-N content was determined and evaluated as described by Kılınç et al. (2003) by Kjeldahl distillation mechanism and expressed as mg TVB-N per 100 g muscle. The method was based on water vapour distillation and separation of volatile base. The value of pH was determined using a pH meter (HM-205, Japan). The samples were prepared as described by Vyncke (1981).

Liquid Holding Capacity (LHC) A centrifugation test was performed to evaluate liquid holding capacity (LHC) of grouper fillets, as described by Rørå et al. (2003). Chopped frozen muscle samples (2 g) were weighed and placed in a centrifuge tube with weighted (V1) filter paper (Whatman, Maidstone, England). Following muscle thawing, the tubes were centrifuged (Hettich universal, Hettich-zentrifugen, D-7200 Tuttlingen, Germany) at 4,000 g for 10 min at 10 °C, and the wet paper was weighted (V2) before drying at 50 °C to constant weight (V3). The percentage value of liquid loss (LL) was calculated as $100 \times (V2 - V1)/S$, where S = weight of muscle sample, water loss as $100 \times (V2 - V3)/S$ and fat loss as $100 \times (V3 - V1)/S$. All losses were expressed as percentage of muscle wet weight.

Microbiological analysis Grouper fillets were taken to estimate total mesophilic counts (TMC) and total psychrophilic counts (TPC). Muscle samples (10 g) were weighted and mixed with 90 ml of Ringer solution [Merck, 1.15525.0001, Darmstadt, Germany], and then Stomachered [IUL instrument, Barcelona, Spain] for 3 min. Further serial dilutions were made in tubes before plating. The media and incubations for mesophilic aerobic and psychrophilic bacteria were plate count PCA agar (PCA, Merck, Kat No: 105463), 37 °C, 24–48 h and PCA agar (PCA, Merck, Kat No: 105463), 5 °C, 72 h, respectively.

Microstructure analysis Samples preparations for microscopic analysis were carried out as described by Alizadeh et al. (2007), with some modification for grouper fillets, to observe extra-cellular space and fibre shrinking in tissue. For each fillet analyzed, three samples of 5 mm were cut transversally to the muscles fibres, using a blade previously cooled to 4 °C, then fixed in Carnoy's solutions (60% absolute ethanol, 30% chloroform and 10% glacial acetic acid, v/v) at 4 °C for 24 h. The fixed samples were then brought to room temperature and were dehydrated with

absolute ethanol for 2 h. Then, they were placed in a second bath containing a solution made of 50% absolute ethanol and 50% toluene bath overnight and finally left in a pure toluene bath for 4 h. The dehydrated samples were immersed in 3 paraffin/toluene baths containing an increasing proportion of paraffin (25, 50 and 75%). At least, the samples were immersed for 1 h in a pure paraffin bath kept at 60 °C. Finally, each sample was embedded in paraffin using a mould (20×15×15 mm). Samples were cut with a microtome (RMT-30, Radical Microtome, India) in 10 µm thick slices. The sections were stained for 5 min in Orange G (0.5% orange G, 1% acetic acid, 98.5% distilled water) for coloration of fibre muscle, and then immersed in a blue aniline (1% blue aniline, 1% acetic acid, 98% distilled water) for 2 min for coloration of collagen. The stained samples were washed with distilled water and sealed on glass plates using mounting with Enthalan (Merck, Germany). The samples were examined in a microscope (CX21FS1, Olympus, Japan) fitted with an Olympus camera (SP-500 UZ, Japan).

Statistical analysis All experiments were done in triplicate. Significant differences between the samples were calculated by SPSS 13.0 for Windows by one-way analysis of variance (ANOVA) using a significance level of $P < 0.05$ by Fisher's Least Significant Differences (LSD).

Results and discussion

Sensory assessment The mean score and standard deviation for overall acceptance of grouper is shown in Fig. 1. The overall acceptance decreased significantly as a function of storage time ($P < 0.05$). Fresh sea weedy odour, Milky white pale pinkish, firm texture and no off-odours were observed in fresh raw fillets and intense sweetness and meaty flavour were tasted in cooked samples. In Fig. 1 it can be seen that excellent and very good grades were scored during the first 4 days storage while moderate grades were obtained between days 5 and 8 of storage. After that, the quality deterioration was observed as off odours, opaque mucus, pink darkening and texture softening, which limited overall acceptability of raw fillets. The shelf life of grouper fillets stored at 4 °C ranged 8–9 days considering fish freshness. Özogul et al. (2008) found a similar pattern of reduced quality at wild white grouper (*Epinephelus aeneus*) stored in ice and at chill temperature (4 °C) and reported a 16 and 4-day shelf life, respectively, in the iced and chilled samples. Wire-netting reef cod (*Epinephelus merra*) was sensorially acceptable on the 17th days of storage (Jeyasekaran et al. 2005).

Fig. 1 Sensory acceptability of grouper fillets during refrigerated (+4 °C) storage ($n=5$)

Physicochemical assessment Changes in proximate composition of grouper fillets during refrigerated storage is summarised in Table 1. In fresh fillet, the moisture, protein and fat contents were 79.76, 18.45, and 0.79 g/100 g sample, respectively. These values were almost similar to those found by Luo et al. (2005), who reported values of 79.20–79.33, 17.88–18.49, and 0.66–1.27 g/100 g grouper muscle. Chemical composition of fish can be various greatly depending on species, age, sex, environment, season, feed intake and reproduction cycle (Reza et al. 2008). There was no significant ($P > 0.05$) effect of storage time of fish fillet on moisture and ash contents (Table 1) while protein levels showed significant differences ($P < 0.05$) during days of storage and decreased from 18.45 g/100 g at 1st day to 17.46 g/100 g at 14th day. Significant reductions in protein content were also observed during chilled storage of other fish species such as silver jewfish, Bombay duck and ribbon fish (Reza et al. 2008), yellowtail minced (Munasinghe et al. 2005) and croaker muscle protein (Dey and Dora 2010). The loss of protein in fish during chilled storage was possibly due to leaching of water soluble protein fraction from fish muscle (Reza et al. 2008). Changes in lipid content of samples were in the range of 0.79–1.17 g/100 g ($P < 0.05$). These variations can be explained by variation of lipid content from fish to fish even within the same fish depending on sex, age, and feeding (Stansby 1962).

The changes in pH, TVB-N content and LHC of grouper fillets during refrigerated storage are presented in Table 1. The initial pH of grouper samples was 6.49 and increased to 7.95 at the end of storage. Statistical analysis showed significant differences ($P < 0.05$) between all days of storage. Huss (1988) suggested that the initial post mortem pH of fish varies with species, catching ground and season. During storage, pH increases slightly because of the formation of alkaline compounds as ammonia compounds and TMA, mainly derived from microbial action (Hebard et al. 1982). In the present study, increase of pH

Table 1 Physical and chemical changes in grouper fillets during refrigerated (+4 °C) storage

		Days of storage				
		Control	4	7	10	14
Values are shown as means ± standard deviation of three replicates. Small letter (a–e) in the same line indicate significant difference ($P < 0.05$)	Protein ^A	18.5±0.06 ^a	18.3±0.32 ^a	18.1±0.04 ^{ab}	18.1±0.73 ^{ab}	17.5±0.23 ^b
	Lipid ^B	0.79±0.07 ^c	0.87±0.04 ^c	1.1±0.06 ^b	1.1±0.03 ^{ab}	1.2±0.05 ^a
	Moisture ^C	79.8±0.14	79.4±0.98	79.9±0.78	79.2±0.92	80.4±0.18
	Ash ^D	0.91±0.21	0.93±0.02	0.92±0.09	1.0±0.03	0.97±0.01
	TVB-N ^E	13.1±0.17 ^c	17.4±0.21 ^d	22.6±0.16 ^c	28.4±0.14 ^b	33.6±0.18 ^a
	pH	6.9±0.02 ^c	6.8±0.03 ^d	7.2±0.06 ^c	7.4±0.10 ^b	8.0±0.07 ^a
	Liquid loss ^F	12.7±2.00 ^c	12.9±1.64 ^c	13.4±1.34 ^c	27.4±0.80 ^b	23.9±2.93 ^a
	Water loss ^G	13.7±0.04 ^c	11.4±1.39 ^c	12.6±0.73 ^c	25.9±1.28 ^b	21.3±3.15 ^a
	Fat loss ^H	1.2±0.04 ^b	1.6±0.42 ^b	0.83±0.66 ^b	1.5±0.78 ^b	2.6±0.39 ^a
^{A–D} g/100 g fillet						
^E mg/100 g fillet						
^{F–H} percentage of muscle wet weight						

throughout 14 days of storage might be attributed to the formation of basic decomposition products, such as ammonia and trimethylamine produced by endogenous enzymes and bacterial spoilage. Sharifian et al. (2011) found that pH value for tiger tooth croaker stored in ice increased progressively throughout 19 days of storage. Chomnawang et al. (2007) found that the pH value of hybrid catfish fillet increased from 6.41 to 7.07 at the end of storage at 4 °C. Jeyasekaran et al. (2005) also reported a significant increase in pH of wire-netting reef cod (*Epinephelus merra*) during ice storage. It suggested that pH changes during refrigerated storage of fish differed according to the species of fish and other factors (Chomnawang et al. 2007).

Total volatile nitrogen content (TVB-N) of fish is an indicator of raw material freshness (De Koning 2001). The average of initial TVB-N content (mg/100 g fillet) for control sample (day 0) was 13.10 mg/100 g and progressively increased to 28.39 at day 10 and to 33.60 mg N/100 g muscle at day 14 ($P < 0.05$). TVB-N content in tiger tooth croaker (Sharifian et al. 2011), red mullet and goldband goatfish (Özyurt et al. 2009) stored in ice and wire-netting reef cod (Jeyasekaran et al. 2005), hybrid catfish (Chomnawang et al. 2007) and sardine (Özogul et al. 2004) during refrigerated storage increased with storage time. In the present study, TVB-N value was 28.39 when the grouper was rejected by panellists after 10 days of storage. However, a level of 30–35 mg TVB-N/100 g of fish muscle is usually regarded as spoiled (Huss 1988). Our results showed that the TVB-N level of between 25 and 30 mg/100 g could be regarded as the limit of acceptability for refrigerated grouper. The results also signified that TVB-N could be used as an indicator of grouper quality, as shown in a variety of fish, such as tiger tooth croaker (Sharifian et al. 2011), red mullet and goldband goatfish (Özyurt et al. 2009) and European eel (Özogul et al. 2005).

The changes in fat loss (FL), water loss (WL) and liquid loss (LL) in the grouper fillets lots are given in Table 1. At

the beginning of the storage period (day 0), FL value was 1.25% and increased to 2.60% at day 14 ($P < 0.05$). It was reported that fat loss increases with storage time as occurred in smoked Atlantic salmon fillets due to collagen denaturation (Rørå et al. 2003). Such an effect was also noted in this study, as FL levels of fillet were affected by storage time. However no correlation was found between muscle fat content and fat loss. Evens and Ranten (1975; cited by Hermansson 1986) indicated that the collagen fraction, and not the fat composition, influenced the quantity of fat loss in mammalian muscle. In the same way, Ofstad et al. (1995) on Atlantic salmon, Mørkøre et al. (2002) on rainbow trout and Attouchi and Sadok (2010) on wild and farmed gilthead sea bream did not find any correlation between muscle fat content and fat loss.

The water holding capacity (WHC), and thus the liquid loss, of muscle is regarded as an essential quality parameter and a high WHC is of great importance both to the industry and the consumer. Variations in liquid and water loss were significant ($P < 0.05$), as shown in Table 1. Initially, the liquid loss of grouper fillets was 12.69% and increased to 23.39% at the end day of storage (day 14). Similar results were found for water loss (WL) of fillets and it remained unchanged at first 7 days ($P > 0.05$) and then sharply increased ($P < 0.05$) until day 14. It was well documented that the liquid-holding capacity of raw muscle decreased with the storage time for several fish species including wild and farmed gilthead sea bream (Attouchi and Sadok 2010) Atlantic salmon (Rørå et al. 2003) and rainbow trout (Mørkøre et al. 2002). The LHC variations were reported to be related to muscle pH increase (Kristoffersen et al. 2006), detachment of sarcolemma, gaps in the extra-cellular matrix, widening of the intermyofibrillar space, and transversal shrinkage of the muscle fibres (Olsson et al. 2003a) and other factors such as ionic strength, and temperature (Ofstad et al. 1995; Olsson et al. 2003b). In the present study, variations in WHC may be explained by the increasing of pH values (Table 1), gaps in the extra-

Fig. 2 Micrographs of grouper tissues during refrigerated storage. Number below figures shown storage time (days)

cellular matrix, widening of the intermyofibrillar space, and transversal shrinkage of the muscle fibres as shown in Fig. 2.

Microstructure assessment The Fig. 2 shows the microstructure of grouper fillets during refrigerated storage. The muscle fibres of control samples (day 0) demonstrated relatively uniform and regular shapes of the cross section. The slightly extra-cellular space and fibre shrinking were observed after 7 days of storage in comparison to control. These items increase during storage and a deterioration of per-cellular connective tissue was visible after 14 days of storage. In fact, it was very difficult to recognize the muscle fibres after 14 days. The increase of myofibre–myofibre detachments with storage time found in our study is in agreement with results of Bahuaud et al. (2008), Ofstad et al. (2006), and Taylor et al. (2002). The changes at myofibrils structure are due to natural degradation from proteases and micro-organisms (Chéret et al. 2005). The effects of proteolysis breakdown are often related to extensive softening of the tissue. Similar results were also observed at sea bass during storage at 4 °C (Chéret et al. 2005).

Microbial assessment Microbial activity is responsible for spoilage of most fresh fish products. The shelf life of fish products, therefore, is markedly extended when products are stored at low temperatures. Total mesophilic count (TMC) and psychrotrophic count (TPC) were used as microbial indices to evaluate the microbiological quality of grouper fillets during refrigerated storage. Changes at TVC and TPC are shown in Fig. 3. The initial number of bacteria was low: it indicated that fish used in this study

was good. The initial value of TVC (2.81 log cfu/g) was also higher than TPC (1.09 log cfu/g) and showed that fish from tropical and subtropical regions are dominated initially by mesophilic bacteria. Both groups of bacteria increased in number during storage ($P < 0.05$) but TPC increasing was higher than TMC in the final days of storage. On day 10 of storage, TMC and TPC were 6.15 and 7.25, respectively. If 10^7 micro-organisms/g are considered as limiting level of acceptability, the shelf life of grouper was approximately 8–9 days, indicating that sensory analysis of groupers correlated well with microbiological analysis. Microbial analysis was also in agreement with chemical and microstructure analysis. Similar results were reported by Özogul et al. (2008) for wild white grouper and Koutsoumanis and Nychas (1999) for Mediterranean Bogue.

Fig. 3 Changes in total mesophilic (TMC) and psychrophilic counts (TPC) of grouper during refrigerated (+4 °C) storage ($n=3$)

Conclusions

The effects of refrigerated storage (+4 °C) on microbiological, chemical, sensory and microstructure properties of grouper (*Epinephelus coioides*) were studied. Grouper stored in refrigerator (+4 °C) as sensory, and microbiological results showed that days 5–6 was the beginning of spoilage and the samples were unfit for human consumption after 9 days. Microstructure observation showed that extra-cellular space and fibre shrinking increase after 7 days of storage. In the present study, TMC values remained under the limited acceptability (10^7 cfu/g) until the end day of storage (day 14) and it seems that TMC can not be considered as a good microbial spoilage index during refrigerated storage of the grouper. Sensory, physicochemical, microstructure and microbial analysis showed that the shelf life of grouper is approximately 8–9 days during storage in refrigerator.

Acknowledgements This study is supported by Persian Gulf and Oman Sea Ecological Research Institute and University of Zabol. The authors also are grateful to Y. Aftabsavar, R. Karimzade, M. Malekouti, A. Heidari and M. Naderi for their valued assistance.

References

- Alasalvar C, Taylor KDA, Öksüz A, Garthwaite T, Alexis MN, Grigorakis K (2001) Freshness assessment of cultured sea bream (*Sparus aurata*) by chemical, physical and sensory methods. *Food Chem* 72:33–40
- Alizadeh E, Chapleau N, De Lamballerie M, Le-Bail A (2007) Effect of different freezing processes on the microstructure of Atlantic salmon (*Salmo salar*) fillets. *Innov Food Sci Emerg Technol* 8:493–499
- AOAC (1995) Official methods of analysis, 16th edn. Association of Official Analytical Chemists, Arlington
- Attouchi M, Sadok S (2010) The effect of powdered thyme sprinkling on quality changes of wild and farmed gilthead sea bream fillets stored in ice. *Food Chem* 119:1527–1534
- Bahuaud D, Mørkøre T, Langsrud Ø, Sinnes K, Veiseth E, Ofstad R, Thomassen MS (2008) Effects of −1.5 °C Super-chilling on quality of Atlantic salmon (*Salmo salar*) pre-rigor Fillets: cathepsin activity, muscle histology, texture and liquid leakage. *Food Chem* 111:329–339
- Chéret R, Chapleau N, Delbarre-Ladra Ch, Verrez-Bagnis V, de Lamballerie M (2005) Effects of high pressure on texture and microstructure of sea bass (*Dicentrarchus labrax*) fillets. *Food Sci* 70:477–483
- Chomnawach C, Yongsawatdigul J, Thawornchinsombut S, Tungkawachara S (2007) Chemical and biochemical changes of hybrid catfish fillet stored at 4 °C and its gel properties. *Food Chem* 103:420–427
- Chotimarkorn Ch (2011) Quality changes of anchovy (*Stolephorus heterolobus*) under refrigerated storage of different practical industrial methods in Thailand. *J Food Sci Technol*. doi:10.1007/s13197-011-0505-y
- De Koning AJ (2001) Quantitative quality tests for fish meal. An investigation of the quality of South African fish meals and the validity of a number of chemical quality indices. *Int J Food Proper* 4(3):501–502
- Dey SS, Dora KC (2010) Effect of sodium lactate as cryostabilizer on physico-chemical attributes of croaker (*Johnius gangeticus*) muscle protein. *J Food Sci Technol* 47:432–436
- Erkan N (2007) Sensory, chemical, and microbiological attributes of sea bream (*Sparus aurata*): effect of washing and ice storage. *Int J Food Proper* 10:421–434
- Fan W, Chi Y, Zhang A (2008) The use of a tea polyphenol dip to extend the shelf life of silver carp (*Hypophthalmichthys molitrix*) during storage in ice. *Food Chem* 10:148–153
- Hebard CE, Flick GJ, Martin RE (1982) Occurrence and significance of trimethylamine oxide and its derivatives in fish and shellfish. In: Martin RE, Flick GJ, Hebard CE, Ward DR (eds) Chemistry and biochemistry of marine food products. Avi, Westport, pp 149–304
- Hermansson AM (1986) Water- and fat holding. In: Mitchell JR, Ledward DA (eds) Functional properties of food macromolecules. Elsevier, London, pp 273–314
- Huss HH (1988) Fresh fish: quality and quality changes. Food and Agriculture Organization (FAO) of the United Nations, Rome
- Jeyasekaran G, Maeswari K, Ganesan P, Jeya Shakila R, Sukumar D (2005) Quality changes in ice stored tropical wire-netting reef cod (*Epinephelus merra*). *J Food Process Preserv* 29:165–182
- Kılınc B, Çaklı Ş, Kışla D (2003) Quality changes of sardine (*Sardina pilchardus* W., 1792) during frozen storage. *Eur J Fish Aqua Sci* 20:139–146
- Koutsoumanis K, Nychas GE (1999) Chemical and sensory changes associated with microbial flora of Mediterranean Bogue (*Boops boops*) stored aerobically at 0, 3, 7, and 10 °C. *Appl Environ Microbiol* 65:698–706
- Kristoffersen S, Tobiassen T, Esaïassen M, Olsson GB, Godvik LA, Seppola MA (2006) Effects of pre-rigor filleting on quality aspects of Atlantic cod (*Gadus morhua* L.). *Aquac Res* 37:1556–1564
- Liu Sh, Fan W, Zhong S, Ma Ch, Li P, Zhou K, Peng Zh, Zhu M (2010) Quality evaluation of tray-packed tilapia fillets stored at 0 °C based on sensory, microbiological, biochemical and physical attributes. *Afr J Biotech* 9:692–701
- Losada V, Pineiro C, Barros-Velázquez J, Aubourg S (2005) Inhibition of chemical changes related to freshness loss during storage of horse mackerel (*Trachurus trachurus*) in slurry ice. *Food Chem* 93:619–625
- Luo Z, Liu YJ, Kai KS, Tian LX, Liu DH, Tan XY, Lin HZ (2005) Effect of dietary lipid level on growth performance, feed utilization and body composition of grouper *Epinephelus coioides* juveniles fed isonitrogenous diets in floating net cages. *Aquac Res* 13:257–269
- Luten JB, Martinsdottir E (1997) QIM—a European tool for fish freshness evaluation in the fishery chain. In: Ólafsdóttir G, Luten J, Dalgaard P, Careche M, Verrez-Bagnis V, Martinsdóttir E, Heia K (eds) Methods to determine the freshness of fish in research and industry. Proceedings of the Final Meeting of the Concerted Action “Evaluation of Fish Freshness”, AIR3CT94 2283 (FAIR Programme of the EU) Nantes Conference, November 12–14. Paris, International Institute of Refrigeration
- Mørkøre T, Hansen AA, Unander E, Einen O (2002) Composition, liquid holding capacity and mechanical properties of farmed rainbow trout: variation between fillet sections and the impact of ice and frozen storage. *J Food Sci* 67:1933–1938
- Munasinghe DMS, Ohkubo T, Sakai T (2005) The lipid peroxidation induced changes of protein in refrigerated yellowtail minced meat. *Fish Sci* 71:462–464
- Ofstad R, Kidman S, Myklebust R, Olsen RL, Hermansson AM (1995) Liquid holding capacity and structural changes in

- comminuted salmon (*Salmo salar*) muscle as influenced by pH, salt and temperature. LWT-Food Sci Technol 28:329–339
- Ofstad R, Olsen RL, Taylor R, Hannesson KO (2006) Breakdown of intramuscular connective tissue in cod (*Gadus morhua* L) and spotted wolffish (*Anarhichas minor* O.) related to gaping. LWT-Food Sci Technol 39:1143–1154
- Olsson GB, Olsen RL, Ofstad R (2003a) Post-mortem structural characteristics and water-holding capacity in Atlantic halibut muscle. LWT-Food Sci Technol 36:125–133
- Olsson GB, Olsen RL, Carlehog M, Ofstad R (2003b) Seasonal variation in chemical and sensory characteristics of farmed and wild Atlantic halibut (*Hippoglossus hippoglossus*). Aquaculture 217:191–205
- Özogul F, Polat A, Özogul Y (2004) The effects of modified atmosphere packaging and vacuum packaging on chemical, sensory and microbiological changes of sardines (*Sardina pilchardus*). Food Chem 85:49–57
- Özogul Y, Özyurt G, Özogul F, Kuley E, Polat A (2005) Freshness assessment of European eel (*Anguilla anguilla*) by sensory, chemical and microbiological methods. Food Chem 92:745–751
- Özogul A, Özogul F, Kuley E, Özkutuk AS, Gokbulut C, Kose S (2006) Biochemical, sensory and microbiological attributes of wild turbot (*Scophthalmus maximus*), from the Black Sea, during chilled storage. Food Chem 99:752–758
- Özogul F, Özogul Y, Kuley E (2008) Nucleotide degradation and biogenic amine formation of wild white grouper (*Epinephelus aeneus*) stored in ice and at chill temperature (4 °C). Food Chem 108:933–941
- Özyurt G, Kuley E, Özkütük S, Özogul F (2009) Sensory, microbiological and chemical assessment of the freshness of red mullet (*Mullus barbatus*) and goldband goatfish (*Upeneus moluccensis*) during storage in ice. Food Chem 114:505–510
- Pons-Sánchez-Cascado S, Vidal-Carou MC, Nunes ML, Verciana-Nogués MT (2006) Sensory analysis to assess the freshness of Mediterranean anchovies (*Engraulis encrasicolus*) stored in ice. Food Control 17:564–569
- Reza MdS, Bapary MAJ, Ahasan CT, Islam MdN, Kamal Md (2008) Shelf life of several marine fish species of Bangladesh during ice storage. Int J Food Sci Technol 44:1485–1494
- Rodríguez Ó, Losada V, Aubourg SP, Barros-Velázquez J (2004) Enhanced self-life of chilled European hake (*Merluccius merluccius*) stored in slurry ice as determined by sensory analysis and assessment of microbiological activity. Food Res Int 37:749–757
- Rørå AMB, Regost C, Lampe J (2003) Liquid holding capacity, texture and fatty acid profile of smoked fillets of Atlantic salmon fed diet containing fish oil or soybean oil. Food Res Int 36:231–260
- Sharifian S, Zakipour E, Mortazavi MS, Arshadi A (2011) Quality assessment of tiger tooth croaker (*Otolithes ruber*) during ice storage. Int j Food Proper 14:309–318
- Stansby ME (1962) Proximate composition of fish. In: Heen E, Kreuzer R (eds) Fish in nutrition. Fishing News Books Ltd, London
- Taylor RG, Fjæra SO, Skjervold PO (2002) Salmon fillet texture is determined by myofiber–myofiber and myofiber–myocommata attachment. J Food Sci 67:2067–2071
- Vyncke W (1981) pH of fish muscle: comparison of methods. 11th Western European Fish Technologists' Association (WEFTA) Meeting, Copenhagen, Denmark
- Whittle K, Hardy R, Hobbs G (1990) Chilled fish and fishery products. In: Gormley T (ed) Chilled foods. Elsevier Applied Science, New York, pp 87–116