# 7 Effects of nutrition and aquaculture practices on fish quality

Kriton Grigorakis

## 7.1 Introduction

The term fish quality is defined by a group of various factors. These include:

1) appearance, shape, size, and external look (colour, malformations, and injuries);
2) nutritional value;
3) fat deposition;
4) organoleptic characteristics (odour, taste, and texture);
5) freshness; and
6) filleting yield.

It is often difficult to outline the way that quality is affected by feeding, due to numerous endogenous and exogenous factors that influence quality simultaneously. In the endogenous factors, size, sex, stage of life cycle, and genetic factors are included. The exogenous factors include feeding, fish population crowding, temperature, salinity, physical exercise of the fish, and sources of external stress. A multifactorial analysis including nutritional and environmental parameters showed clearly that the effects of feeding on fish quality strongly depended on the environmental factors and that the interaction of feeding and environment actually defined the final results [1]. Despite the complicated interactions, the ability still exists to relate feeding to the produced quality and at the next level to tailor quality through feeding. This chapter attempts to outline the effects of feeding and aquaculture handling on fish quality and to examine to what extent the quality of the end-product can be manipulated.

## 7.2 The role of muscle composition and fat deposition in fish quality

The edible part of the fish is actually the fillet. Therefore, the fillet composition is what defines the fish quality. Fish store energy as fat to be utilised when needed. Fat is abundant

*Handbook of Seafood Quality, Safety and Health Applications*
Edited by Cesarettin Alasalvar, Fereidoon Shahidi, Kazuo Miyashita and Udaya Wanasundara
ISBN: 978-1-405-18070-2

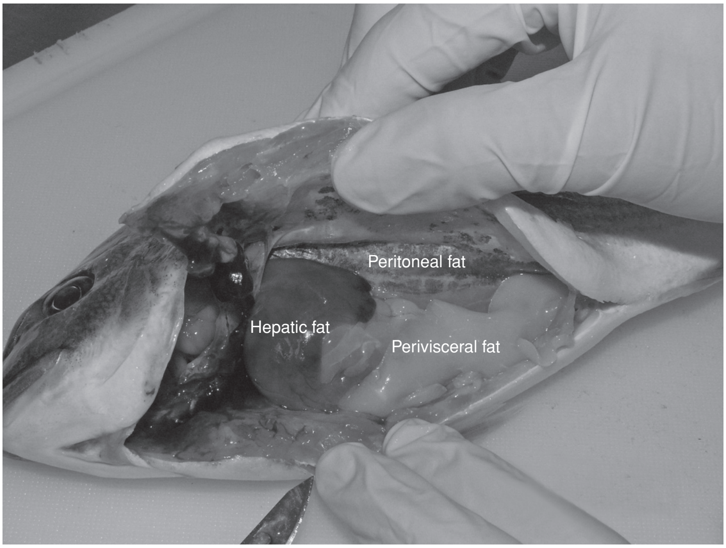

**Fig. 7.1** Anatomy of gilthead sea bream – forms of deposited fat, excluding muscle fat that is not visible. For a colour version of this figure, please see the colour plate section.

in four deposited forms:

1) the liver or hepatic fat;
2) the muscle fat;
3) the perivisceral fat (also termed as visceral fat or mesenteric fat); and
4) the peritoneal fat, deposited around the peritoneum (Fig. 7.1).

The distribution of these fat deposits mainly depends on the fish species. The three forms of fat (muscle, perivisceral, and peritoneal) are important in terms of fish quality. The role of these fat deposits in fish quality is summarised in Table 7.1. Muscle protein content may not have the prime importance of fat, but also contributes to the sensory quality through water-interacting proteins. Also, in cases of long-term fasting, when losses of muscle protein occur, the cooked flesh becomes soft with reduced cohesiveness [2]. Another important quality parameter with respect to the nutritional value of proteins is the amino acid composition and, in particular, the essential to total amino acids ratio. Non-protein nitrogen (NPN) is another important qualitative determinant in fish. NPN contributes 9 to 18% of the total nitrogen in teleost fish. It mainly consists of volatile bases, creatine, creatinine, free amino acids, nucleotides, and purines. Volatile nitrogen plays an important role in the organoleptic properties of the fish, since it contributes to its flavour and odour [3].

## 7.3 Effect of feeding and aquaculture practices on quality characteristics

### 7.3.1 Feeding and its impact on fish fat

Feeding has a key role in the quality of the aquacultured fish. Generally, fat deposits increase with weight irrespective of the feeding; for example, larger fish tend to have higher lipid

**Table 7.1** Roles of fat deposits in fish quality

| Fat form | Quality attribute | Role of fat in quality |
|---|---|---|
| Muscle fat | Taste | Fats have slight taste themselves. |
| | Flavour | Lipid-derived volatile compounds characterise fish flavour and spoilage off-flavour. |
| | Mouth sensation | Tissue becomes softer, fattier, and juicier when fat increases. A 1–2% fat increase drastically changes the quality on non-fatty fish (e.g. halibut), while in fatty species (e.g. salmon) it has negligible impact. |
| | Texture | Decrease of firmness when fat increases. |
| | Nutritional value | Increase of PUFA contents is related to health benefits: reduction of heart diseases and inflammatory diseases, contribution against some forms of cancer, and significant role in embryonic brain development. |
| Perivisceral fat | Visual sense | Increased quantity negatively affects consumers' impression about the fish when fish commercialised as whole ungutted. |
| | Smell | Characteristic, strong, and not pleasant smell of perivisceral fat. |
| Peritoneal fat | Taste or flavour | Unknown impact, since this fat form is consumed together with the fish fillet. |

content. This has already been shown for gilthead sea bream [4], eel [5], catfish species [6], carp [7], and salmonids [8–10].

#### 7.3.1.1 *Feeding intensity and dietary fat*

The seasonal differences in fish fat deposits in Nature occur, beyond the sexual maturation process, due to different feeding intensity throughout the year. In feeding intensity, seasonal differences exist because of lower food availability in the cold months and also due to reduced metabolism when water temperatures decrease. This metabolism reduction is confirmed, even for intensively aquacultured fish, where feed availability is not an issue.

The impact of feeding on fat deposits depends, to a large extend, on the species of interest (Table 7.2). Thus, there is a preferable deposition in the muscle fat for certain species, such as flatfish [13,34], while other species, such as perch, preferably accumulate fat in the peritoneum [28]. Some species also follow a completely different pattern of fat deposition, such as cod that tend to accumulate the dietary fat almost exclusively as liver fat [26,35], and the adult eel, where feeding seems to have almost negligible impact because main muscle fat deposition occurs earlier during its development [5]. However, contradictory results have been found, even within the same species, with respect to the effects of feeding rate, dietary lipids, and starvation, in the fish fat deposits. The main reason is the variability of the experimental conditions. Most studies focus on the results of a dietary treatment under specific or stable environments and in these cases the environmental impact is not obvious.

In most cases, increase of feeding rate and dietary fat leads to increased muscle and perivisceral fat. In salmonids, it was shown that leaner fish were obtained when the feeding rate was reduced, even when referring to high fat feeds [9,18]. This indicates that the feeding rate in salmonids plays a more important role in fat deposition than the dietary fat.

Each aquaculture fish species has its own energy needs and thus its own dietary lipid needs. When dietary lipids exceed these limits, the result is an excessive fat deposition.

**Table 7.2** Effects of various feeding treatment on the fat depots of various aquacultured fish species. All effects refer to the end-product quality

| Species | Feeding manipulation | Effects on muscle fat | Effects on visceral/peritoneal fat | Remarks | Reference |
|---|---|---|---|---|---|
| Gilthead sea bream (*Sparus aurata*) | Increase of dietary fat | Muscle fat unchanged | Increase of perivisceral and peritoneal fat | *Ad libitum* feeding, dietary fat 10–20% | [11] |
| | Increase of feeding ratio | Increase of muscle fat | | | [11,12] |
| | Comparative feeding with pelleted and extruded diet | Increased muscle fat in fish received the extruded diet | | Extruded diet with lower fat levels | [13] |
| | 3-week starvation | Decrease of muscle fat | No reduction of perivisceral fat | | [4] |
| Sea bass (*Dicentrarchus labrax*) | Increase of dietary fat | Increase of muscle fat | Increase of perivisceral and peritoneal fat | Dietary fat 11–19% | [14] |
| | 60 days starvation | | Reduction of perivisceral fat | | [15] |
| Sunshine bass (*Morone chrysops x M. saxatilis*) | Increase of dietary fat | Small increase of muscle fat | Increase of perivisceral fat | Dietary fat 9–17% | [16] |
| Atlantic salmon (*Salmo salar*) | Increase of dietary fat | Increase of muscle fat or negligible effect | Higher increase of perivisceral fat | Dietary fat 21–30% | [17,18] |
| | Increase of feeding ratio | Significant increase of muscle fat | No effect (increase in other cases) | | [10,19] |
| | Increase of dietary carbohydrates | Increase of muscle fat | Increase of perivisceral fat | For given dietary fat level | [20] |
| | 3–86 days starvation | | No effect | | [19] |
| Pacific salmon (*Oncorhynchus tshawytscha*) | Increase of dietary fat | Increase of muscle fat | Increase of deposit fat | | [21] |
| | Increase of feeding ratio | No effect | No effect | | [22] |

(*Continued*)

**Table 7.2** (*Continued*)

| Species | Feeding manipulation | Effects on muscle fat | Effects on visceral/peritoneal fat | Remarks | Reference |
|---|---|---|---|---|---|
| Rainbow trout (*Oncorhynchus mykiss*) | Increase of dietary lipid + increase of its feeding duration | Increase of muscle fat | Increase of perivisceral fat (higher than muscle fat) | Dietary fat 19–31% | [23] |
| | Increase of feeding ratio | | No effect in perivisceral fact | | [9] |
| | 61 days starvation | Intensive decrease of muscle fat | Moderate decrease of perivisceral fat | | [23] |
| | 2–3 months starvation | Small decrease | decrease of perivisceral fat | | [9] |
| Brown trout (*Salmo trutta*) | Increase of dietary fat | Increase of muscle fat (higher than in perivisceral fat) | Increase in perivisceral fat | Triploid fish<br>Dietary fat 11–26% | [24] |
| | 8 weeks starvation | Decrease of muscle fat | Perivisceral fat unchanged | Triploid fish | [24] |
| Atlantic halibut (*Hippoglossus hippoglossus* L.) | Increase of dietary fat | Higher increase of muscle fat | Increase of perivisceral fat | | [25] |
| | Increase of pellet size | Small increase of muscle fat | | Pellet diameters 16–27 mm | [25] |
| Cod (*Gadus morhua*) | Increase of dietary fat | Negligible effect | Negligible effect | Increase of liver fat | [26] |
| White fish (*Coregonus lavaretus*) | Increase of dietary fat | Increase of muscle fat | Increase of perivisceral fat | Dietary fat 12 and 27.5% | [27] |
| Eurasian perch (*Perca fluviatilis*) | Increase of dietary fat | Minimum effect in muscle fat | Mainly increase of perivisceral fat | | [28] |
| European eel (*Anguilla anguilla*) | Increase of dietary fat | No alteration in fat depots | | | [5] |

| | | | | | |
|---|---|---|---|---|---|
| Carp (*Cyprinus carpio*) | Increase of dietary fat | Increase of muscle fat | Increase of perivisceral fat | | [7] |
| | Increase of feeding rate | Increase of muscle fat | Increase of perivisceral fat | | [7] |
| | Starvation | Decrease of muscle fat | | | [29] |
| European catfish (*Silurus glanis*) | Natural feeding vs. industrial feed | Higher muscle fat in fish receive industrial diet | No alteration in perivisceral fat | Feeding *ad libitum*, in tanks. | [30] |
| Channel catfish (*Ictalurus punctatus*) | Increase of dietary fat | Increase of muscle fat | | | [6] |
| | Increase of feeding rate | Increase of muscle fat | Increase of total deposit fat | Restricted feeding vs. *ad libitum* | [3] |
| African catfish (*Clarias gariepinus*) | Increase of dietary fat | Muscle fat unchanged | Increase of perivisceral fat | Dietary fat 8 and 13% | [32] |
| Blue catfish (*Ictalurus furcatus*) | Increase of dietary protein from 27–36% | Significant increase of muscle fat | Unchanged perivisceral fat | | [33] |

Thus, in gilthead sea bream, where the optimum dietary fat level is 15%, feeds with 20% lipid significantly increase fat deposition. Sea bass, on the other hand, exhibiting a more carnivorous feeding behaviour, is better adapted to the higher fat feeds and has much better quality characteristics when receiving them [36]. The salmonids, in general, are better accustomed to feeds with even higher lipid contents, where dietary fat reaches 30% [9].

Limited information is available on the exact impact of various protein levels and of dietary carbohydrates in fish quality. However, the optimum protein levels for achieving a good quality product depend on the fish needs in the way they are dictated by their nature. These requirements are lower for herbivorous and omnivorous species and higher for carnivorous species. In general, increase of dietary protein in isoenergetic diets (e.g. same lipid) often leads to a higher muscle fat [28]. With respect to carbohydrates, fish have negligible requirements, with few exceptions. In feeds, carbohydrates are used as low-cost energy sources and as binders to ensure cohesion of the feed pellet in the water. Increase of digestible dietary carbohydrates in the diet leads to a higher fat deposition [7,20].

There are indications that dietary treatments may also affect the fatty acid composition of the muscle. A well-established rule is that muscle fatty acids of the fish reflect the dietary fatty acids, and this has been confirmed for most of the aquacultured fish species, including salmonids [9,37], Mediterranean species [36,38], carps [7], cod [35], catfish species [6], and flatfish [34]. Therefore, manipulation of the fatty acid profile of the end-product can be achieved.

In salmonids, there were cases that showed a decrease of docosahexaenoic acid (DHA, 22:6 n-3) and omega-3 polyunsaturated fatty acids (PUFA), and a respective increase of monounsaturated fatty acids (MUFA) when feeding rate increased [8]. In gilthead sea bream and sea bass, there were indications of positive correlation between dietary fat and the omega-3 levels [36].

#### 7.3.1.2 *Fish oil substitution*

Due to the sustainability issues that the use of fish oils raises, there is a turn towards the use of plant oils in fish feeds. The result of dietary fish-oil substitution by plant oils is a change in fish fatty acid composition. In all cases, the most profound alterations in fish muscle are the decrease of eicosapentaenoic acid (EPA, 20:5 n-3) and DHA in net quantities, as well as the decrease of EPA/DHA and n-3/n-6 ratios [35,38]. Reduction of arachidonic acid (ARA, 20:4 n-6) was also observed in the cases of experimental substitution with soybean oil, rapeseed oil, sunflower oil, and linseed oil, but not in the case of substitution with olive oil [39,40]. The magnitude of these changes depends on the feeding period and the degree of the fish oil substitution [40–42].

#### 7.3.1.3 *Finishing diets*

Part of the research also focuses on the effects of the finishing diets on fish quality. Thus, re-feeding fish that previously received plant oils with diets containing fish oil retrieves, up to a great extent, the initial fatty acid profile. It is shown that a feeding period of 90 days with a fish oil-containing diet is adequate to restore almost fully the initial muscle fatty acids in both gilthead sea bream and sea bass. However, EPA cannot be recovered, even within a longer period (150 days) [40,41]. However, in red sea bream (*Pagrus auratus*), linoleic acid (18:2 n-6) is the fatty acid that is not easily restored [38]. Atlantic salmon that previously received vegetable oils fully restored the omega-3 PUFA when fed with fish-oil finishing diets [43]. Finishing diets have also been effectively used for freshwater aquacultured fish such as carp and tench (*Tinca tinca*) [44]. Beyond the inter-species differences, the recovery changes depend on the plant oil that has been previously used. Thus, red sea bream that was previously fed on soybean-oil retrieved EPA quicker than fish previously fed on canola oil [38]. Finally, there are indications that fatty acid recovery also depends on fish size and that larger fish tend to have slower fatty acids recovery [38].

#### 7.3.1.4 *Fasting*

During fasting, there are different fat deposits mobilisation patterns in different species (Table 7.2). Water temperature also seems to influence the fasting effects for most of the aquacultured species [9,15]. In addition, Rasmussen [9] has noted that mobilisation is dependent upon the genetic pool of the fish, fish density, and water salinity. The previous feeding history also seems to be important in determining the fasting impact [4,9]. Finally, the magnitude of the impact is found to depend on the duration of fasting. Usually, in custom aquacultural conditions, food deprivation occurs only for a few days, aiming at emptying the fish intestines, and has no effect in the fish fat depots. Furthermore, fasting can affect the muscle fatty acids. Thus, in some cases (e.g rainbow trout), a reduction in the relative MUFA is observed, while in others (e.g Atlantic salmon) there is an increase or no impact in the MUFA level [9]. In farmed sea bass, a two-month food deprivation showed reduction of saturated fatty acids (SFA), especially 17:0, and retained the total PUFA, but was accompanied with a reduction in EPA, as well as formation of 20:2 n-6 as a 18:2 n-6 elongation product [45].

#### 7.3.1.5 *Factors other than feeding that affect fish fat*

Since most of the existing research focuses on feeding, less data are available on other factors that may be employed to manipulate fish fat. Genetic predetermination in fish fat deposition has been shown in various cases [6,9]. The degree of exercise seems also to be a determinant of muscle fat in salmonids [9]. Moreover, environmental factors including salinity and water temperature are found to influence both fat deposition and fatty acid composition [46].

### 7.3.2 Feeding and handling: effect on muscle protein/amino acids

Under normal situations, the levels of muscle protein remain unchanged in organisms that have completed their development (adults). With respect to the amino acid composition, factors such as salinity and season seem to exert an effect [36]. Contradictory data about the effect of feeding on muscle amino acids have appeared in salmonids [47], but not in other species such as carp [7].

### 7.3.3 Feeding and aquaculture handling: effects on colour

The colouration of skin and flesh is clearly related to the feeding of the organism. Thus, carotenoid intake, to a great extent, defines the colour of the fillet. Astaxanthin and castaxanthin absorption in salmonids and the dietary factors that affect it have been reviewed in the literature [37,48]. Mathematical modelling of salmon pigmentation also occurs [49].

Beyond the dietary carotenoids, the colour of fish fillet is related to feeding due to the impact of the fat content. Elevated muscle fat is accompanied by a more whitish appearance of the flesh. Flesh colour is also related to aquaculture practices and specifically the rearing temperature [50]. External colouration of the fish depends on fish feeding practices. Thus, the external colouration of gilthead sea bream can be manipulated through various dietary carotenoid sources [51], and has also been noted to alter with fasting [4]. One of the most important problems in external colouration is that of red porgy (*Pagrus pagrus*), which under aquaculture conditions become grey. Although the exact nature of the problem is still unknown, an improved colouration has been achieved through dietary carotenoids [52].

### 7.3.4 Feeding and body shape

Beyond colouration, feeding also affects the body shape of the fish. In Atlantic salmon, rainbow trout, and gilthead sea bream, reduced feeding rates or fasting result in a more spindle-shaped body [4,19]. However, the body shape seems rather genetically predetermined than regulated by feeding. Thus, geometrical modelling in gilthead sea bream shows that fish derived from different hatcheries and therefore genetically different, can be distinguished based on their morphometry, even if they have been raised at the same farms and under identical feeding conditions [53].

### 7.3.5 Feeding and effect on taste and flavour

Besides the impact of feeding on fillet fat, which in turn affects its taste and flavour, the effects of feeding in the formation of taste and flavour is not very distinct. Most existing studies do not find any quality differences between fish that have been fed with diets containing various fish meal substitutes, mostly of plant origin. However, there are some exceptions, where organoleptic differences have been found in gilthead sea bream that have received diets with soy meal at high substitution levels. The latter has been found to have a less pronounced "seaweed" flavour than the fish receiving fish meal diets. These differences can possibly be justified as free amino acid differences or generally as NPN differences [42].

Organoleptic differences often occur between fish that have received different fish oils or fish receiving different plant oils. These differences are more pronounced for higher plant oil inclusion levels [54]. This is due to the different fatty acids of the diets, since fatty acids are primers for a large number of volatiles characterising fish flavour [55]. A direct correlation of dietary lipids [56], or dietary sulphur-containing amino acids [57], to the flavour compounds of the fish seems to occur in some cases. However, to what extent a dietary control can be achieved remains unknown.

### 7.3.6 Dietary and handling impacts on texture

As already mentioned, muscle fat increase results in a softer and less firm texture [2,36]. There are observations in salmonids, positively relating hypertrophy (diameter increase) and hyperplasia (number increase) of muscle fibre to the growth rate [9]. Since the number and distribution of muscle fibres defines the texture and in particular the hardness of muscle [3], any treatment that affects the growth rate can have an impact on muscle texture and this has been confirmed for salmon [58]. However, some contradicting results also exist, such as those in Atlantic halibut, where no dietary impact on the distribution and generation of muscle fibres was found [34].

Starvation seems to be the treatment with the most pronounced impact on fish muscle texture. In some cases, short-time fasting improves the texture, producing a firmer muscle

[9], while in other cases reduction of feeding or prolonged starvation results in reduced firmness and increase of moistness and sweating of muscle [2,24]. Besides the dietary effects, rearing temperatures have been found to affect textural characteristics, with softer and less elastic flesh observed for fish reared at lower temperatures [50].

### 7.3.7 Impact of aquaculture handling and killing procedure on post-mortem quality

Seasonality has been observed with respect to the post-mortem quality of fish [59,60]. In general, temperate-water fish in summer appear to have a slightly better quality. A possible explanation could be that summer elevated temperatures can result in a longer microbial lag phase due to the stronger thermal shock of the microflora when placed in ice. Further to the seasonality, the life history of the fish seems to play an important role in the post-mortem quality; a direct relationship of culture conditions to fish freshness has been indicated [12].

Both the pre-slaughter conditions and the killing procedures affect the post-mortem quality of fish. Crowding stress results in longer struggling during killing, earlier rigor mortis onset, and more intense and shorter rigor mortis [61,62]. The impact of the killing method on the post-mortem quality is related to the amount of stress the fish receives. A stressful killing method, such as asphyxia, usually results in reduced post-mortem quality, organoleptically expressed as a low flavour score [59]. Most of the killing procedures tested fail to show any particular quality advantage [9,63]. However, there are indications that rapid killing methodologies, such as spiking the brain, can result in longer shelf-life in some cases [63]. Some results for Mediterranean fish species show improved quality with slurry ice-killing over the classic ice-killing [64], while others find practically no difference [65]. However, cloudy eyes have been mentioned as a negative impact of the use of slurry ice [65].

### 7.3.8 Effect of feeding on post-mortem quality and technological properties

An important feeding factor that can affect the post-mortem quality of fish is the dietary fatty acids, since PUFA are more susceptible to lipid oxidation. Thus, rancidity can be more pronounced for fish that have been fed higher levels of omega-3 fatty acids [66]. A dietary treatment with the aim of improving post-mortem quality is the use of various antioxidants in the diet, such as tocopherols and astaxanthine. Although results are generally contradictory, a better oxidative stability has been observed in fish receiving high dietary vitamin E [66]. There are indications that short-time fasting, applied in the aquaculture practice (1–2 days), leads to better preservation due to reduction of peptic enzymes in the intestine and consequently slower autolytic action [67].

The impact of feeding on flesh lipid also affects the ability to fillet and to process the fish thermally. In salmon, increase of the feeding rate and dietary fat induces the post-mortem gaping of the fish fillet [9,19,68]. Fish that have received diets with soybean oil at high substitution levels show less gaping than fish receiving fish oils [35]. The fillet gaping is a serious technological problem, especially in smoked fillet production, and it has been related to low post-mortem pH and its impact on the connective tissues [2]. Therefore, it is directly related to the nutritional status of the fish, but also to the stress the fish might have received prior to killing and depletion of the glycogen reserves [9].

## 7.4 Conclusions

Although the relationships between feeding and quality are complicated due to the impact of extrinsic factors, some manipulation of the end-product quality can be achieved though feeding and handling. Thus, fat deposition in the fillet can be regulated through dietary lipid, feeding ration size, and fasting. The most profound regulation that can be achieved through diet is that of the muscle fatty acids. Beyond these, skin and muscle colouration can be manipulated through the intake of dietary carotenoids. Post-mortem quality of the fish is highly affected by the amount of stress the fish receives through handling and during killing.

## References

1. Gardeur, J.N., Mathis, N., Kobilinsky, A. & Brun-Bellut., J. (2007). Simultaneous effects of nutritional and environmental factors on growth and flesh quality of *Perca fluviatilis* using a fractional factorial design study. *Aquaculture*, **273**, 50–63.
2. Love, R.M. (1992). Biochemical dynamics and the quality of fresh and frozen fish. In: *Fish Processing Technology*. Hall, G.M. (ed.), Blackie Academic, London, UK, pp. 1–30.
3. Venugopal, V. & Shahidi, F. (1996). Structure and composition of fish muscle. *Food Reviews International*, **12**, 175–197.
4. Grigorakis, K. and Alexis, M. (2005). Effects of fasting on the meat quality and fat deposition of commercial-size farmed gilthead sea bream (*Sparus aurata* L.) fed different dietary regimes. *Aquaculture Nutrition*, **11**, 341–344.
5. Luzzana, U., Scolari, M., Campo Dall'Orto, B., Turchini, G., Orban, E. & Sinesio, F. (2003). Growth and product quality of European eel (*Anguilla anguilla*) as affected by dietary protein and lipid sources. *Journal of Applied Ichthyology*, **19**, 74–78.
6. Fauconneau, B. & Laroche, M. (1996). Characteristics of the flesh and quality of products of catfishes. *Aquatic Living Resources*, **9**, 165–179.
7. Fauconneau, B., Alami-Durante, H., Laroche, M., Marcel, J. & Vallot, D. (1995). Growth and meat quality relations in carp. *Aquaculture*, **129**, 265–297.
8. Kiessling, A., Pickova, J., Johansson, L., Åsgård, T., Storebakken, T. & Kiessling, K.-H. (2001). Changes in fatty acid composition in muscle and adipose tissue of farmed rainbow trout (*Oncorhynchus mykiss*) in relation to ration and age. *Food Chemistry*, **73**, 271–284.
9. Rasmussen, R.S. (2001). Quality of farmed salmonids with emphasis on proximate composition, yield and sensory characteristics. *Aquaculture Research*, **32**, 767–786.
10. Jobling, M. & Johansen, S.J.S. (2003). Fat distribution in Atlantic salmon (*Salmo salar* L.) in relation to body size and feeding regime. *Aquaculture International*, **203**, 311–316.
11. Grigorakis, K. (1999). *Quality of Cultured and Wild Gilt-Head Sea Bream (Sparus aurata) and Sea Bass (Dicentrarchus labrax)*. PhD Thesis, University of Lincoln, Lincoln, UK.
12. Flos, R., Reig, L., Oca, J. & Ginovart, M. (2002). Influence of marketing and different land-based system on gilthead sea bream (*Sparus aurata*) quality. *Aquaculture International*, **10**, 189–206.
13. Aksnes, A., Izquierdo, M.S., Robaina, L., Vergara, J.M. & Montero, D. (1997). Influence of fish meal quality and feed pellet on growth, feed efficiency and muscle composition in gilthead sea bream. *Aquaculture*, **153**, 251–261.
14. Lanari, D., Poli, B.M., Ballestrazzi, R., Lupi, P., D'Agaro, E. & Mecatti, M. (1999). The effects of dietary fat and NFE levels on growing European sea bass (*Dicentrarchus labrax* L.). Growth rate, body and fillet composition, carcass traits and nutrient retention efficiency. *Aquaculture*, **179**, 351–364.
15. Pastoureaud, A. (1991). Influence of starvation at low temperatures on utilization of energy reserves, appetite recovery and growth character in sea bass, *Dicentrarchus labrax. Aquaculture*, **99**, 167–178.
16. Webster, C.D., Tiu, L.G., Tidwell, J.H., Van Wyk, P. & Howerton, R.T. (1995). Effects of dietary protein and lipid levels on growth and body composition of sunshine bass (*Morone chrysops* X *M. saxatilis*) reared in cages. *Aquaculture*, **131**, 291–301.

17. Bjerkeng, B., Refstie, S., Fjalestad, K.T., Storebakken, T., Rødbotten, M. & Roem., A.J. (1997). Quality parameters of the flesh of Atlantic salmon (*Salmo salar*) as affected by dietary fat content and full-fat soybean meal as a partial substitute for fish meal in the diet. *Aquaculture*, **157**, 297–309.
18. Hillestad, M., Johnsen, F., Austreng, E. & Åsgård, T. (1998). Long-term effects of dietary fat level and feeding rate on growth, feed utilization and carcass quality of Atlantic salmon. *Aquaculture Research*, **4**, 89–97.
19. Einen, O., Mørkøre, T., Rørå, A.M.B. & Thomassen., M.S. (1999). Feed ratio prior to slaughter – a potential tool for managing product quality of Atlantic salmon (*Salmo salar*). *Aquaculture*, **178**, 149–169.
20. Aksnes, A. (1995). Growth, feed efficiency and slaughter quality of salmon, *Salmo salar* L., given feeds with different ratios of carbohydrate and protein. *Aquaculture Nutrition*, **1**, 241–248.
21. Shearer, K.D., Silverstein, J.T. &. Dickhoff., W.W. (1997). Control of growth and adiposity of juvenile Chinook salmon (*Oncorhynchus tshawytscha*). *Aquaculture*, **157**, 311–323.
22. Kiessling, A., Higgs, D.A., Dosanjh, B.S. & Ealses, J.G. (1994) Influence of sustained exercise at two ration levels on growth and thyroid function of all-female chinook salmon (*Oncorhynchus tsawytscha*) in sea water. *Canadian Journal of Fisheries and Aquatic Sciences*, **51**, 1975–1984.
23. Rasmussen, R.S., Ostenfeld, T.H., Rønsholdt, B. & McLean, E. (2000). Manipulation of end-product quality of rainbow trout with finishing diets. *Aquaculture*, **6**, 17–23.
24. Regost, C., Arzel, J., Cardinal, M., Laroche, M. & Kaushig, S.J. (2001). Fat deposition and flesh quality in seawater reared, triploid brown trout (*Salmo trutta*) as affected by dietary fat levels and starvation. *Aquaculture*, **193**, 325–345.
25. Nortvedt, R. & Tuene, S. (1998). Body composition and sensory assessment of three weight groups of Atlantic halibut (*Hippoglossus hippoglossus*) fed three pellet sizes and three dietary fat levels. *Aquaculture*, **161**, 295–313.
26. Jobling, M., Knudsen, R., Pedersen, P.S. & Dos Santos, J. (1991). Effects of dietary composition and energy content on the nutritional energetics of cod, *Gadus morhua. Aquaculture*, **92**, 243–257.
27. Koskela, J., Jobling, M. & Savolainen, R. (1998). Influence of dietary fat level on feed intake, growth and fat deposition in the whitefish (*Coregonus lavaretus*). *Aquaculture International*, **6**, 95–102.
28. Mathis, N., Feidt, C. & Brun-Bellut, J. (2003). Influence of protein/energy ratio on carcass quality during the growing period of Eurasian perch (*Perca fluviatilis*). *Aquaculture*, **217**, 453–464.
29. Takeuchi, T., & Watanabe, T. (1982). Effects of various polyunsaturated fatty acids on growth and fatty acid compositions of rainbow trout (*Salmo gairdneri*), coho salmon (*Onchorhynchus kisutch*), and chum salmon (*Onchorhynchus keta*). *Nippon Suissan Gakaishi*, **48**, 1745–1752.
30. Jankowska, B., Zakeś, Z., Zmijewski, T., Ulikowski, D. & Kowalska, A. (2007). Slaughter value and flesh characteristics of European catfish (*Silurus glanis*) fed natural and formulated feed under different rearing conditions. *European Food Research & Technology*, **224**, 453–459.
31. Li, M. & Lovell, R.T. (1992). Comparison of satiate feeding and restricted feeding of channel catfish with various concentrations of dietary protein in production ponds. *Aquaculture*, **103**, 165–175.
32. Wedekind, H. (1995). Dietary influences on product quality in African catfish (*Clarias gariepinus*). *Journal of Applied Ichthyology*, **11**, 347–353.
33. Webster, C.D., Tiu, L.G., Tidwell, J.H., & Reed, E.B. Jr. (1995). Effects of feeding the repartitioning agent L644,969 on growth and body composition of blue catfish, *Ictalurus furcatus*, fed diets containing two protein levels reared in cages. *Aquaculture*, **134**, 247–256.
34. Haugen, T., Kiessling, A., Olsen, R.E., Rørå, M.B., Slinde, E. & Nortvedt, R. (2006). Seasonal variations in muscle growth dynamics and selected quality attributes in Atlantic halibut (*Hippoglossus hippoglossus* L.) fed dietary lipids containing soybean and/or herring oil under different rearing regimes. *Aquaculture*, **261**, 565–579.
35. Morkore, T., Netteberg, C., Johnson, L. & Pickova, J. (2007). Impact of dietary oil source on product quality of farmed Atlantic cod, *Gadus morhua. Aquaculture*, **267**, 236–247.
36. Grigorakis, K. (2007). Compositional and organoleptic quality of farmed and wild gilthead sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) and factors affecting it: A review. *Aquaculture*, **272**, 55–75.
37. Lie, Ø. (2001). Flesh quality – the role of nutrition. *Aquaculture Research*, **32**, 341–348.
38. Glencross, B.D., Hawkins, W.E. & Curnow, J.G. (2003). Restoration of the fatty acid composition of red sea bream (*Pagrus auratus*) using a fish oil finishing diet after grow-out on plant oil based diets. *Aquaculture Nutrition*, **9**, 409–418.

39. Mourente, G., Good, J.E. & Bell, J.G. (2005). Partial substitution of fish oil with rapeseed, linseed and olive oil in diets for European sea bass (*Dicentrarchus labrax* L.): effects on flesh fatty acid composition, plasma prostaglandins E2 and F2a, immune function and effectiveness of a fish oil finishing diet. *Aquaculture Nutrition*, **11**, 25–40.
40. Montero, D., Robaina, L., Caballero, M.J., Gines, R. & Izquierdo, M.S. (2005). Growth, feed utilization and flesh quality of European sea bass (*Dicentrarchus labrax*) fed diets containing vegetable oils: a time-course study on the effect of a re-feeding period with a 100% fish oil diet. *Aquaculture*, **248**, 121–134.
41. Izquierdo, M.S., Montero, D., Robaina, L., Caballero, M.J., Rosenlund, G. & Gines, R. (2005). Alterations in fillet fatty acid profile and flesh quality in gilthead sea bream (*Sparus aurata*) fed vegetable oils for long term period. Recovery of fatty acid profiles by fish oil feeding. *Aquaculture*, **250**, 431–444.
42. Martínez-Llorens, S., Moñino, A.V., Vidal, A.T., Salvador, V.J.M., Torres, M.P. & Cerdá, M.J. (2007). Soybean meal as a protein source in gilthead sea bream (*Sparus aurata* L.) diets: effect on growth and nutrient utilization. *Aquaculture Research*, **38**, 82–90.
43. Bell, J.G., Tocher, D.R., Henderson, R.J., Dick, J.R. & Crampton, V.O. (2003). Altered fatty acid compositions in Atlantic salmon (*Salmo salar*) fed diets containing linseed and rapeseed oils can be partially restored by a subsequent fish oil finishing diet. *Journal of Nutrition*, **133**, 2793–2801.
44. Steffens, W. & Wirth, M. (2007). Influence of nutrition on the lipid quality of pond fish: common carp (*Cyprinus carpio*) and tench (*Tinca tinca*). *Aquaculture International*, **15**, 313–319.
45. Delgado, A., Estevez, A., Hotrelano, P. & Alejandre, J. (1994). Analyses of fatty acids from different lipids in liver and muscle of sea bass (*Dicentrarchus labrax* L.). Influence of temperature and fasting. *Comparative Biochemistry & Physiology*, **108A**, 673–680.
46. Cordier, M., Brichon, G., Weber, J.-M. & Zwingelstein, G. (2002). Changes in the fatty acid composition of phospholipids in tissues of farmed sea bass (*Dicentrarchus labrax*) during an annual cycle. Roles of environmental temperature and salinity. *Comparative Biochemistry & Physiology*, **133B**, 281–288.
47. Yamamoto, T., Shima, T. & Furuita, H. (2004). Antagonistic effects of branched chain amino acids induced by excess protein-bound leucine in diets for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture*, **232**, 539–550.
48. Shahidi, F.D., Metusalach & Brown J.A. (1998). Carotenoid pigments in seafoods and aquaculture. *Critical Reviews in food Science and Nutrition*, **38**, 1–67.
49. Forsberg, O.I. & Guttormsen, A.G. (2006). Modelling optimal dietary pigmentation strategies in farmed Atlantic salmon: Application of mixed-integer non-linear mathematical programming techniques. *Aquaculture*, **261**, 118–124.
50. Gínes, R., Valdimarsdottir, T., Sveinsdottir, K. & Thorarensen, H. (2004). Effects of rearing temperature and strain on sensory characteristics, texture, colour and fat of Arctic char (*Salvelinus alpinus*). *Food Quality & Preference*, **15**, 177–185.
51. Gomes, E., Dias, J., Silva, P. *et al.* (2002). Utilization of natural and synthetic sources of carotenoids in the skin pigmentation of gilthead sea bream (*Sparus aurata*). *European Food Research & Technology*, **214**, 287–293.
52. Tejada, N., Cejas, J.R., Rodriguez, C. *et al.* (2007). Pigmentation, carotenoids lipid peroxides and lipid composition of skin of red porgy (*Pagrus pagrus*) fed diets supplemented with different astaxanthin sources. *Aquaculture*, **270**, 218–230.
53. Loy, A., Boglione, C. & Cataudella, S. (1999). Geometric morphometrics and morpho-anatomy: a combined tool in the study of sea bream (*Sparus aurata*, sparidae) shape. *Journal of Applied Ichthyology*, **15**, 104–110.
54. Thomassen, M.S. & Rosjo, C. (1989). Different fats in feed for salmon: influence on sensory parameters, growth rate and fatty acids in muscle and heart. *Aquaculture*, **79**, 129–135.
55. Josephson, D.B., Lindsay, R.C. & Stuiber D.A. (1984). Variations in the occurrences of enzymatically derived aroma compounds in salt- and freshwater fish. *Journal of Agricultural and Food Chemistry*, **32**, 1347–1352.
56. Turchini, G.M., Mentasti, T., Caprino, F., Panseri, S., Moretti, V.M. & Valfrè, F. (2004). Effects of dietary lipid sources on flavour volatile compounds of brown trout (*Salmo trutta* L.) fillet. *Journal of Applied Ichthyology*, **20**, 71–75.
57. Schlüter, S., Steinhart, H., Schwarz, F.J. & Kirchgeddner, M. (1999). Changes in the odorants of boiled carp fillet (*Cyprinus carpio* L.) as affected by increasing methionine levels in feed. *Journal of Agricultural and Food Chemistry*, **47**, 5146–5150.

58. Folkestad, A., Rørvik, K.-A., Kolstad, K. & Mørkøre, T. (2008). Growth rates of individual farmed Atlantic salmon (*Salmo salar* L.) influence the texture of raw and smoked fillets. *Aquaculture Research*, **39**, 329–332.
59. Tejada, M. & Huidobro, A. (2002). Quality of farmed gilthead sea bream (*Sparus aurata*) during ice storage related to the slaughter method and gutting. *European Food Research & Technology*, **215**, 1–7.
60. Grigorakis, K., Alexis, M., Gialamas, I. & Nikolopoulou, D. (2004). Sensory, microbiological and chemical spoilage of cultured common sea bass (*Dicentrarchus labrax*) stored in ice: a seasonal differentiation. *European Food Research & Technology*, **219**, 584–587.
61. Skjervold, P.O., Fjæra, S.O., Østby, P.B. & Einen, O. (2001). Live-chilling and crowding stress before slaughter of Atlantic salmon (*Salmo salar*). *Aquaculture*, **192**, 265–280.
62. 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.
63. Poli, B.M., Parisi, G., Scappini, F. & Zampacavallo, G. (2005). Fish welfare and quality as affected by pre-slaughter and slaughter management. *Aquaculture International*, **13**, 29–49.
64. Kılınc, B., Caklı, S., Cadun, A., Dincer, T. & Tolasa, S. (2007). Comparison of effects of slurry ice and flake ice pretreatments on the quality of aquacultured sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) stored at 4°C. *Food Chemistry*, **104**, 1611–1617.
65. Huidobro, A., Mendes, R. & Nunes, M.L. (2001). Slaughtering of gilthead sea bream (*Sparus aurata*) in liquid ice: influence on fish quality. *European Food Research & Technology*, **213**, 267–272.
66. Waagbø, R., Sandnes, K., Torrissen, O.J., Sandvin, A. & Lie, Ø. (1993). Chemical and sensory evaluation of fillets from Atlantic salmon (*Salmo salar*) fed three levels of n-3 polyunsaturated fatty acids at two levels of vitamin E. *Food Chemistry*, **46**, 361–366.
67. Paterson, B., Goodrick, B. & Frost, S. (1997). Controlling the quality of aquacultured food products. *Trends in Food Science & Technology*, **8**, 253–257.
68. Sheehan, E.M., O'Connor, T.P., Buckley, D.J. & FitzGerald, R. (1996). Effect of dietary fat intake on the quality of raw and smoked salmon. *Irish Journal of Agriculture & Food Research*, **35**, 37–42.