Chapter 33
Concept and Determinism of Quality in Percid Fishes

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Abstract The development of the Percid fish industry calls for reflection on the concept and determinism of quality. This chapter starts with some general considerations illustrating the evolution of quality perception over time. The sense of the word 'Quality' is now polysemic; this brings together information about fish characteristics according to their origins (wild versus farmed), but also consideration on how fishes are produced. The complex picture of quality in Percid fishes is here illustrated with the study of nutritional, technological, sensory and sanitary components. We show on the basis of numerous studies that the determinism of quality is multifactorial. Quality components are thus governed by several biological (species, age, genotype, level of domestication…) and environmental (water characteristics, diet, season..) factors. However the quality objectives in Percid Fishes may vary depending on the stakeholders (fish farmer/fisherman, processor or consumer). As far as possible, the various expectations need to be addressed under the target values for the different quality components. In conclusion, we propose the adoption of multifactorial approaches to provide best information in understanding of determinism quality in Percid fishes.

Keywords Quality concept • Sensory attributes • Sanitary component • Nutritional component

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33.1 General Quality Concept

While it was evident to bring up quality in Percid fishes as agri-food products in the chapter entitled "*Marketing and Economics*", it is only since the Fordist model crisis that this notion of quality has taken on its full meaning and magnitude. Generally speaking, we have switched from a mass production system to one based on developing products with intrinsic characteristics that meet user expectations. And yet, the concept of quality is complex, taking on highly heterogeneous outlines and contents, especially when it applies to food products from different sources (natural environments vs. farming systems), as is the case herein. Therefore, defining quality is a challenge for the informed consumer, wise producer, experienced processor, knowledgeable distributor and expert researcher alike! The reason is that this concept, which is common but at the same time not readily accessible, is perceived differently among the stakeholders in the sector and throughout the life cycle of the product, from its source to its use and final destination.

But let us dare to take on this challenge and thus attempt to explain what the word "Quality" means, by first referring to the International Standard Organization (ISO 8402–94), which defines quality as "*the set of characteristics of an entity that give that entity the ability to satisfy expressed and implicit needs*". A general framework is thus proposed but surely needs clarification, especially since it keeps changing. Without completely going into its background, we should remember that when pasteurisation was introduced, quality was directly connected to the bacteriological status of the food product. In the 1960s, quality referred more to the product composition (water, protein and fat content). Later on, in the 1970s and 1980s, quality focused on chemical substances and other additives, for which the terms Acceptable Daily Intake and Maximum Residue Limit (Nardone and Valfré 1999), among others, were introduced. Nowadays, we cannot overlook nutritional values and the health properties of food, which include essential amino acid and lipid content, essential fatty acid, vitamin and mineral sources, and so on. However, expectations go beyond that (Valfré and Moretti 1991) and products should also meet sensory (colour, flavour, texture, aspect) and technological (processability, preservability, etc.) requirements. Does this mean that together, all these components – hygienic, nutritional, sanitary, sensory and technological – are enough to fully define what is meant by "Quality"? The answer is a resounding "NO", as the definition takes into consideration not just the product itself, but also how it is produced and where it comes from (Hirczak 2007; Mariojouls 2000).

This complex picture of quality in its broadest terms is shown in the synoptic chart in Fig. 33.1, which illustrates the many components at different levels (product, production and/or supply systems) and for the various parties involved in the sector (fish farmer/fisherman, processor, consumer). In the area of food quality and safety, the fish supply market must meet a number of challenges, "from the net to the plate". This figure shows that while some quality components are of interest for only one party, others are pertinent to several, or even all the parties involved. Nevertheless, while the distinction between specific and common interests allows

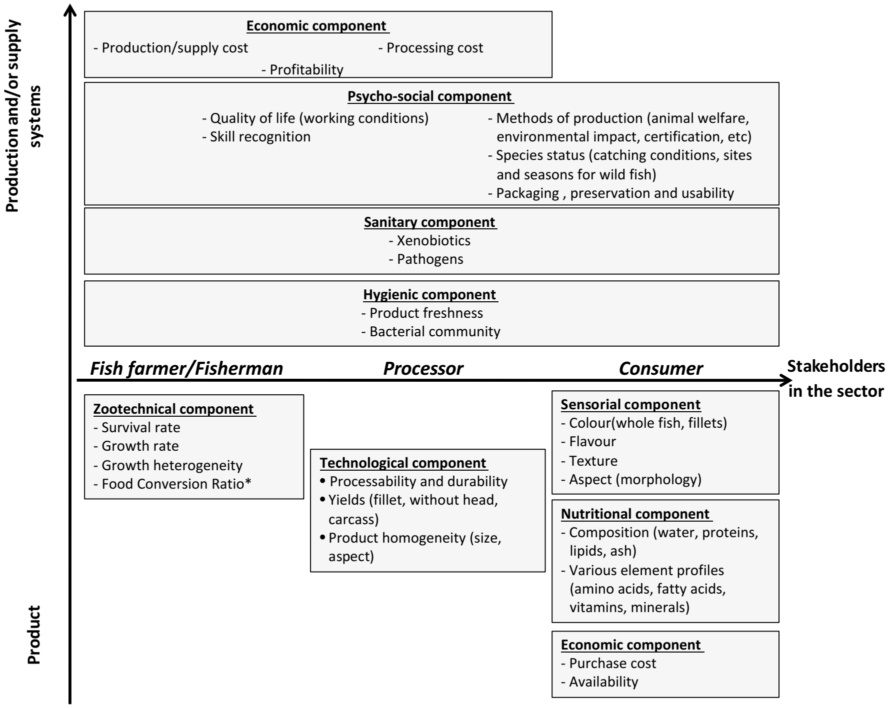

Fig. 33.1 Overview of fish quality components, at different levels (product, production and/or supply systems) and depending on various stakeholders in the sector. **Food Conversion Ratio or* $FCR = F\,x\left(w_t - w_0\right) - 1$ *, where F is the total amount of feed per fish consumed during growth period* (*g*) *and* w_0 *and* w_t *are the initial and the final average fish body mass* (*g*)

for a convenient representation, it is a rather simplified view of a more complex reality. For instance, the nutritional component is essential for consumers, yet it is obviously a concern for producers, too. Likewise, we will henceforth take a look at some of these components, focusing on the different notions that overlap as well as on the exogenous and endogenous factors governing their expression.

33.2 Fish Quality Components

This section deals specifically with the nutritional, technological, sensory and sanitary components in Percid fishes. The economic component is addressed in Chap. 10.2 ("*Economics of Percid Culture*") in this book. Similarly, the reader can find, in Sects. 3 and 4, a compilation of current knowledge on the zootechnical parameters to be controlled in order to satisfy the quality criteria breeders expect (e.g., survival, growth performance, decrease in growth heterogeneity, etc.).

33.2.1 Nutritional Component

The nutritional component refers to the biochemical composition of fish. Generally speaking, the content of the main components found in fish flesh may vary widely from fish to fish and from species to species: 53–81 % water, 13–24 % proteins and 0.1–31 % lipids (Dunajski 1979). As the lipid content and fatty acid profiles are essential descriptors of this component, this is what we will deal with first in Percid fishes. Then we will give a more global overview of the other nutritional components within the same group of fish.

33.2.1.1 Fatty Acid Content and Composition

Percid fishes are lean (flesh lipid content below 2/100 g). It has been clearly established that diet plays a major part in the lipid content of fish and this relationship is tissue-dependent. An increase in the lipid content of the food does not have any significant effect on the lipid content in the muscle of Eurasian perch (Xu et al. 2001; Mathis et al. 2003). However, it affects the perivisceral tissue, a favoured storage site in Percid fishes (Jankowska et al. 2003; Kestemont et al. 2001; Xu and Kestemont 2002). In addition, while Cox and Karahadian (1998) did not find any significant differences in lipid content between wild and farmed yellow perch, other studies have shown that the muscle lipid content is usually higher in farmed fish than in wild fish (Table 33.1).

These differences in intramuscular lipid content between wild and farmed fish could be partly explained by (i) the quality of food (higher content of fat in commercial feed compared to natural food in general), (ii) the availability of food (with potential fasting periods for wild fish) and (iii) the maturation of gonads (generally prevented in farmed fish because of constant photoperiod and temperature, but occurring naturally in wild populations with a subsequent energy transfer from the muscle to the gonads).

Along with the lipid content, the fatty acid profile is a key descriptor of nutritional quality. Indeed, one of the features that distinguish fish from other meat food (pig, beef, and poultry) is their high polyunsaturated fatty acid (PUFA) content. Thus, beneficial effects of fish consumption on human health appear to be related to the high content of PUFA (15–36 % of the total fatty acids). It concerns in particular *n*-3 PUFA such as docosahexaenoic (DHA, 22:6*n*-3) and eicosapentaenoic (EPA, 20:5*n*-3) acids (Calder and Yaqoob 2009; Uauy and Valenzuela 2000).

Table 33.1 Intramuscular lipid content (% wet weight) in wild and farmed Percid fishes

Species	Intramuscular lipid content (% ww)		References
	Wild	Farmed	
Eurasian perch (*Perca fluviatilis*)	1.2	2.5	Mathis et al. (2003)
Yellow perch (*Perca flavescens*)	1.4	2.8	Gonzàlez et al. (2006)
Pikeperch (*Sander lucioperca*)	0.9	2.9	Jankowska et al. (2003)

Diet plays a major role here, with the composition of fatty acids in flesh lipids largely reflecting that of the food lipids. Thanks to Δ5 and Δ6 desaturase activity, Percid fishes, like freshwater fish in general, can use C18 precursors[1] from their diet to achieve bioconversion reactions leading to longer-chain fatty acids (Sargent et al. 2002; Xu and Kestemont 2002). Wild Percid fishes feed on prey that is mainly composed of linoleic acid, but also of α-linolenic acid and DHA (Henderson and Tocher 1987). When fish are farmed, the fatty acid profile in the flesh can be modulated by combining different sources of plant or animal dietary lipids. Fatty acid profiles have been described in different food and environmental contexts for *P. fluviatilis* (Blanchard et al. 2005; Orban et al. 2007; Mairesse et al. 2006, 2007; Stejskal et al. 2011a; Xu and Kestemont 2002; Xu et al. 2001), *P. flavescens* (Gonzàlez et al. 2006; Twibell et al. 2001), *S. lucioperca* (Celik et al. 2005; Guler et al. 2011; Jankowska et al. 2003; Kowalska et al. 2012; Molnár et al. 2006; Uysal and Aksoylar 2005) and *S. vitreum* (Czesny et al. 1999). The various studies have established that the main fatty acids found in flesh are usually palmitic acid (16:0), oleic acid (18:1*n*-9), linoleic acid (18:2*n*-6), eicosapentaenoic acid (20:5*n*-3), and docosahexaenoic acid (22:6*n*-3), to which arachidonic acid (20:4*n*-6) can be added for wild fish populations in particular, with concentrations that vary with protocol or diet.

However, lipid content and fatty acid profiles may be affected by other factors (seasons, breeding conditions, origins of the fish and so on). Indeed, it has been suggested that **rearing conditions** and **fish strain** may have an influence on the lipid content in *Perca* fish muscle. This hypothesis has been confirmed by Gardeur et al. (2007), who showed among twelve tested rearing factors that only water temperature and food lipid source (fish oil vs. fish oil and rapeseed oil) interaction had a significant effect on the lipid content in the fillet of *P. fluviatilis*. However carcass lipid content in *S. lucioperca* was no affected by water temperature ranging between 20°C and 28°C (Wang et al. 2009). Other non-food-related factors, such as the **genotype**, the **level of domestication** or the **physiological state** of the fish, have been suggested as influential factors (Mairesse et al. 2007; Gjedrem 1997). Mairesse (2005) showed differences in the fatty acid profiles for juvenile Eurasian perch of different origins, but reared from the egg stage under the same environmental and trophic conditions. In the same way, Rosauer et al. (2011) revealed differences in fillet fatty acid composition, including arachidonic acid and eicosapentaenoic acid concentrations, for three different stocks of *P. flavescens* reared over a 12-month period under similar conditions. The nutritional quality of Percid fishes thus appears to depend not only on the food factor, but on **genetic factors** as well. This relationship had already been put forth by Sargent et al. (1995) who reported that, for freshwater fish, the ability for C18 polyunsaturated fatty acids to be converted to highly unsaturated fatty acids such as DHA varies between and within species, or between different stocks. On this account, domestication has been said to be a factor of influence on saturated fatty acid content (Mairesse et al. 2007). It would also affect the polyunsaturated fatty acid profiles of *n*-3 and *n*-6 series, though just moderately

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[1] C18 precursors such as linoleic acid [18:2*n*-6] (*n*-6 series precursor) and α-linolenic acid [18:3*n*-3] (*n*-3 series precursor) (*see* Sect. 5 "*Nutrition, feeds, and feeding practices*").

when compared to the lipid source. A change in the regulation of lipogenesis pathways for fish fed artificially over several generations could be responsible for these differences, as already mentioned by Bell and Dick (2004).

Finally, Percid fish flesh is proving to be a product of nutritional interest, with its low lipid content and high *n*-3/*n*-6 ratios. Therefore, consuming this product, rich in PUFA and even more so in DHA, makes a worthwhile contribution toward recommended EPA and DHA dietary allowances for adults (ANSES 2011). Furthermore, determinism of this quality component is mainly driven by diet, a factor that is fully controlled in fish culture.

33.2.1.2 Other Descriptors

As well as containing polyunsaturated fatty acids, which is of interest for consumers, Percid fishes are also and primarily a source of **proteins**. Indeed, proteins are the main organic compounds of fish flesh. In Percid fishes, they account for 18–21 % of wet weight (Jankowska et al. 2003; Mathis et al. 2003; Mjoun et al. 2012). The protein content in fish is usually recognized as mostly stable and not dependent on the sex and size of the fish. Moreover, while an increase in the feed protein content may have led to an increase in protein content for *Oreochromis niloticus* (Gunasekera et al. 1997), such an effect has not been demonstrated for *P. fluviatilis* (Mathis et al. 2003).

Although less documented, the **amino acid composition** and **mineral** content are other descriptors of nutritional quality. Several studies can be referred to for more information on these descriptors in Percid fishes (Gonzàlez et al. 2006; Mai et al. 1980; Mjoun et al. 2012; Tidwell et al. 1999). As an illustration, the mineral composition in *P. flavescens*, *P. fluviatilis* and *S. lucioperca* are given in Table 33.2. The interest consumers have in the mineral content in regards to essential minerals

Table 33.2 Mineral elements for three species in Percid fishes

		Mineral concentration (Mean in mg/g)					
Species	Origins	Na	K	Mg	Ca	P	References
Perca flavescens	Great Lakes (United States)	0.50	2.63	0.22	0.16	1.64	Gonzàlez et al. 2006
	Virginia Tech Aquaculture Center (United States)	0.32	3.72	0.29	0.28	2.08	
Perca fluviatilis	Bolsena lake (Italy)	0.33	3.78	0.26	0.85	2.23	Orban et al. 2007
	Bracciano lake (Italy)	0.25	3.25	0.21	0.46	2.31	
Sander lucioperca	Fish cooperative (Turkey)	0.66	3.54	0.37			Özyurt et al. 2009
	Caspian Sea	0.48	2.68	0.49	0.63	1.08	Pirestani et al. 2009

(e.g., phosphorus, calcium, magnesium, etc.) is offset by their concerns about heavy metals in the muscle (e.g., lead, cadmium, copper, etc.). This latter issue will be dealt with in Sect. “Sanitary Component” of this chapter.

33.2.2 Technological Component

Technological quality is a key quality component for fish farmers, processors and distributors, as they want products that are homogeneous in aspect and size, that are easy to process and that remain fairly stable through time. Percid fishes are consumed as fillets or provided gutted. It is thus interesting to focus on two particular descriptors of the technological component – the fillet yield and the carcass yield. A few of these yield values, which have been recorded for different Percid species, are shown in Table 33.3.

Technological quality descriptors are dependent on a large number of intrinsic and environmental factors, which shall be presented. Thus, **fish size** is a factor whose influence on the fillet yield has been shown. As noted in Table 33.3 for *P. flavescens*, Lindsay (1980) recorded higher fillet yields for the bigger farmed fish.

Table 33.3 Fillet and carcass yields (mean value ± S.E.M [min-max]) according to the fish species and different characteristics (weight, origin, etc.)

Species	Characteristics	Fillet yield (%)[a]	Carcass yield (%)[b]	References
Perca fluviatilis	Mean weight: 131 ± 9 g	42 ± 1 [37.3–47.3]		Mathis et al. 2003
	Wild versus farmed fish	40.1 vs.42.8		Mairesse et al. 2007
	Extensive versus intensive farming conditions	42.3 vs. 39.8		Mairesse et al. 2005
Perca flavescens	Wild versus farmed fish[c]	42.5–43.5 vs. 40–42		Lindsay 1980
	Weight range (g): 52.0 ± 2.5 to 138.1 ± 6.9	Between 34.57 ± 0.01 and 35.22 ± 0.01		Rosauer et al. 2011
Sander lucioperca	Wild versus farmed fish	51.2 ± 0.6 vs. 48.1 ± 0.9	88 ± 0.7 vs. 83.8 ± 1.3	Jankowska et al. 2003
			79–89	Bykowski and Dutkiewicz 1996
Sander vitreus	Fillet, skin-off	33.6		Summerfelt et al. 1996
	Fillet, skin-on	42.1		

[a] Versus fish weight

[b] Gutted carcass

[c] Body weight of 175–200 g (length: 20–23 cm) and 150 g (length: 18 cm) for wild and farmed fish, respectively

For *P. fluviatilis*, Mathis et al. (2003) showed no relationship between fish weight and fillet yield, whereas it generally appeared that among fish of the same age, the skeleton, fin and head share was higher for the smaller fish, which meant a decrease in fillet yield (Einen et al. 1999; Mørkøre and Austreng 2004). Furthermore, even if the impact of the fish's **sex** on fillet yields has been discussed, there did not seem to be a change in fillet yields for *P. fluviatilis* weighing less than 130 g (Mathis et al. 2003). The authors pointed out that the fish used were not yet sexually mature, a useful detail in view of the fact that technological criteria also vary with the fishing period according to the physiological status of the perch (Mairesse et al. 2005). Indeed, during the **spawning period**, gonad weight will determine fillet yield. In *P. fluviatilis* females, the ovary weight may account for up to a quarter of the body weight (Sulistyo et al. 1998; Rougeot et al. 2003), thus explaining fillet yield differences between sexes. In this species, energy mainly accumulates as perivisceral fat (Xu et al. 2001). Accordingly, it has been shown that the perivisceral fat index is at a maximum in October for perch caught in Lake Geneva and progressively decreases with gonad maturation and consequently with an increasing gonado-somatic index (Mairesse et al. 2005). So, logically, the carcass yield[2] in *P. fluviatilis* also exhibits yearly fluctuations – 93 % between May and September, and 72 % between March and April (Mathis, unpublished data) – in relation to the development of perivisceral fat reserves and the development of gonads.

The technological quality in fish also depends on **trophic factors**. Improvement of growth performance through dietary practices (highly energetic, lipid-rich feeds) leads to a significant development of fat reserves in perivisceral tissue of farmed fish. However, these fats impair their ability to be processed, with a particular decrease in yields (Borresen 1992; Fauconneau et al. 1996). Mathis et al. (2003) reported that perch which were fed with dietary energy levels of 19.6 $\mathrm{kJ.g^{-1}}$ had a higher fillet yield than those obtained with higher dietary energy levels (22.1 $\mathrm{kJ.g^{-1}}$) – i.e., 43.1 % and 41.1 %, respectively. There is thus a threshold effect of diet: as long as it increases growth without significantly changing perivisceral fat content, fillet yield will improve. On the other hand, as soon as dietary energetic supplement is stored as perivisceral lipids, a decrease in yield will occur. Similarly, the source of dietary lipids (animal vs. plant) has also been shown to affect fillet yield and the viscero-somatic index in Eurasian perch, both of which decrease when vegetable oil is added to the feed (Mairesse et al. 2007). These authors showed that the level of **domestication** should also be taken into account when interpreting fillet yield differences.

To conclude this section, it should be noted that issues related to fish morphotypes or to gaping are not (or poorly) documented in Percid fishes. We should however keep in mind that technological quality determinism in Percid fishes is multifactorial. Yields (fillet and carcass) depend on various intrinsic, environmental and trophic factors, which can be controlled in rearing conditions. Similarly, while it is possible practically speaking to fillet fish at different times with respect to *rigor mortis*, processors most often favour *post rigor* filleting, for optimal yield but also

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[2] $\text{Carcass yield} = (\text{carcass weight} / \text{body weight}) \times 100$

for a sensory quality which is said to be better. This is precisely the component which will be discussed hereafter.

33.2.3 *Sensory Attributes*

The sensory component encompasses all descriptors that can be perceived by the different senses: appearance (especially colour, shape and aspect of the fish), texture, odour and flavour.

33.2.3.1 Aspect: Morphology

The shape and aspect of the fish are quality descriptors, naturally perceptible by the observer, but whose assessment may sometimes be considered complex since it is based on a set of heterogeneous criteria. Indeed, some criteria may be determined objectively, such as the relationship between fish shape and fillet yield. Nevertheless, other criteria are of a more subjective nature, tied to cultural practices and consumers' preferences for example.

Beyond these considerations, studies on the phenotypic expression in Percid fishes have focused on the combined influence of the **genome** and **environment**. Turki-Missaoui et al. (2011) have recently showed the morphological differences within and between *S. lucioperca* populations from Tunisia which were nevertheless derived from a single gene pool. According to the authors, these morphological differences could be an adaptation to using different habitats, a result of dietary and reproductive behaviours that vary with the environment. In *P. fluviatilis*, Mairesse et al. (2005) similarly showed that the overall fish morphology (compact body, head and mouth relative lengths) is a factor allowing fish to be differentiated according to their origins (Lake Geneva, Rhine River). However, the latter study did not take into account the genotypic factor (Mairesse et al. 2005). The trophic environment (habitat use, resource type) would also affect morphological determinism in Percid fishes, as has already been demonstrated in *P. fluviatilis* (Svanbäck and Eklöv 2002). Environmental complexity has also been put forward as a factor to be considered for the phenotypic determinism of wild perch (Mairesse et al. 2005). In this respect, when looking at farmed Percid fishes, the environment they live in has characteristics which are less heterogeneous and, most importantly, more stable than natural ecosystems. However, rearing conditions also affect fish morphology, due to stocking densities, reduced activity, lack of flow conditions, and feed quality and amount (Sarà et al. 1999; Favaloro and Mazzola 2003). These variations in fish shape are often related to skeletal malformations and indirectly affect growth performance, mortality and acceptability of the product (Favaloro and Mazzola 2003). Moreover, rearing systems allow malformed fish to survive possible predation in the wild. These malformations, which are after all quality defects, occur in different parts of the body and have been described in *P. fluviatilis* (Jacquemond 2004). In particular fin damage was reported in intensively cultured perch (Stejskal et al. 2011b); it can affect acceptance by consumers and reduce the economic value of fish sold whole. According to these authors, water turbidity may play a role in reduction of fin damage.

33.2.3.2 Colour

Colour is one of the most important factors that encourage the consumer to buy and accept the product (Baker and Gunther 2004). This parameter applies both to the whole fish and to fish fillets. As opposed to Salmonid fishes, there are few studies on this parameter in Percid fishes, whose flesh is white. The main pigments which affect fish colour (concerning the whole fish and fillets) and which have been investigated, are:

- Carotenoids (ß-carotene commonly found in the environment, as well as astaxanthin and canthaxanthin in shellfish and molluscs) responsible for the orangey-red colour;
- Melanin, which would mainly have an effect on skin darkness (blackness).

Fish, which are unable to synthesise carotenoids *de novo*, must get them through their **diet**. Such is the case for wild perch that are yellow-red in colour when they feed on shellfish (Craig 2000). Under farming conditions, Mathis et al. (2003) further demonstrated that dietary carotenoids (4 %), together with temperature, have an effect on the colour of the fins (increasing red colour). Indeed, while ingested carotenoid pigments may be excreted unchanged in faeces, they are also absorbed, stored or converted. Fish accumulate carotenoids mainly in skin chromatophores, muscle and gonads. In the muscle, carotenoids may be either dissolved in lipid droplets between muscle fibres, or bound to other molecules such as sugar (glycosylated carotenoids) or proteins (caroteno-proteins) in the sarcoplasmic membrane of muscle fibres. Accordingly, it has already been established that fillet colour is generally affected by its **lipid content** (Baker et al. 2002) and its **composition in fatty acids**, mainly polyunsaturated ones (Sargent et al. 1989), due to significant oxidation processes (Lie 2001). Therefore, the fatty acid profile of the muscle, which is dependent on that of the feed, could at least partly explain the effect of trophic factors on fillet colour in *P. fluviatilis* (Mairesse 2005).

Fish colour is also governed by **environmental factors**. Indeed, the genus *Perca* exhibit wide variations in colour depending on where they live, with no real consensus on determinism among studies. According to Craig (2000), in shallow environments where light easily penetrates, fish are dark coloured, whereas in poorly lit environments lacking vegetation they are of brighter colours. Conversely, Mairesse et al. (2005) observed that brighter coloured fish are caught in clearer waters (i.e., from Lake Leman vs. Rhine River with water transparency of 7.5 m and 0.6 m, respectively). These authors have suggested a possible correlation between water temperature on the one hand and the colour contrast between stripes and interstripes in perch on the other hand.

A final factor noted in literature as having an effect on the colour parameter in Percid fishes is the level of **domestication**. According to Mairesse et al. (2007), this influences the colour of the tail fin, the difference in brightness between stripes and interstripes, and the saturation of the fillet *P. fluviatilis*. In this respect, Lindsay (1980) reported differences in fish colour between wild *P. flavescens* (blue-green colour) and their farmed counterparts (yellow-green colour). There also seems to be differences in fillet colour between wild and farmed fish, the latter having whiter flesh (Mathis, unpublished data). However, according to Jankowska et al. (2003), the brightness and redness of both wild and farmed pikeperch tissues were similar while the yellowness was different. Thus, wild fish are characterised by a lower intensity of tissue colour.

In brief, colour in Percid fishes is considered to be a major sensory quality attribute, which is governed by intrinsic, trophic and environmental factors.

33.2.3.3 Texture

Texture is another important attribute of fish flesh sensory quality, which covers all rheological and structural properties of a product. Depending on whether it is assessed by a sensory analysis panel or by using test instruments, texture is expressed through a wide variety of terms which include hardness, springiness, cohesiveness, gumminess and mouth feel, among others (Haard 1992; Cardello et al. 1982). In any case, its assessment requires specific conditions to be established, especially when *rigor mortis* occurs, as well as conditions for product preservation (shelf life, method) and preparation (raw vs. cooked), which may dramatically affect the various descriptors measured.

On the whole, flesh texture is influenced by many factors, including the structure of the muscle and properties of its components, in particular myofibrillar and connective tissue proteins and fat. On the other hand, growth rate has a significant impact on the content of muscle fibre, and therefore, potentially influences flesh texture (Johnston 1999). Fish muscle is known to be composed of two main types of fibres, red and white, which vary with the species. In Percid fishes, white fibres make up most of the muscle (the same holds true for most fish), whereas the red muscle appears as a single superficial layer along the horizontal septum (Lindsay 1980).

A number of comparative studies have focused on texture in Percid fishes, taking into account the origin of the fish. In *P. fluviatilis*, Mathis et al. (2000) established that hardness and mouth feel descriptors alone may allow wild fish to be distinguished from their farmed counterparts. In the same way, Gonzàlez et al. (2006) showed that farmed *P. flavescens* are not as firm as wild fish. This result could possibly be attributed to a higher fat content in farmed fish (Lie 2001) as well as higher levels of activity in wild fish, which may improve texture. On the other hand, Lindsay (1980) found no significant differences between deep-fried wild and farmed yellow perch, while Delwiche and Liggett (2004) found significant differences between skin-on, battered- and -fried farmed and wild yellow perch fillets.

Moreover, fillet texture is clearly influenced by rearing conditions in Eurasian perch (Stejskal et al. 2011a). According to these authors, the culture system has a strong effect on fish flesh texture, with lower levels of all texture parameters (hardness, springiness, cohesiveness and gumminess) in fish reared in intensive conditions (recirculation system) compared to the results recorded in fish from ponds.

33.2.3.4 Other Sensory Characteristics

Sensory quality for Percid fishes was also reported for other attributes such as odour, flavour and aftertaste (Delwiche et al. 2006; Lindsay 1980; Stejskal et al. 2011a). Although studies are scarce, a few lessons can be drawn. There are studies that suggest that differences in flavour and preference do exist between farmed and wild *P. flavescens*, with a preference toward wild-caught as reported by Delwiche and Liggett (2004). Fish caught in the wild are generally described as having a more pronounced flavour and are less bland than farmed fish. In addition, Cox and Karahadian (1998) reported differences in sweetness and oxidised flavour between butter-broiled farmed and wild *P. flavescens* fillets at different stages of storage. Usually, wild and farmed fish diverge in flavour because of differences in fatty acid profiles, oxidation processes, dietary ingredients, mineral and amino acid content (Haard 1992). On the other hand, no difference was reported between deep-fried wild and farmed *P. flavescens* (Lindsay 1980). In the same way, Gonzàlez et al. (2006) observed a similar flavour between wild and farmed yellow perch.

According to these authors, the rearing system (recirculation vs. pond) may be an important determinant with respect to off-flavour development. Furthermore, a study focusing on farmed Eurasian perch showed that the culture system (extensive polyculture in pond and natural preys vs. intensive recirculating systems and formulated feed) had no effect on sensory attributes such as odour, flavour, aftertaste and consistency (Stejskal et al. 2011a). Indeed, no aftertaste was detected in 31 % of the samples of intensively farmed fish or in 27 % of the samples of extensively farmed perch. This result must be seen in relative terms knowing that all the fish were kept in clear water for 7 days without feeding before analysis. The aftertaste reported in cultured fish flesh was found to be the result of geosmin and 2-methylisoborneol (Howgate 2004; Selli et al. 2006; Yamprayoon and Noohorm 2000). In this respect, we note that growth of micro-organisms which produced these compounds is dependent on rearing system (i.e. ponds vs. recirculating systems including the water treatment units).

Sensory quality determinism is therefore governed by several factors. While particular emphasis has been placed on *ante mortem* conditions, *peri*- and *postmortem* conditions of the product, from its origin to its consumption, not to mention storage and preparation steps, also affect the various sensory attributes. Comparisons among studies are still tricky, and the determinism of this quality component remains to be fully understood.

33.2.4 Sanitary Component

An issue often brought up by many experts in debates on the "Benefit-Risk" ratio of fish consumption is that of sanitary quality. It covers the qualitative and quantitative analysis of chemical and biological compounds (i.e., heavy metals, organic contaminants, veterinary drugs, additives, mycotoxins, phycotoxins, bacteria, viruses, etc.) that are potentially present in products. While fish is generally recognized as a healthy food providing proteins and nutrients, as well as a good source of unsaturated fatty acids, it may also be an important source of contaminants. In this respect, it is assumed that more than 90 % of human exposure to Persistent Organic Pollutants (POPs) is caused by consumption of contamined animal-based food products, with the largest contribution to this exposure being from fish (Liem et al. 2000). Similarly, fish consumption is the primary pathway to methylmercury exposure in humans in the United States (Driscoll et al. 2007). That is the reason why we have decided to focus on chemical compounds in this section.

Naturally, the sanitary aspects of fish are subject to the same regulations as other foodstuffs. Such legislation aims to strike the appropriate balance between the benefits and risks of substances intentionally used in the production chain (veterinary drugs and additives), as well as to limit contaminant levels in food (heavy metals, organic pollutants, etc.). This idea is to ultimately ensure the health of consumers. Table 33.4 lists maximum values that should not be exceeded in the muscle meat of fish – including in Percid fishes – for a set number of chemical contaminants, as defined by European regulations (Commission Regulation 2008, 2011). This table underscores concerns over metals (lead, cadmium, mercury) and organic pollutants (Polycyclic Aromatic Hydrocarbons, dioxins, Poly-Chlorinated Biphenyls).

The sanitary quality of fish is of interest for all stakeholders in the sector: fishermen, fish farmers, processors and consumers. As opposed to most animal products, the fish supply sector is unique in that it gives consumers the opportunity to choose between wild and farmed products. This is also increasingly true for Percid fishes,

Table 33.4 Maximum levels for different contaminants in muscle meat of freshwater fish, with the exception of diadromous fish species caught in freshwater (According to Commission Regulation 2008, 2011). Dioxins (Poly-Chlorinated DibenzoDioxins or PCDDs and Poly-Chlororinated DibenzoFurans or PCDFs) and Poly-Chlorinated Biphenyls or PCBs

Contaminants	Maximum levels in muscle meat of fish	
Lead	0.3 mg/kg wet weight	
Cadmium	0.05 mg/kg wet weight	
Mercury	0.5 mg/kg wet weight	
Benzo(a)pyrene	2 µg/kg wet weight	
	Sum of dioxins (WHO-PCDD/F-TEQ[a])	Sum of dioxins and dioxin-like PCBs (WHO-PCDD/F-PCB-TEQ)
Dioxins and PCBs	4 pg/g wet weight	8 pg/g wet weight

[a] System of toxic equivalents (TEQs) calculated by using the toxic equivalency factors (TEFs) of each specific compound as established by the World Health Organization (WHO)

whose culture has boomed over the past few years (see Sect. 9 ‘*Commercial Production*’ and Session 10 ‘*Marketing and Economics*’). The diet and environment of farmed fish are closely monitored,[3] unlike those of their wild counterparts, which may come from potentially contaminated areas. Yet it needs to be understood that the health issue cannot be addressed without taking into account the origin of the fish. The reason for that is simple: contaminants enter organisms mainly through trophic pathways, with gills and skin being secondary pathways (Di Giulio and Hinton 2008). Consequently, apart from incidents or failings in the rearing process, chemical-related health issues mainly apply to wild fish. Nevertheless, we should also mention the particularity of fish produced in ponds. These polyculture systems are closely connected to their surrounding watersheds. As a consequence, these fish could be contaminated by substances derived from several sources (atmospheric deposition, runoff, effluent and food web). The very few studies on the matter – especially aimed to provide quantitative levels of contamination by persistent organic compounds and residues of pesticides in *P. fluviatilis* from extensive fish ponds –did not however give any cause for concern (Lazartigues et al. 2012; Thomas et al. 2012).

When contaminated food (prey) is ingested, xenobiotics are absorbed and, if excretion and metabolic rates are low,[4] they accumulate in organs (mostly in the adipose tissues of organisms for hydrophobic compounds). This process is called “bioaccumulation”. Some xenobiotics are persistent, with their concentrations increasing at each trophic level (i.e., with each prey-predator transfer). Thus, carnivorous fish, with a high trophic level, may be especially vulnerable to the so-called biomagnification processes. One such example is contamination of Percid fishes by mercury (Hg), one of the most toxic heavy metals in the environment (Table 33.5). Therefore, in order to protect human health, different safety guidelines have been proposed for total mercury concentrations not to be exceeded in fish, i.e. below 0.3 mg/kg ww (wet weight) according to the U.S. Environmental Protection Agency or below 0.5 mg/kg ww as established by European Commission Regulations. The action level of the U.S. Food and Drug Administration was set at 1 mg/kg ww, the value beyond which fish is considered unfit for human consumption. Taking these values into account, published articles have reported cases which can sometimes be deemed worrisome for some Percid species – *P. flavescens*, *P. fluviatilis* and *S. vitreus* – in which safety guidelines were exceeded (Table 33.5). Conversely, mercury concentrations in *S. lucioperca* were found to be within safety guidelines.

Understanding the determinism of fish sanitary quality thus requires taking **abiotic factors** into consideration, as local conditions affect bioaccumulation processes. Indeed, it is well established that lowering the **pH** of water increases mercury accumulation in fish (Porvari 1998). Furthermore, the **level of contamination of the local environment** influences contaminant distribution in tissues. Havelková

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[3] Indeed, some standards define, for example, the maximum contaminant levels in raw materials to be used in formulated feed.

[4] As such is the case for PCBs and dioxins, for example.

Table 33.5 Examples of studies that measured total mercury levels (in mg/kg wet weight) in the muscle tissue of four Percid species, according to their geographical origins

Species	Origins	Mercury levels[a]	References
Perca flavescens	The Laurentian Great Lake Region (USA)	[0.018–1.2]	Wiener et al. 2012
	Sand Lake	0.75	Dittman and Driscoll 2009
	Upper sister Lake	1.11	
	Sunday Lake	1.08	
	(Adirondack region of New York – USA)		
	Ontario lakes (Canada)	1.20	Rajotte and Couture 2002
Perca fluviatilis	Finnish reservoirs	0.65	Porvari 1998
	Russian lakes	[0.04–1.0]	Haines et al. 1995
	Lake Balkyldak (northern Kazakhstan)	0.70 ± 0.49	Ullrich et al. 2007
		[0.19–1.68]	
	Nitra River (Slovakia)	4.50 ± 1.27	Andreji et al. 2005
		[2.73–6.52]	
Sander vitreus	Supermarkets (Illinois – USA)	0.51 ± 0.13	Burger and Gochfeld 2006
	Lakes in the Abitibi area (Canada)	0.65	Abdelouahab et al. 2008
Sander lucioperca	River Irtysh (northern Kazakhstan)	0.114 ± 0.001	Ullrich et al. 2007
		[0.113–0.115]	
	Four rivers (France)	0.187 ± 0.077	Noël et al. 2012
		[0.112–0.290]	

[a] Data are mean ± standard deviation and/or [minimal – maximal values]

et al. (2008) demonstrated that in *P. fluviatilis* from contaminated locations, total mercury concentrations in the liver are significantly higher than in muscle tissue. Conversely, in fish from uncontaminated locations, mercury concentrations in muscle tissue are usually higher than in the liver. Tissue distribution also varies with **xenobiotics**. In *S. lucioperca*, the target organ of mercury deposition is the muscle, whereas the kidney is the main organ for cadmium deposition (Kenšová et al. 2010). In *P. fluviatilis*, it has also been shown that metal distribution in tissues may vary with **the seasons** (Szefer et al. 2003). This result seems to reflect differences in terms of both metal bioavailability and fish metabolism.

This leads us to look at **biological factors**, which also have an impact on sanitary quality determinism. Simoneau et al. (2005) suggested that faster-growing walleyes have lower mercury concentrations at a given length than their slower-growing counterparts. According to the authors, the **growth rate** as a biological factor outweighs all other environmental factors in accounting for differences in mercury concentrations in the walleye populations studied. This conclusion is supported by findings from other studies focusing on the influence of the fish's **sex** on contaminant levels (Gewurtz et al. 2011; Madenjian et al. 2009). They observed that male walleyes had higher mercury and total-PCB concentrations than females. They see this difference as possibly being attributed to slower growth and lower **gross growth efficiency** (amount of growth per unit of food consumption) in males than in females. PCB concentrations have been shown to be inversely proportional to gross growth efficiency (Madenjian et al. 2009). This study indicated that the release of gametes has very little effect on PCB concentrations in fish. In all the cases, these sex-specific differences in contaminant accumulation in fish in general and in *S. vitreus* in particular should be a consideration in programmes that monitor contaminant concentrations. In the same way, Dittman and Driscoll (2009) reported that total mercury concentrations increase with fish **age** in *P. flavescens*. These authors also used fish condition as an important index of the methyl status of fish. As the fish condition increases, fish can exhibit 'growth dilution' of tissue contaminants leading to lower total mercury concentrations.

In conclusion, sanitary quality determinism is also multifactorial. We decided here to focus solely on chemical contamination, for which the origin of fish (wild vs. farmed) appeared to be a determining factor. The reader should however keep in mind that other compounds may deliberately[5] or inadvertently[6] come into contact with the fish, subsequently affecting their sanitary quality.

33.3 Conclusion: Determinism of Fish Quality

The development of the Percid fish industry – encouraged by intensive research on the domestication of new species (Fontaine 2009; Teletchea et al. 2009) – calls for reflection on the concept and determinism of quality. While the complexity of this broad term has been reaffirmed through the presentation of its multiple components, its outlines and contents have yet to be completely defined, especially for Percid fishes.

First, quality determinism must be looked at differently, depending on whether the fish are wild or farmed-raised. For wild fish, quality is the outcome of an environment which is often complex, heterogeneous and within which intrinsic and extrinsic factors are little or not at all controlled. In other words, fish quality reflects the abiotic and biotic conditions of their habitat. Thereby, wild fish quality, as particularly shown for *P. fluviatilis* (Mairesse et al. 2005, 2006), may understandably vary with the seasons, geographic origins or the physiological status of individuals. Conversely, farmed fish grow in largely controlled environments, which allow quality to be orientated, provided that its determinism is controlled. This information may relevantly be considered when a new industry such as that of Percid fishes emerges. As brought up by Fauconneau (2004), the successful introduction of a new

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[5] Such as veterinary drugs.

[6] As can happen with bacteria, viruses, etc.

farmed fish species on the food market depends on how it is valued and how it compares with other existing products. In Percid fishes, like in most fish, this comparison is made with wild fishery products. All in all, the latter would be seen as a quality standard, particularly with consumers who spontaneously compare what is new (farmed Percid fishes) to what they have known (wild Percid fishes). In the light of the results previously shown, the question arises whether such a comparison (farmed vs. wild Percid fishes) is relevant. Another strategy, which will be the second point of this report, may be considered.

We have previously mentioned that stakeholders in the sector cannot reach a consensus on quality indicators. For example, while fish growth heterogeneity matters little to consumers, it is a crucial quality feature for fish farmers. Therefore, quality improvements could apply just as well to the method of production (including dependence on some inputs) as they could to environmental impacts on rearing systems, their productivity, fish sensory/nutritional/sanitary/technological characteristics, animal welfare, and so on. This long but incomplete list indeed requires prioritising the various quality components so as to reach a compromise between the various expectations of the stakeholders in the sector, something which merits particular attention. The following step would then be to define target values for the different quality criteria previously selected, keeping in mind that instead of being fixed, these criteria are subject to change, such as in an evolving social context. In all cases, implementing such a strategy requires quality determinism to be clearly and concisely understood. This will be the third and final point to be considered here.

Throughout this chapter, an attempt has been made to describe the influence that some environmental and/or biological factors may have on Quality components in Percid fishes. We have made reference to numerous studies which have sought to establish the link between trophic factors (food characteristics) and fish nutritional quality (fatty acid profiles), for example. These mostly one-factor studies contribute to providing information that can be useful in understanding the determinism of quality development. Nevertheless, the recorded results can take a variety of pathways depending on the experimental context. It is thus possible to observe either excellent or poor growth in *P. fluviatilis* when given a specific food, or record divergent results in regards to nutritional characteristics, and this in relation to other environmental characteristics (Gardeur et al. 2007). These findings clearly argue the case for studies to adopt multifactorial approaches, such as those already initiated with the experimental rearing of *P. fluviatilis* (Gardeur et al. 2007; Mairesse et al. 2007). These studies allow potentially interesting combinations of factors to be formulated according to selected criteria and target values by looking at the influence of various factors and their interactions on the building of fish quality. Biotic (level of domestication) and trophic (source of lipids) factors seem to play a key role, alone or in combination, on the sensory, nutritional and technological components of fish.

However, *peri* and *post mortem* conditions must not be allowed to ruin all efforts made throughout the different stages of fish rearing. Besides, the intrinsic characteristics of the fish also appear to have a critical influence on quality determinism. Consequently, genetic and epigenetic studies should be included in future research work on fish quality determinism.

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