Aquaculture and Sensometrics: the need to evaluate sensory attributes and the consumers' preferences

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Abstract

Aquaculture represents a vital food production industry that contributes to the global economy and fish supplies. Several studies had suggested that changes in the production process, especially those related with nutritional and feeding interventions, may have an impact on the final quality of farmed animal food products including those from aquaculture. An integrated approach is needed for close the gap between consumers' response and aquaculture products which sensorial quality aspects could be altered by the inclusion of new alternative protein and lipid sources in aquafeeds. Applied research efforts in aquaculture should recognize the significance of consumers' behavior and preferences with the aim of making this industry economically sustainable. Until now, sensory research in aquaculture has been developed in different ways depending on the commercial interest of the species implicated. The sensory analyses generally used in aquaculture were identified in four main application research areas: nutrition and feeding, production aspects, quality product and marketing topics. Applied aquaculture research for the continued growth of this industry need to be complemented with the findings and possibilities offered by sensometrics. This paper aims to provide an overview of sensory analysis used in aquaculture as an activity that supplies products to the market. The primary opportunity that sensometrics could offer to the aquaculture industry is to apply an accurate approach that takes into account the consumer.

Keywords: aquaculture, animal nutrition, farmed fish market and consumers, sensometrics, quality assessment

Introduction

Aquaculture is considered an essential food-producing sector in the world, supplying a significant percentage of all fish consumed globally today, and is set to play a critical role in meeting the future rising demand for fishery products (FAO, 2018). As global fisheries yield is constrained by ecosystems productivity and management effectiveness, *per capita* fish consumption can only be sustained if aquaculture maintains its increasing contribution to the global fish supplies (Merino *et al*., 2012). Therefore, while the importance of this industry is accepted and encouraged, it also requires the generation of specific strategies and interdisciplinary applied research that ensure its sustainability and continued growth (Engle, 2016). Aquaculture challenges require not only the knowledge and concepts but the research methodology from different disciplines.

While fisheries and aquaculture are similar industries regarding the production of aquatic food, both sectors differ in numerous productivity and management features (Muir & Young, 1998). One of the main differences is the degree of control on the production process associated with property rights (Natale *et al*., 2013). Still, wild-caught fish is considered in great measure the general fish products quality reference for consumers, resulting in a critical limitation for a more extensive approval of farmed fish (Claret *et al*., 2016). However, modern aquaculture practices allows the production of seafood with a consistent quality which is an advantage for the development of new marketing opportunities. Product optimisation is one of the most strategic research goals for every food producer and manufacturer. In this sense, aquaculture can provide fish and aquatic food products with comparable quality characteristics that become very familiar to consumers, but this also makes them more sensitive to perceive changes in these characteristics. For this reason, it is indispensable that aquaculture operations base its production processes on the markets and

customer's preferences. Consumer preferences affect all stakeholders in the value chain (Alfnes *et al*., 2018). Consequently, a comprehensive approach aimed at satisfying consumer needs and sustainability of the sector is key for the future development of aquaculture.

The consumer's knowledge about aquaculture operations and products is quite limited and in most cases generic, vague, controversial, or severely affected by opposing interests, which reflect the global and complex nature of seafood markets and the food industry in general (European Commission, 2014). The fact that there are substantial distinctions among consumers from different regions and countries need to be recognised. It is essential to consider the type of information that fish consumers are interested in, the information sources they use and how available information is related with their quality expectations and preferences (Pieniak *et al*., 2013). There is limited knowledge about consumers' understanding and acceptance of aquaculture practices and products. For example, Risius *et al.* (2017) confirmed that even though consumers are supporting sustainable production practices, certification schemes for sustainable aquaculture products are not of high importance for purchase decisions. Consumers may be highly opinionated, and they usually find difficult to give a detailed explanation about the preference between one product to another, making the results interpretation very complicated (Sveinsdóttir *et al*., 2009; Badiola *et al*., 2017). On the other hand, they could be heavily influenced by other factors such as price and seasonality. In this way, aquaculture research efforts should consider studying aspects related to marketability and consumers´ preferences to fill the knowledge gaps and make the production of farmed aquatic species more economically sustainable.

During the last few years, significant advances have been achieved in sensory and consumer research. Accordingly, sensometrics which is devoted to the analysis of data arising from this research field has also made significant progress (Qannari, 2017).

96 Sensometrics can be defined as the cross-disciplinary scientific field dealing with the human
97 perception of stimuli and the way they act upon sensory input (Brockhoff, 2011a). Sensory
98 food research focuses on developing a better understanding of how the senses react during
99 food intake; and it encompasses a set of tools that allow obtaining information derived from
100 human senses which can be used in quality control, market research, consumer choice and
101 innovative product development (Brockhoff, 2011b; Qannari, 2017).

102 In the agro-food industry, sensory and consumer data are frequently produced and used as
103 the fundamental support for decision-making strategies (Cejudo-Bastante *et al.*, 2013).
104 Sensory data can efficiently be used to evaluate the specific product features that determine
105 the consumer preferences (Pieniak *et al*., 2013). Product perception could be affected by the
106 belief that quality cues provide enough information for an adequate evaluation of the product.
107 Consumer beliefs are influenced by previously acquired knowledge and experience and do
108 not depend only on available information about the product (Kole *et al*., 2009). These aspects
109 are increasingly gaining importance because of the consumer specific perception about
110 products sensory quality characteristics and its influence on their purchase decisions. To
111 remain competitive, producers of raw material and food manufacturers need to know how
112 the consumers perceive their products. For this, evaluation of product consumption
113 experience is critical.

114 While food quality is based on chemical and physical data, sensory data plays an integral
115 part in determining its commercial success. Until recent decades, the food product research
116 and development usually have had a narrow scope based on the lineal and proportional
117 relationship between sensory responses and the physicochemical data. Nowadays
118 sensometrics offers a comprehensive evaluation by taking into account a larger number of
119 variables involved in human responses and using different mathematical and statistical

120 methods to measure, interpret, and evaluate these responses (CAMO Software®, 2018).
121 Thus, high precision analytical tools used by sensometrics studies provide more accurate and
122 efficient results that fit better to reality. This article aims to offer an overview of the use of
123 sensory analysis in aquaculture as a major food production sector that supplies diverse
124 products to the market, especially fresh fish.
125
126 **Sensometrics, a comprehensive approach to aquaculture**
127 Sensory analysis has been widely used in quality control of food products with the primary
128 aim of understanding the relationship between its physicochemical characteristics and
129 sensory responses (Van Trijp & Schifferstein, 1995; Giacalone, *et al*., 2013). Sensory
130 evaluation procedures require the use of often well-trained testers (sensory panel), to
131 maintain proper control over the testing situation and to maintain a clear distinction between
132 sensory and hedonic measurements. Most aquaculture related studies apply "Sensory
133 Descriptive Analysis," because it provides precise results that easily correlate with
134 physicochemical parameters. However, although descriptive sensory tests represent a
135 sophisticated tool and are valuable for food quality analysis, comparison of product
136 prototypes, sensory mapping, and product matching, they require previous knowledge,
137 continuous training, and considerable financial investment, which could be a determinant
138 limitation (Gacula, 1997).
139 Sensory and consumer research has reached a significant development, and in the same
140 way, sensometrics applied to the evaluation of data derived from this research field is forging
141 ahead at an increasing rate (Qannari, 2017). A consumer, person who uses a product (ISO
142 5492:2008), represent a valuable source of information and collecting sensory information
143 regarding consumer preferences has gained increasing significance and relevance. Over the

144 last years, there have been numerous methodological and technological advances that allow
145 to directly collecting sensory data from consumers' perception of specific products.
146 Frecuently used profiling techniques, which are considered appropriate for working with
147 untrained individuals, include: Penalty Analysis, Free-Choice Profiling, Projective Mapping,
148 Flash Profiling, Sorting and Check-All-That-Apply (Williams & Langron, 1984; Plaehn &
149 Horne, 2008; Meyners *et al*., 2013; Giacalone *et al*., 2013; Jaeger *et al*., 2013; Reinbach *et*
150 *al*., 2014; Mamede & Benassi, 2016).
151
152 Food marketing
153 The food marketing identifies and defines intrinsic and extrinsic information cues that
154 consumers use as quality indicators. Intrinsic cues are those inherent to the product (colour,
155 flavour and smell) while extrinsic cues include any external aspects, as the price or packaging
156 (Gaviglio *et al*., 2014). Quality cues used to analyze fish consumption should include
157 intrinsic cues (taste, odour, texture and perceived freshness) and extrinsic cues (price,
158 branding, consumption context, production methods, quality certification, origin, expert
159 opinion and nutritional information) (Birch & Lawley, 2012). Sensory satisfaction is the most
160 influential determinant of fish consumption intention and purchases demand, but information
161 derived from consumers opinions can be confusing (Verbeke & Vackier 2005; Badiola *et al*.,
162 2017). Almost all consumers consider that good taste is an essential aquaculture product
163 attribute that is often associated with "freshness" (Risius, 2017).
164 Taking into account the above, Nguyen *et al.* (2015) applied a labelled choice experiment
165 (LCE) to investigate consumer demand and choice behaviour for fresh fish and seafood at a
166 retail market. This model for seafood choice behaviour was similar to the brand choice
167 models that have been widely applied in marketing research. One of the most relevant

findings from this work was that consumers appear to have high willingness to pay for wild-caught seafood over the farmed alternative. Even though this investigation represents an excellent example of research that takes into account some aquaculture aspects, it has an essential weakness. The design did not include additional confirming information related with sensory quality attributes such colour, freshness, and texture that are crucial considerations for the consumer purchase decision (Verbeke *et al*. 2007; Claret *et al*. 2012). All this information is required for a better and accurate assessment of the consumer choice behavior.

The research developed by Kole *et al.* (2009) is a more adequate example to appreciate the synergy between sensometrics and marketing. This work evaluated the effects of different types of product information on fish consumers in real life settings. For this purpose, cod from two different origins (wild and farmed) were presented together with product information to 1440 consumers drawn from the Dutch TasteNet consumer panel for assessment in their own households. Quality Index Method (QIM) with an appropriately trained panel was carried out to assess freshness of the fish and assure constant quality throughout the experiments. Information from consumers was obtained using two different questionnaires. One related with holistic, credence and analytical attributes, and the second one related to the consumers' attitudes covering fish consumption behaviour, price, quality, safety and environmental aspects. The interaction of the information provided with product perception demonstrated an association between farmed fish and less favourable product characteristics. The information offered on several advantages of aquaculture production methods had an adverse effect on the appraisal of the product. In fact, the positive effect of price on same product evaluation was minimized when fish farming information was included. Consumer choice between wild and farmed fish appears to be influenced by beliefs

192 resulting from stereotypes, emotional sensations and incorrect information that make them
193 ignoring numerous potential advantages of fish farming (Verbeke et al., 2007; Kole et al.,
194 2009).

195 The preference for wild fish over farmed fish is a well-known situation that does not
196 benefit aquaculture. However, several studies have established that consumers do not seem
197 to be very interested in the production method and consider it less relevant than other
198 attributes of fish during the purchasing decision process (Vanhonacker *et al*., 2011; Claret *et*
199 *al*., 2012).

200 Claret *et al.* (2016) designed a study to determine Spanish consumers' liking for both
201 farmed and wild fish. Furthermore, this work evaluated the effect of the information provided
202 regarding the species and the method of production. The result showed that information has
203 a significant effect on the hedonic assessment of wild and farmed fish. The number of
204 consumers preferring captured fish in the informed condition was more than three times
205 higher than those preferring fish coming from aquaculture. However, in the blind condition
206 study, participants that preferred farmed fish doubled the number of those preferring wild
207 fish samples. The study also indicates that sensory attributes of farmed fish seem to meet the
208 quality requirements expected by Spanish consumers who might be more accustomed to fish
209 from aquaculture. Although most producers put emphasis not only on improving productivity
210 but some of the sensory quality aspects of farmed fish, the results from this study suggest
211 that these efforts should be more focused on the enhancement of consumer opinion about
212 aquaculture operations (Claret *et al*., 2016).

213 Sensory properties are a determinant condition of the acceptance and choice of consumers
214 concerning all types of food, including fish. The sensory preference for a specific type of fish
215 could be explained by the consumption habits of the consumers (Claret *et al*., 2014). Sensory

studies using trained assessors have confirmed significant differences between wild-caught and aquaculture fish (Grigorakis, 2007; JACUMAR, 2012). Nevertheless, there is still limited information about how consumer's perception is affected by sensory properties in both types of fish.

Food product research & development

Sensory analysis is considered a necessary part of food product development (Giacalone *et al*., 2013). In this sense, the scientific focus of any food production initiative needs to relate sensory properties of products to human response (Meiselman, 1993). Based on these premises, Mauracher *et al.* (2013) investigated about consumer preferences regarding the introduction of a new organic Mediterranean Seabass in the Italian market. The study focused on the consumer attitudes towards organic fish and aimed to verify whether production method should be preferred to other differentiating strategies such as geographic origin. The objectives of this work were accomplished by means of a choice experiment (CE), which is a classical methodology in products research and development usually applied to evaluate people's preferences regarding products, services or policies in economic terms (Batsell & Louviere, 1991). The conclusion of this research suggests that while organic aquaculture might be a novel strategy for diversification if appropriate communication and information are not considered, the final consumers might not be aware of the advantages of the production method.

Quality management in the seafood industry

The sensometrics could represent an excellent decision-making tool for the quality management systems in the seafood industry. Calanche *et al.* (2013) assessed the

effectiveness of a cold chain for fresh fish, salmon (*Salmo salar*) and sardine (*Sardina pilchardus*), in a food processing plant. Sensory analysis was applied using an "official UE sensory assessment scoresheets for fish and shellfish". This study established that there is a great susceptibility of fresh fish quality parameters to the cold chain, being able to differentiate a uniform process for salmon and other highly heterogeneous for sardines. The results could be attributed to the fish different production methods, farmed and captured respectively. This study demonstrated that aquaculture could improve both a standard quality (homogeneity) and availability of fish to make final products.

Any food production operation needs to consider and improve each step in the whole process of food reaching the final consumer, from the way it is cultivated, to how it is harvested, processed, packaged, sold and consumed (FAO, 2003). It is possible to sustain that having the right resources, especially appropriate software and techniques, aquaculture sector could develop, through sensometrics, comprehensive data to adjust and improve its production practices and final products. Aquaculture development has increasingly contributed to the availability, accessibility, and stability of fish supply all around the world. Part of this development has been driven by transformation of diets, supply chains and new technologies (Belton *et al*., 2018).

Environmental issues

Nowadays, sustainable development and ecological production are essential issues to be considered in the aquaculture industry. Sensometrics together with marketing research would be a useful tool to address these issues adequately. People's risk perception can modify consumer acceptability of fish products, hence lessening the potential contribution of fish to nutrition and health. Eltholth *et al.* (2018) developed a study aimed to assess the prevalence

and level of contamination with selected chemical and microbiological pollutants in farmed tilapia produced and marketed as fresh fish in the Nile delta of Egypt. The results revealed that farmed tilapia in the Nile Delta presents a relatively low level of chemical contaminants (pesticide residues and heavy metals) and is safer than wild caught fish in contradiction to consumers' perceptions (Eltholth *et al*., 2015). Sensory analysis could complement and strengthen the results from this type of study.

Van Osch *et al.* (2017) applied a choice experiment to estimate whether the Irish public is willing to pay a price premium for a more environmentally friendly farm-raised salmon through Integrated Multi-Trophic Aquaculture (IMTA) systems where several species are combined in the production process. The results of this work revealed that Irish public has a favourable preference for more environmentally sustainable and locally produced salmon. The paper also concludes stressing the need for further research to assess other potential impacts of IMTA. Although the attributes evaluated in this research were limited to production location, sustainability level and price, an essential aspect of further studies should include sensory quality assessment of farmed fish produced by IMTA systems.

An example of the above was project SEACASE, which succeeded in proposing tools to minimize the environmental impacts of the sector and to improve the quality and public image of aquaculture products. Quality criteria, such as sanitary condition, nutritional value, yields, body traits, color, sensory attributes and muscle structure were identified as potential markers to differentiate fish reared in different systems. (SEACASE, 2010).

Multidisciplinary approaches

Some studies have compared wild and farmed fish applying a multidisciplinary approach to establish differences in consumption patterns and preferences. Eltholth *et al.* (2015) focused

on the characterization of production, marketing and consumption patterns of farmed tilapia in the Nile Delta of Egypt as part of the required information to overcome production, quality and safety constraint along the farmed fish value chain. This study was based on comprehensive surveys that evaluated the practices and perceptions of all value chain actors, including producers, transporters, retailers and consumers of farmed tilapia in Egypt. The findings of this work suggest that there is a lack of knowledge and traceability affecting consumers' behaviour and farmed tilapia value chain in Egypt. Despite being a study with integral focuses on the agri-food chain, it lacks a minimum analysis that involves the sensory properties of farmed tilapia. In contrast with the previous work, Rickertsen *et al.* (2017) designed one of the most comprehensive studies to investigate French consumers´ preferences for wild and farmed fish, from different origins. This research copes with the need to acknowledge consumer motivations and choices as essential components of any food-producing industry. The experimental design included the assessment of different factors and levels of perception that can influence consumers through a hedonic appraisal, an economic valuation, and a survey focused on attitudes and socio-economic variables. By gathering all this multidisciplinary information, this work offers a complete overview of consumer attitudes and preferences toward wild and farmed fish. The outcomes of this study provide valuable and consistent information that could be applied to optimise the processes within farmed fish value chain in relation to markets? final customers and consumers.

Sensometrics in practice

Sensory evaluation is used to evoke, measure, analyze and interpret reactions to stimuli perceived through the senses (ASTM E253-18a, 2018). The scientific focus of any food production initiative needs to relate sensory properties of products to human response

(Meiselman 1993). This open new possibilities for innovation and quality control in the field of agro-industry since they could be applied to assess the effect of changes in raw material, process and packaging on finished product quality, to verify changes in formulations during product development, to detect and quantify changes in food quality over shelf life and to establish acceptability and preference for consumption. Nowadays, transference of sensory methods to the consumer is a new trend in marketing research. According to this, sensory data can be used to analyze consumer preferences for particular features in a product. Furthermore, consumer attitudes towards food products can be assessed to determine specific markets among consumers (Verbeke et al., 2007; Kole et al., 2009 & Claret et al., 2014). Thus, product characteristics from the consumers' perspective could be established and measured.

Who should participate in a sensory study?

The sensory properties of food products are a major factor in ensuring product success. Sensory analysis requires human factor as a fundamental tool to make judgments about the perception of stimuli generated by organoleptic properties of food. There are many reasons for using people in food analysis and agrifood marketing. The main motives include that there are not appropriate instruments available to measure sensory quality in a general way. Besides, human being is relatively easy to train and provides a quick response with valuable qualitative and quantitative information that could be efficiently analyzed and interpreted.

Selection of people is a key step in the sensory analysis and it will be determined by the main objectives of the research. A sensory analysis panel constitutes a true "measuring instrument", and consequently the result of the analysis depends on its members. The recruitment of people willing to participate in a panel therefore needs to be carried out with

care and to be considered as a real investment, both in time and money (Legarth & Zacharov, 2009).

There are different kinds of categories for people employed in sensory evaluation, each one is called in a specific way and these terms have been standardized in the agricultural food industry to describe different kinds of assessors. According to ISO 8586:2012 (2012), sensory assessment can be performed by: a) "Sensory assessors" who is any people taking part in a sensory test. They can be "naive assessors" who do not have to meet any precise criterion, or "initiated assessors" who have already participated in sensory tests (ISO 5492:2008, 2008). It is important to emphasize that the use of consumers in order to assess some food aspect that require perceiving, evoking and remembering sensory properties will be inside this category. b) "Selected assessors" are chosen for their ability to perform a sensory test. c) "Expert sensory assessors" are selected assessors with a demonstrated sensory sensitivity and with considerable training and experience in sensory testing, who are able to make consistent and repeatable sensory assessments of various products (ISO 5492:2008)./

Studies focused in hedonic aspects or preferences (beliefs, values and prejudices) should use consumers or sensory assessors for collect data through the application of affective tests. The information gathered from these tests will be very subjective but it involves a global appraise where many variables have been considered in an unconsciously way. For that reason, the use of this kind of assessors should be avoided to develop objective studies that involve specific quantitative assessments. When it is intended to establish, describe, compare and quantify intensities of sensory attributes, or another activity that requires previous training, knowledge or expertise, "Selected assessors" or "Expert sensory assessors" should be used. Another option could be to employ "Experts", who are persons that, due to their knowledge or experience, are competent to give an opinion in the areas in which they are

consulted (ISO 5492:2008). However, this choice could provide limited information and it is expensive. It is not advisable to use expert and trained judges to perform affective tests because their criteria may be far from those of an average consumer.

Main areas of application

During the last two decades, aquaculture has been focused on different topics or areas of research related to sensometrics where "nutrition and feeding" has a significant share. For most aquaculture operations is very important to test and verify the effects of diets on the growth and development of fish with commercial importance. The substitution of ingredients used in the manufacture of aquafeed has been a recurring theme and in force (Izquierdo *et al*., 2005; Sanchez-Losano *et al*., 2009; Valente *et al*., 2015; Sheperd *et al*., 2017).

Another topic of research is related to the link between "quality of the final product" and "effects of production parameters." The quality of farmed fish is an intricate balance among morphological, physicochemical and sensory characteristics, which are vulnerable to the farming conditions, product manipulation and the general processing. Therefore this is considered as a critical point because one of the advantages offered by aquaculture is the supply of standard products, especially in species marketed as a whole (Regost *et al*., 2001; Jones *et al*., 2016; O´Neill *et al*., 2016; Fragkoulis *et al*., 2017). Many parameters involved in the aquaculture production process have a significant role in the final product quality. Breeding techniques, harvesting methods, and slaughtering practices represent the most critical areas for sensory studies application (Palmeri et al., 2009; Cassol et al., 2015; Zhang *et al*., 2017).

Understanding consumer behaviour and opinion is a vital aspect of marketing and is the? key to the success of any business enterprise where aquaculture is no exception. Consumers´

preferences or beliefs play an essential role in the buying decision-making process. In this sense, some of the most common examples are the comparison between local and imported fish, or the preference for wild-caught versus farmed-raised fish (Rincon *et al*., 2016; Badiola *et al*., 2017).

Table 1 offers a general summary about studies in aquaculture, published during the last 20 years (2001-2019), that considered the effect of different variables over organoleptic properties of farmed fish or seafood. The purpose of this table is to serve as a brief reference for the design and development of research in aquaculture. This synoptic table includes information about authors, year, species, location, application area, and purpose of research, analytical methods and sensory aspects (applied analysis, tools or methods, kind of assessors employed and sensory attributes evaluated).

Species considered

The sensory analysis research applied to aquaculture has been developed in different ways depending on the species implicated. Production technologies of both freshwater and marine finfish aquaculture species have evolved according to their economic value but also by the investment of resources in research, development and innovation activities.

Gilthead seabream

Among fish species involved in sensory analysis research, gilthead seabream (*Sparus aurata*) is one of the leading aquaculture species with the highest number of studies. Most of the experiments in this species aim to assess the functional and sensory properties in the final product as result of the dietary modification, substitution or supplementation with different compounds. The use of plant ingredients has been evaluated in diets for gilthead seabream

with different results on composition, sensory properties, and nutritional value of final products (Izquierdo *et al*., 2005; Sanchez-Losano *et al*., 2009; Matos *et al*., 2012; Peso-Echarri *et al*., 2012; Ribeiro *et al*., 2015; Alexi *et al*., 2016). A scale of quality for the body shape of gilthead seabream has been designed through a sensory study that used as main reference the phenotype of wild-caught fish and taking into account the consumer preferences, (Fragkoulis *et al*., 2016).

Trout

Many studies have been published with sensory analysis from various trout, primarily rainbow trout (*Oncorhynchus mykiss*). Sensory analysis research on trout has been mainly directed to evaluate the effect of nutritional changes, but not all include the quality assurance of the final product. Brinker and Reiter (2011) studied the use of different plant protein ingredients as fishmeal replacement; assessment of flesh quality parameters from fish fed the test diets showed slight variations among groups although these were not detected by a sensory test panel. Gai *et al*. (2016) evaluated the use of bacterial protein meal and pea protein concentrate as dietary protein sources in rainbow trout. The sensory analysis used an untrained panel, with a higher preference for fillets of trout fed the diet that combined both alternative protein sources. Turchini *et al*. (2013) evaluated the substitution of fish oil by canola oils at increasing dietary inclusion levels (60%, 75%, and 90%) in a feeding experiment with rainbow trout. This study detected only minor effects on organoleptic/sensorial attributes using a Quantitative Descriptive Analysis (QDA). Trullas *et al*. (2017) evaluated quality characteristics of fillets of rainbow trout fed acid and re-esterified rapeseed oils like fish oil dietary replacers. However sensory analysis, a vital aspect of the quality fillet evaluation was not developed. In a paper with pertinent information for the

aquaculture feed industry and fish consumers, Valente *et al*. (2015) evaluated the effect of *Gracilaria vermiculophylla* at different dietary inclusion levels (0, 5 and 10%) on rainbow trout growth and flesh quality attributes. This study demonstrated that inclusion of *G. vermiculophylla* up to 5% could modify the nutritional value of rainbow trout by increasing the iodine content in the flesh. Sensometrics applied in this work was very successful and adequate. The sensory panel perceived that samples of fish fed diets with 5% of the algae had the higher colour intensity and were juicer than those fed the diet without seaweed.

A study aimed to evaluate the inclusion of a full-fat *Tenebrio molitor* larvae meal in aquafeeds for rainbow trout reported no significant effects of this alternative ingredient on growth (Belforti *et al*., 2015). However, dorsal muscle proximate and fatty acid compositions in the groups of fish fed the experimental diets were affected. The authors recognize the importance of further studies aiming to limit the negative effects of this insect meal on the nutritional value of trout fillets and assume it could be a promising candidate as an ingredient for growing phases of rainbow trout. This study, as many other studies focused on the evaluation of alternative protein ingredients for aquafeeds, did not consider the relevance of a complete sensory quality description. In contrast, Seally *et al*. (2011) investigated the effects of replacing dietary fish meal with enriched black soldier fly prepupae (*Hermetia illucens*), in rainbow trout and concluded that inclusion of this alternative ingredient could be used to replace up to 50% of the fishmeal in practical diets for trout without significantly affecting fish growth or the sensory quality of fillets.

Salmon

Salmonids constitute a high-value fish group in aquaculture and one of the most important seafood commodity traded worldwide (Tveterås *et al*., 2012). The importance of analysing

456 different parameters related to salmon farming conditions and their effects on the final quality
457 of fillet is now increasingly recognised (Ørnholt-Johansson *et al*., 2017). However, a majority
458 part of the studies conducted with salmon and other high-value aquaculture species is limited
459 to the determination of final product physicochemical differences without considering the
460 sensory assessment. If the consumers and/or a trained panel are not able to perceive the
461 reported differences, the results derived from this type of studies would not have a real impact
462 on the final product quality regarding consumer preferences. Badiola *et al*. (2017) recognise
463 that any food product needs to meet consumers demand and that descriptive sensory tests
464 offer a sophisticated tool to evaluate sensory attributes of different products through
465 consumer responses. The authors studied the consumers' acceptance of experimentally
466 reared and commercial reared salmon flesh finding no significant differences in sensorial
467 properties between fillet samples. The organoleptic, sensory and consumer preference
468 information provided by this work is a valuable assessment of new aquaculture technologies.
469 Shepherd *et al*. (2017) analysed the trends in the salmon diets composition changes at
470 Scottland concerning the availability and use of main feed ingredients. The authors concluded
471 that Scottish salmon farming supply a differentiated product and that any change in the diet
472 composition will still support the production of high quality, healthy farmed salmon.
473 However, to cope with this goal salmon industry, in general, need to base their whole
474 production processes on consumers behaviour and responses.
475
476 Inland fish
477 Inland aquaculture species, excluding those already traditional as trout, are beginning to have
478 a meaningful market share, where species like Tilapia, Panga, Nile Perch, Barramundi and
479 others have well-defined customers and markets. Wing-Keong and Bahurmiz (2009)

480 evaluated the impact of dietary oil source and frozen storage on the physical, chemical and
481 sensorial quality of fillets from market-size red hybrid tilapia, *Oreochromis sp.* Sensory
482 qualities using a quantitative descriptive analysis revealed a little impact on sensory attributes
483 of fillet from tilapia fed diets with 100% substitution of fish oil with palm oil. Teixeira *et al*.
484 (2017) evaluated the potential use of *Aloysia triphylla* essential oil (EOAT) as an anaesthetic
485 for Nile tilapia demonstrating its effectiveness, and that does not affect organoleptic
486 characteristics of the fillets based on taste or odour. However, the use of a discrimination
487 test, such as the Duo-Trio, would have been more appropriate to achieve the primary
488 objective of this study.

489 There is, in less number, other sensorial quality studies dedicated to freshwater
490 aquaculture species with an emerging commercial value in different parts of the world.
491 Palmeri *et al*. (2009) researched biometric, nutritional and organoleptic attributes of Murray
492 cod (*Maccullochella peelii peelii*) during the purging process, which is commonly applied in
493 recirculating aquaculture systems to ensure that the fish reaches the marketplace with an
494 empty gastrointestinal tract and without possible off-flavours. The use of sensory analysis
495 in this study would have made the information on volatile compounds much more valuable
496 and determinant to evaluate consumer preferences and responses. Conversely, Jones *et al*.
497 (2016) evaluated the use of the algae *Ulva ohnoi* in a finishing diet for barramundi (*Lates*
498 *calcarifer*) as a way to alter its organoleptic characteristics. The authors stress that the
499 primary consideration when formulating aquafeeds is to maximise growth without much
500 consideration about the effect on flavour, taste, and aroma of the final fillet. An adequate
501 sensorial analysis was applied in this study, confirming that feeding barramundi a diet
502 supplemented with *U. ohnoi* was a useful way to modify the organoleptic attributes of fillet,
503 which resulted with a distinctive seafood-like flavour. Cassol *et al*. (2015) conducted a study

to check the effect of different stunning methods on the meat quality of the hybrid Pintado Amazônico, stored on ice. Sensory quality attributes of fish samples were assessed correctly over the storage time by a trained panel proving the direct influence of the well-being of fish during the stunning that precedes slaughter on the quality of the end product.

Other species of interest for marine aquaculture

Other marine fish species, especially those with a growing commercial interest, has been the subject of research in aquaculture studies that included the use of sensory analysis. For example, Rincon *et al.* (2016) verified the differences between wild-caught and farmed blackspot seabream (*Pagellus bogaraveo*), which is a promising aquaculture species. The authors recognise that the improvement of sensory and compositional knowledge are vital tools to establish specific husbandry conditions that help to reach the consumers' preferences in final products. Besides the evaluation of some parameters affecting quality, the authors conducted an extensive sensory assessment in this study through a Quantitative Descriptive Analysis. This work concluded that wild-caught and aquaculture blackspot seabream might be differentiated using sensory evaluation, total lipid and collagen content, fatty acid profile, skin colour and muscle fibre proportion and morphology. This study can be considered as one of the most complete regarding the use of sensometrics in aquaculture research.

Cabral *et al*. (2013) evaluated the replacement of fishmeal by increasing levels of plant protein sources on growing sole (*Senegalese sole*). The sensory results from this work using Quantitative Descriptive Analysis showed that the replacement did not have a significant impact on the majority of the descriptors assessed. Regost *et al*. (2001) developed a study in turbot (*Psetta maxima*) to assess the effects of fat concentration in diets on chemical

composition, lipogenesis and flesh quality. Sensory analyses employing intensity scales detected a difference of sweet flavour.

Many studies, directly related to the quality of farmed marine fish, actually do not consider the application of any sensory methodology despite the prominent role of sensory analysis in quality control for this kind of food products. For example, O´Neill *et al*. (2016) determined the degree of nutritional variation within cultured yellowtail (*Seriola lalandi*) as a way to inform which fish portion best meet consumer's nutritional needs without considering if they will accept its sensory quality.

Seafood (shellfish and crustaceans)

Shrimp, together with salmon, are the most traded seafood commodity worldwide. Shrimp farming represents a major food-producing industry around the world and a vital source of income and employment in different countries. As in fish farming, the research subject of dietary improvement by raw-materials substitution is in force. The effect of substituting fishmeal by terrestrial protein alternatives on production and economic performance of this species has been widely studied (Molina-Poveda *et al*., 2015; Sabry-Neto *et al*., 2016; García-Ulloa *et al*., 2017). However, most feed and nutrition studies with shrimp did not consider the use of sensory analysis, although a change in diet usually implies a modification in the organoleptic properties of the final product.

The same situation is evident in other studies with different aquatic species. In octopus (*O. vulgaris*), Cerezo and García (2016) investigated the influence of semi-moist diets formulated with an improved amino acid profile and a mixture of binders on growth. Gianasi *et al.* (2017) researched about the influence of diets on sea cucumber (*Cucumaria frondosa*) morphological and biochemical plasticity. Zhang *et al.* (2016) evaluated if different

551 production methods affect oysters quality (*Crassostrea virginica*). Authors applied a set of
552 quality measures based on physicochemical properties. The main conclusion derived from
553 this study was that methods and quality indicators established an efficient and objective way
554 to evaluate oysters quality and freshness compared with sensory panel assessment. Although,
555 most aquaculture nutrition and feeding studies include the topic of "final product quality"
556 among their main aims almost none of them do apply sensory analysis. In our judgment, a
557 study that does not correlate the data obtained from physicochemical assays with an adequate
558 sensometrics report has a limited scope. Thus, it is evident that aquaculture still has much to
559 learn from other areas of knowledge to improve its development and to extend its reach,
560 especially from sensometrics.
561
562 What should researchers in sensory analysis propose to producers and marketers?
563 From a global perspective, fish or seafood consumers' preferences are related to those
564 attributes that could be considered common to all species, for example: freshness of product
565 (day on ice), attractive prices, permanent availability and correct labelling (Alfnes et al, 2018;
566 Claret et al., 2012; Kole et al., 2010). However, in sensory field each species has some
567 specific characteristics that define it and determine its commercial importance. Regular or
568 casual consumers of farmed fish, after some time, become accustomed to its sensory
569 characteristics, setting them as quality criteria (Claret et al. 2014). Nevertheless, due to a lack
570 of information they are unaware of this fact. In this sense, there is an important need to
571 standardize the sensory criteria for the different agents in the agro-food chain, especially in
572 the consumer. This could be achieved through adequate education that made the consumer
573 able to recognize the quality requirements for farmed fish in a clear way. Likewise,
574 fishmongers and fish-farmers should try to harmonize their criteria about sensory quality and

join forces in the same direction to achieve the appropriate sensory requirements detected from specific consumer´s needs and expectations (Arditti 1997).

Conclusion

One of the bottlenecks for future intensive aquaculture growth and development is the high dependence on fishmeal and fish oil, especially for high-value carnivorous fish species. The sector is nowadays moving towards partial or total dietary substitution of these marine ingredients for alternative sources of protein and lipid. Nevertheless, the real value of such efforts remains controversial. Developing an effective strategy to replace fishmeal and fish oil in feeds is a priority aim. However, the research developed to improve this situation must take into account the primary purpose of aquaculture, supply aquatic food for people where consumer perception has a crucial importance regarding consumption and purchase. Satisfying nutritional demands is one of the essential requirements of consumers but ensuring their satisfaction about the sensory characteristics of the food that makes it appeal and tasty also plays a crucial role. If produced not only efficiently but considering sensory quality aspects, farmed fish could become the best option for consumers. Aquatic animals produced with new aquaculture technologies and alternative feed ingredients will have to consider sensory quality aspects of the final products to be widely accepted by consumers. Of course, without leaving aside that these products must be healthy and sustainable the consumer perception need to be considered since it is more than relevant to the acceptance and commercial success of aquaculture-derived foods

What is needed, above all, is close the gap between consumer response concerning the effect of nutrition and feeding modifications, changes in production aspects, quality requirements alterations and the marketing strategies implementation. The above only will

599 be possible if current aquaculture practices enhance its production processes with the findings
600 and possibilities offered by sensometrics. Aquaculture producers and researchers must start
601 paying attention to the consumers and getting to know them. Future technological
602 development must face the challenges in aquaculture industry based on an approach that
603 includes sensometrics as a strategic decision-making tool that fully satisfies the consumer
604 needs.

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610

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Table 1. Synoptic table of some studies in aquaculture related to sensory properties of farmed fish during the last 20 years

Specie	Country	Application area	Principal purpose of research	Use of analytical methods	Sensory analysis applied	Sensory data collected from	Tools/method used for sensory data collection	Sensory aspects valuated	Authors
Arapaima gigas	BRASIL	New development	To carry out R + D + i activities	×	×	Selected assessors	Hedonic scale	General acceptance	Pino *et al.* (2017)
Bivalves	PORTUGAL	Marketing	To develop consumer research	×		Consumers opinion	Quality Index Method	Freshness	Cassol *et al.* (2015)
Bream	SPAIN	Quality product	To establish quality attributes for fish	×	×	Selected assessors	QDA	Sensory profile	Rincón *et al.* (2016)
Cod	NETHERLANDS	Marketing	To compare wild vs. farmed (information effect)		×	Consumers opinion	Survey	Marketing	Kole *et al.* (2009)
Cod	EUROPE	New development	To carry out R + D + i activities		×	Sensory assessors & selected assessors	Intensity scale/ hedonic valuation/on line questionnaire	Sensory profile/ preference	Sveinsdóttir *et al.* (2009)
Eurasian perc	CZECH REPUBLIC	Production	To compare sensory and physicochemical parameters with farming methods	×	×	Selected assessors	Intensity scales	Odour, flavour, aftertaste and consistency	Stejskal *et al.* (2011)
Fish	PORTUGAL	Nutrition & food	To analysis the state of the art (alternative oils for use in diets)	NA				Final quality of products	Oliva-Teles *et al.* (2015)
Giant perch	AUSTRALIA	Quality product	To improve the sensory quality	×	×	Selected assessors	Triangle/intensity	QDA	Jones *et al.* (2016)
Meagre	PORTUGAL	Quality product	To compare wild and farmed	×	×	Selected assessors	QDA	Sensory profile (flesh texture)	Saavedra *et al.* (2017)
Meagre	SPAIN	Quality product	To evaluate the loss of quality and freshness	×	×	Selected assessors	Continuous scale of demerit points	Quality & freshness	Hernández *et al.* (2009)
Murray Cod	AUSTRALIA	Production	To evaluate the effect of purge in the farm					Quality (fat & TVB-N)	Palmeri *et al.* (2009)
Mussels	PORTUGAL	Quality product	To compare different origins from bivalves	×	×	Selected assessors	Categorical scale	Sensory attributes fresh and cooked	Oliveira *et al.* (2015)
Octopus	SPAIN	Nutrition & food	To improve diets	×					Cerezo and García (2016)
Oyster	CHINA	Production	To assesses farming methodology	×				Texture	Zhang *et al.* (2017)

Table 1 (continued)

Specie	Country	Application area	Principal purpose of research	Use of analytical methods	Sensory analysis applied	Sensory data collected from	Tools/method used for sensory data collection	Sensory aspects valuated	Authors
Pintado amazónico	BRASIL	Production	To evaluate the effect of slaughtering	×	×	Consumers opinion & selected assessors	Lineal scales	Appearance, flavour & texture	Valente *et al.* (2015)
Red drum (*S. Ocellatus*)	MEXICO	Production/ quality products	To evaluate aquaculture systems (freshwater vs sea)	×	×	Selected assessors	Hedonic scale	Texture, odour and colour	Klanian and Alonso (2013)
Salmon	UK	Nutrition & food	To replacement with vegetable proteins			Consumers opinion	Survey	Willingness to pay	Van Osch *et al.* (2017)
Salmon	SPAIN	Quality product	To compare local vs. imported		×	Consumers opinion	Survey	Origin of fish	Shepherd *et al.* (2017)
Salmon	IRISH	Marketing	To establish WTP for sustainable production			Consumers opinion	Likert scales	General aspect	Badiola *et al.* (2017)
Salmon	DENMARK	Quality product	To compare different origin from fish	×				Texture	Ørnholt-Johansson *et al.* (2017)
Salmon	CANADA	Nutrition & food	Full & partial substitution of oil fish by camelina and camelina oil	×	×	Sensory assessors	QDA/discriminant test/hedonic scale	Sensory profile/ preferences/ appearance, odour & texture	Hixson *et al.* (2014)
Salmon	SPAIN	Quality product	To evaluate the effect of cooking method and origin of fish	×				Lipids and volatile components	Nieva-Echevarría *et al.* (2018)
Sea urchin	ITALY	Nutrition & food	To evaluate the effects of diets in overall quality	×	×	Selected assessors	Subjective score scale	Colour, texture (firmness) and flavour	Prato *et al.* (2018)
Seabass	ALGERIA	Production	To evaluate the effects of farming conditions over quality	×	×	Expert sensory assessors	UE freshness rating	Freshness	Mokrani *et al.* (2018)
Seabass	ITALIA	Marketing	To establish the willingness to pay (WTP)			Consumers opinion	Choice experiment	Willingness to pay	Mauracher *et al.* (2013)
Seabass	ITALY	Production	To differentiate ecological products	×				Colour	Costa *et al.* (2013)
Seabass	SPAIN	Quality product	To evaluate the relationship between sensory quality and free amino acids	×	×	Expert sensory assessors	UE freshness rating/ torry scheme/quality descriptive analysis (QDA)	Freshness/sensory profile	Calanche *et al.* (2019)
Seabream	PORTUGAL	Marketing	To establish consumers' preferences in fish consumption		×	Consumers opinion	Questionnaire	Consumers' expectations	Ribeiro *et al.* (2019)

Table 1 (continued)

Specie	Country	Application area	Principal purpose of research	Use of analytical methods	Sensory analysis applied	Sensory data collected from	Tools/method used for sensory data collection	Sensory aspects valuated	Authors
Seabream	GREECE	Quality product	To compare Wild Vs. Farmed	×	×	Consumers opinion		Final quality of products	Trullàs *et al.* (2017)
Seabream	GREECE	Nutrition & food	To improve the sensory quality	×	×	Selected assessors	Intensity scales	Appearance, flavour and texture	Alexi *et al.* (2016)
Seabream	PORTUGAL	Nutrition & food	To evaluate effects of diets with macroalgae	×	×		Survey	Marketing and production	Eltholth *et al.* (2015)
Seabream	PORTUGAL	Nutrition & food	To try supplementation with vegetable sources	×	×	Selected assessors	Non-structured scale	Colour, odour and flavour	Matos *et al.* (2012)
Seabream	SPAIN	Nutrition & food	To evaluate the effect of alginate in diets	×	×	Selected assessors	Duo-trio	Appearance & texture	Peso-Echarri *et al.* (2012)
Seabream	FRANCE	Production/ quality products	To evaluate the effect of the farming method over the standard quality	×	×	Selected assessors	Intensity scales	Odour, flavour, texture and appearance in cooked fish	Cardinal *et al.* (2011)
Seabream	SPAIN	Nutrition & food	Changes in diets (vegetable sources)	×	×	Selected assessors	Triangle	Flavour, texture & juiciness	Sánchez-Lozano *et al.* (2009)
Seabream	SPAIN	Marketing	To evaluate different diets	×	×	Selected assessors	Likert scales	Aspect & colour	Izquierdo *et al.* (2005)
Seabream	SUDAFRICA	Quality product	To assess the final quality of the product	×					O'Neill *et al.* (2017)
Seriola	ECUADOR	Nutrition & food	To evaluate effects of vegetable diets	×					Molina-Poveda *et al.* (2015)
Shrimp (*L. vannamei*)	PORTUGAL	Nutrition & food	To evaluate changes in diets (vegetable sources)	×	×	Selected assessors	Intensity scales	Appearance, flavour & texture	Cabral *et al.* (2013)
Sole	ITALY	Quality product	To compare Wild Vs. Farmed	×	×	Selected assessors	Triangle test/QDA	Farming method/ sensory profile	Parma *et al.* (2019)
Sole	BRASIL	Production	To evaluate the effect of anaesthesia	×	×	Consumers opinion	Anchored scales	Odour and flavour	Teixeira *et al.* (2017)
Tilapia	EGIPT	Marketing	To make a Cross-sectional study			Consumers opinion	On line survey	Preference	Anacleto *et al.* (2014)
Tilapia	MALASIA	Nutrition & food	To evaluate effects of diets	×	×	Selected assessors	Descriptive test	QDA	Wing-Keong and Bahurmiz (2009)
Tilapia	USA	Nutrition & food	To evaluate effects of different diets (alternative protein)	×	×	Sensory assessors	Paired difference test & paired preference test	Aroma, flavour, and texture	Craft *et al.* (2016)
Trout	SPAIN	Nutrition & food	To try a change in the composition of diets (Oils added)	×		Consumers opinion	Survey	Morphology	Fragkoulis *et al.* (2017)

Table 1 (continued)

Specie	Country	Application area	Principal purpose of research	Use of analytical methods	Sensory analysis applied	Sensory data collected from	Tools/method used for sensory data collection	Sensory aspects valuated	Authors
Trout	ITALY	Nutrition & food	To evaluate different diets	×	×	Consumers opinion	Likert scales	Aspect & colour	Gai *et al.* (2016)
Trout	PORTUGAL	Nutrition & food	To try diets with seaweed added	×	×		Lineal scales	General aspect	Ribeiro *et al.* (2015)
Trout	AUSTRALIA	Nutrition & food	To evaluate the effect of vegetable oils added	×	×	Selected assessors	Intensity	QDA	Turchini *et al.* (2013)
Trout	USA	Nutrition & food	To evaluate different diets with *H. illicuens* incorporated	×	×	Consumers opinion & sensory assessors	Quality descriptive analysis/triangle difference test	Sensory aspects: odour, flavour & texture	Sealey *et al.* (2011)
Trout	GERMANY	Nutrition & food	To evaluate different diets	×	×	Selected assessors	Intensity scales	Aspect & colour	Brinker and Reiter (2011)
Trout	DENMARK	Nutrition & food	To evaluate the effect of garlic in diets	×	×	Expert sensory assessors	Quality Index Method/ hedonic scale	Freshness/global acceptability	Green-Petersen and Hyldig (2010)
Trout	FRANCE	Quality product	To assess the final quality of the product	×	×	Selected assessors	Intensity (lineal scales)	Appearance, flavour & texture	Regost *et al.* (2001)
Turbot	FRANCE	Marketing	To explorer WTP in consumer preferences study	×	×	Consumers opinion	Check-all-that-apply/ QDA	Preference/sensory profile	Lazo *et al.* (2017)
Greater amberjack, Pikeperch, Grey mullet, meagre & Wreckfish	EUROPE	New development	To carry out R+D+i activities		×	Sensory assessors & selected assessors	Survey/hedonic score	Willingness to pay/ general acceptance	Rickertsen *et al.* (2017)
Salmon, Cod, Monkfish, and Pangasius	SPAIN	Marketing	To establish consumer's liking for fish		×	Consumers opinion	Likert scale/survey	Production/ marketing	Claret *et al.* (2016)
Black spot sea bream, sea bream, sea bass & turbot	EUROPE	Quality product	To evaluate fish's origin effect		×	Consumers opinion	Cross-sectional consumers/ questionnaire	Marketing	Vanhonacker *et al.* (2011)