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Sensory characterization, physico-chemical properties and somatic yields of five emerging fish species

Oxana Lazo[a,d], Luis Guerrero[a,*], Niki Alexi[b,e], Kriton Grigorakis[b], Anna Claret[a], José A. Pérez[c], Ricard Bou[a]

[a] IRTA-Food Technology, XaRTA, Finca Camps i Armet s/n, E-17121 Monells, Girona, Spain
[b] Hellenic Centre for Marine Research, Agios Kosmas Hellinikon, 16777 Athens, Greece
[c] Universidad de La Laguna Departamento de Biología Animal, Edafología y Geología, Avda. Astrofísico Francisco Sánchez s/n, 38206 San Cristóbal de La Laguna, Santa Cruz de Tenerife, Spain
[d] CIBA Research Center for Applied Biotechnology, Carretera Estatal Santa Inés Tecuexcomac Km 1.5, 90700 Tepetitla, Tlaxcala, Mexico
[e] Food Quality Perception & Society, Department of Food Science, Aarhus University, Kirstinebjergvej 10, DK-5792 Aarslev, Denmark

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ABSTRACT

Aquaculture plays an important role in supplying the fresh fish. However its production is dominated by only few long-established species that in turn limit the variety of available products in the market. Therefore, new fish species need to be properly introduced to create a diversification in the current market. In order to achieve this goal, it is important to know, understand and characterize their quality features so they can be addressed to local and global markets. Sensory, compositional, instrumental texture parameters and somatic properties of five emerging fish species, namely wreckfish, greater amberjack, grey mullet, meagre, and pikeperch, were examined for characterization purposes. Sensory references were specifically developed for the training of the assessors, both from a qualitative and quantitative perspective. Twenty two sensory descriptors were used for describing the samples. Several differences were observed among the measured parameters. Somatic measures revealed the filleting yield to be the most important of them. Regarding the compositional parameters, fat content was among the most relevant discriminating aspect between species, while hardness was among the most differentiating ones when dealing with texture. Greater amberjack was described with sour flavor, pikeperch was associated to an earthy flavor and grey mullet was characterized by bitter flavor. Sensory firmness was clearly distinctive for wreckfish, while meagre related to juicy texture. The analysis of the relationship between all parameters provided important correlations, especially those related to texture parameters, fat content, laminar structure and teeth adherence. The species in this study exhibited a wide range of physicochemical and sensory characteristics that show their potential for being further exploited when designing new products.

1. Introduction

Aquaculture plays an important role in the fish supply of the European market. Europe is the fifth largest producer worldwide, providing about 3.2% of global fish production. However, aquaculture is still far from reaching its full potential development, since only 20% of the total fish production is of aquaculture origin (Europa, 2013). This fact can be attributed to the production costs, the competition for space (inland and coastal) with other activities, as well as to the less positive image of farmed fish when compared with wild-caught counterparts among consumers (Claret, Guerrero, Gartzia, Garcia-Quiroga, & Ginés, 2016; Claret et al., 2014). The relative low market share of aquaculture can also be a direct consequence of the poor variety of aquaculture products in the market, and in particular because of the lack of processed aquaculture foodstuffs (Failler, 2007; FAO, 2012). It is important to remark that product variety has been identified as a relevant factor in order to stimulate consumers' purchase (Lähteenmäki & Arvola, 2001), thus avoiding boredom and satisfying individual curiosity. European aquaculture production is dominated by only few long-established species such as Atlantic salmon (*Salmo salar*), rainbow trout (*Oncorhynchus mykiss*) common carp (*Cyprinus carpio*), European sea bass (*Dicentrarchus labrax*) and gilthead sea bream (*Sparus aurata*) (EATIP, 2012), that in turn limits the number of aquaculture products available in the market. Increasing global consumption of aquaculture fish constitutes a great challenge and opportunity for the EU aquaculture industry. Therefore, the demand for European aquaculture products

* Corresponding author.
E-mail address: lluis.guerrero@irta.es (L. Guerrero).

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Table 1
Origin, season, sample (N), feed and size information of the selected fish species.

Species	Season	N	Origin – farming conditions	Feed	Fish size
Greater amberjack (*Seriola dumerili*)	Winter	8	Farm (Argosaronikos S.A.) – Attiki, C. Greece - floating sea cages	Frozen fish	15–20 kg
Pikeperch (*Sander lucioperca*)	Summer	10	Farm France –sweet water intensive farming	Commercial extruded feed	1–2 kg
Grey mullet (*Mugil cephalus*)	Winter	10	Wild fish. Bay of Cadiz – earthen ponds with sea water	Natural feeding	500 g–1 kg
Meagre (*Argyrosomus regius*)	Winter	10	Farm (Andromeda Group), Burriana, Spain – floating sea cages	Commercial extruded feed	1.5–2 kg
Wreckfish (*Polyprion americanus*)	Winter	5	Wild specimens: 2 caught in FAO 34.1.2 ATLANTIC N by the Canary Islands fishermen and 3 caught in Azores by Galicia's fisheries	Natural feeding	Two specimens of 25–30 kg[a] Three specimens of 2–3 kg

[a] These high weight value specimens were kept to include the range of commercial sizes available in the market.

needs to be further developed. A possible way to satisfy this request could be rearing new emerging species that would provide a higher variety within the EU market.

In order to successfully introduce new species, it is important to characterize their quality features so they can be properly addressed to local and global markets. This characterization often includes somatometric and edible parts' compositional parameters, which could be advantageous tools for product design. Sensory characteristics are also important determinants of food quality and drivers for consumer acceptance and food choice (Siret & Issanchou, 2000); they can also provide valuable information in order to select the most appropriate market for each species and their respective products. Defining and measuring the sensory attributes that characterize fish, seems to be necessary for product development in order to satisfy consumer expectations. The better the knowledge about accurate descriptors that best define fish, the less time needed for its product development (Carpenter, Lyon, & Hasdell, 2000). Moreover, in the case of fish, taste has proven to be the strongest motive of consumption intention (Verbeke & Vackier, 2005).

In order to cover the entire European fish culture domain and to stimulate different aquaculture categories, five species were selected in the present study based on both their biological and economical potential: meagre (*Argyrosomus regius*) and greater amberjack (*Seriola dumerili*) for marine warm-water cage culture, wreckfish (*Polyprion americanus*) for warm- and cool-water marine cage culture, grey mullet (*Mugil cephalus*) for warm-water pond, extensive and integrated culture, and pikeperch (*Sanders lucioperca*) for freshwater intensive culture using Recirculation Aquaculture Systems (RAS). These species, when farmed with sustainable methods, could help the development of high added-value products and represent an important driver for the growth of the of EU aquaculture market.

Several preliminary studies have been already performed over these selected species. Regarding greater amberjack, proximate and fatty acid composition of wild and reared fish (O'Neill, Le Roux, & Hoffman, 2015; Rodríguez-Barreto et al., 2012; Shioya, Takemura, Ishizuka, & Yamaguchi, 2012; Zupa et al., 2017) and some somatometric evaluations and lipid analysis (Rodríguez-Barreto et al., 2012) have been carried out. Respective data on pikeperch are scarce. Pikeperch quality has been assessed focusing on the freshness of wild fish (Özyurt et al., 2007). Some information is also available regarding the quality of farmed fish (Zakęś, Szczepkowski, Jankowska, Kowalska, & Demska-Zakęś, 2012), while Jankowska, Zakes, Zmijewski, and Szczepkowski (2003) compared wild and cultivated pikeperch by analyzing, color, compositional parameters and fatty acid profiles. Meagre has received much more attention in aspects of composition and sensory quality and relevant studies have been recently published (Grigorakis, Alexi, Vasilaki, Giogios, & Fountoulaki, 2016). Giogios, Grigorakis, and Kalogeropoulos (2013) measured somatometric parameters, volatile compounds and fatty acids between two groups of meagre of different size. Overall acceptability was also assessed in order to validate the existence of organoleptic differences as well. In addition, Hernández et al. (2009), estimated the shelf-life of commercial-sized meagre fillets held in ice storage. Sporadic data exist on fat composition (reviewed by Grigorakis et al., 2016) and post-mortem quality changes (Bahmani et al., 2011; Cayhan & Selli, 2011; El-Sabaiy, Metwalli, & Khalil, 1987) of grey mullet. Very few studies have been published regarding wreckfish characteristics. Roncarati, Cappuccinelli, Stocchi, and Melotti (2014) analyzed the proximate composition and fatty acid profile of meat in a wreckfish population from the Mediterranean Sea.

In any case, it is important to highlight that none of the studies found in the scientific literature about these five species focused in their complete sensory quality description, nor the relationship between their different characteristics. Therefore, the aim of this study is to characterize these five fish species based on their somatometric features, compositional, instrumental texture and sensory properties as well as to outline the existing relationship between these quality parameters.

2. Materials and methods

2.1. Experimental fish

Specimens of meagre, greater amberjack, and pikeperch used in the present study were of aquaculture origin whereas wreckfish and grey mullet were caught from the wild (unavailability of reared specimens because of the existence of important bottlenecks for its incorporation into the aquaculture industry) by commercial fishing vessels using long line or fishing nets, respectively (Table 1).

The greater amberjack was slaughtered by bleeding after cutting gill arches, while the meagre and pikeperch were ice-slaughtered according to custom commercial EFSA-approved method (European Food Safety Authority, 2009). Fish were subsequently packed with flaked ice into polystyrene boxes until the somatometric analysis was performed within the first 24 h.

2.2. Somatometric measurements

After reception, total weight and body length were measured in all sampled individuals. Fish from each species were gutted and body weight, visceral, gonad and liver weights were measured as well. Samples were subsequently filleted and fillets were also weighed. The following somatometric indexes were calculated individually:

$$\text{Condition index (CI)} = [100 \times (\text{body weight}/\text{body length})]$$

$$\text{Dressing yield (DY)} = [100 \times (\text{gutted body weight}/\text{body weight})]$$

$$\text{Filleting yield (FY)} = [100 \times (\text{fillet weight}/\text{body weight})],$$

$$\text{Hepatosomatic index (HSI)} = [100 \times (\text{liver weight}/\text{body weight})],$$

Gonadosomatic index (GSI) = [100 × (gonad weight/body weight)]

Viscerosomatic index (VSI) = [100 × (total viscera weight/body weight)].

2.3. Proximate composition

Protein, moisture and ash contents were determined according to standard AOAC (2005) methods. Moisture was calculated gravimetrically after complete drying of fish tissue in an oven at 110 °C overnight, and total inorganic content (ash %) through combustion of organic matter in a muffle furnace for 24 h at 450 °C. Total protein content was determined by the Kjeldahl method and calculated as % Nitrogen × 6.25. Total lipid (TL) was extracted by sample homogenization in chloroform/methanol (2:1, v/v) according to the method of Folch, Lees, and Stanley (1957). The organic solvent was evaporated under a stream of nitrogen and the lipid content was determined gravimetrically (Christie, 1982). All these analyses were performed on three animals from each species.

2.4. Instrumental texture analysis

The right fillets from five animals from each species (pikeperch, meagre, greater amberjack, grey mullet and wreckfish) were used for the instrumental texture analysis. Two different tests were carried out: a non-destructive compression test (compression rate 30%) with a spherical probe (18.4 mm diameter) and a Texture Profile Analysis (TPA, compression rate 75%) (Bourne, 1978) with a cylindrical probe (25 mm diameter). All the tests were performed with a TA-HD plus Texture Analyzer (Stable Micro System, Surrey, England) at a constant speed of 1 mm/s. The non-destructive test (spherical probe) was performed both in the same raw and cooked samples (20 min at 115 °C) in three different parts along the fillet, whereas the TPA was only carried out in cooked samples (because its destructive nature) in two different fillet locations along the whole fillet. Mean values of measurements of each test per animal were retained for statistical analysis. Left fillets from the same animals were vacuum packed and frozen at − 20 °C for sensory analysis.

2.5. Sensory analysis

2.5.1. Panelists and procedure

A panel of eight assessors (with previous experience in sensory analysis of different foods) was chosen in order to select the attributes that best described the fish species and characterize their sensory properties. A total of 21 descriptors (4 for odor modality, 6 for appearance, 5 for flavor and 6 for texture) were selected for the final descriptive profile of these five fish species (Table 2). Descriptors were chosen by means of Check-All-That-Apply (CATA) on a 49 list of attributes from a previous work (Lazo, Claret, & Guerrero, 2016) in one tasting session. In addition to these 21 attributes, sour was also included as a relevant descriptor associated with greater amberjack, since it was clearly identified by all the panelists, so a final list of 22 descriptors was used. To validate the discriminant ability of the selected descriptors between the fish species, assessors also quantified the selected attributes in two sessions. All the descriptors were discriminant among species and were consequently retained for sensory training.

2.5.2. Sensory training

Once the final list of descriptors was settled, reference scales were developed for each of the selected sensory descriptors in order to facilitate the training of the panelist. This procedure was used to help assessors to identify what constitutes high and low amounts of each attribute (Lawless & Heymann, 2010). Appearance, flavor, odor and texture scales were developed using specific references. Fig. 1 (appearance descriptors) and Table 3 show the characteristics of the different reference scales developed for all attributes and their corresponding score obtained as a result of the consensus between all panelists during the training sessions. Sensory references are set by presenting an array of chemicals, ingredients, spices or products that cover the entire sensory spectrum to be described (Rainey, 1986). Along this process, panelists became familiarized with the different descriptors and their intensity scales in order to assess the samples in a more accurate form (Braghieri et al., 2012).

Table 2
Selected descriptors used for the final descriptive profile along with their description.

Attributes	Description
Appearance	
Color intensity	Color intensity from white to light brown inside the flesh of the fish
Color uniformity	Color homogeneity inside the flesh of the fish without black veins or spots
Exudate quantity	Quantity of liquid released after cooking the sample
Fat droplets	Fat released in fish exudate in the form of oil droplets
Laminar structure	Visual distinction of muscular structures when removing the skin of the fish
Turbidity of exudate	Suspended particles in exudate that block transparency
Odor	
Butter	Intensity of odor like butanedione
Earthy	Intensity of odor like humid earth
Sardine	Intensity of odor like fish oil
Sea food	Intensity of characteristic odor
Flavor	
Sour	Flavor like citric acid
Boiled vegetable	Flavor like cooked vegetable
Butter	Flavor intensity like butanedione
Bitter	Flavor like quinine
Earthy	Flavor like humid earth
Sea food	Flavor like seafood
Texture	
Chewiness	Number of chews before swallowing
Crumbliness	Degree of fish disintegration in the first bite
Firmness	Force required to deform the fillet between the tongue and palate
Juiciness	Liquid released when chewing the fish sample
Pastiness	Degree in which fish turns in to a paste after chewing
Teeth adherence	Degree in which fish sticks between molars

2.5.3. Assessment of fish samples

Once panelists were familiarized and trained with the sensory descriptors, quantitative analysis of the fish samples was carried out. Fish fillets had been previously stored, vacuum packed in double aluminum foil bags and frozen at − 20 °C for a maximum of one month period except pikeperch that was stored for 5 months (being acquired during summer season due to its limited availability). Samples were thawed the night before analysis by placing them in the refrigerator (4 °C). Left fillets from the same five animals selected for the instrumental texture analysis were used and cut in pieces of 2 × 2 cm. In all cases, samples were cooked in a convection oven at 115 °C for 20 min (HR 100%) in individual transparent glass jars (Model B-250, Juvasa, Spain) in order to make samples easy to visualize. Jar lids were used throughout preparation and until final assessment to preserve the samples' odor. Immediately after cooking, jars were placed inside a portable electrical heating chamber (Solac, Model 212, 220–240 V) set at 60 °C to keep them warm until being tasted. All five species were evaluated five times in five different sessions (five animals per species). In each session, the order of sample presentation and the first order and carry-over effects were blocked (Macfie, Bratchell, Greenhoff, & Vallis, 1989). Sensory evaluation was performed in a test room designed according to ISO guidelines (ISO 8589:2007). Each panelist assessed the samples placed inside the portable electrical heating chamber so temperature would be maintained. Samples were assessed by means of a semi-structured 10 cm-lineal scale anchored in the two extremes (0 = no presence of

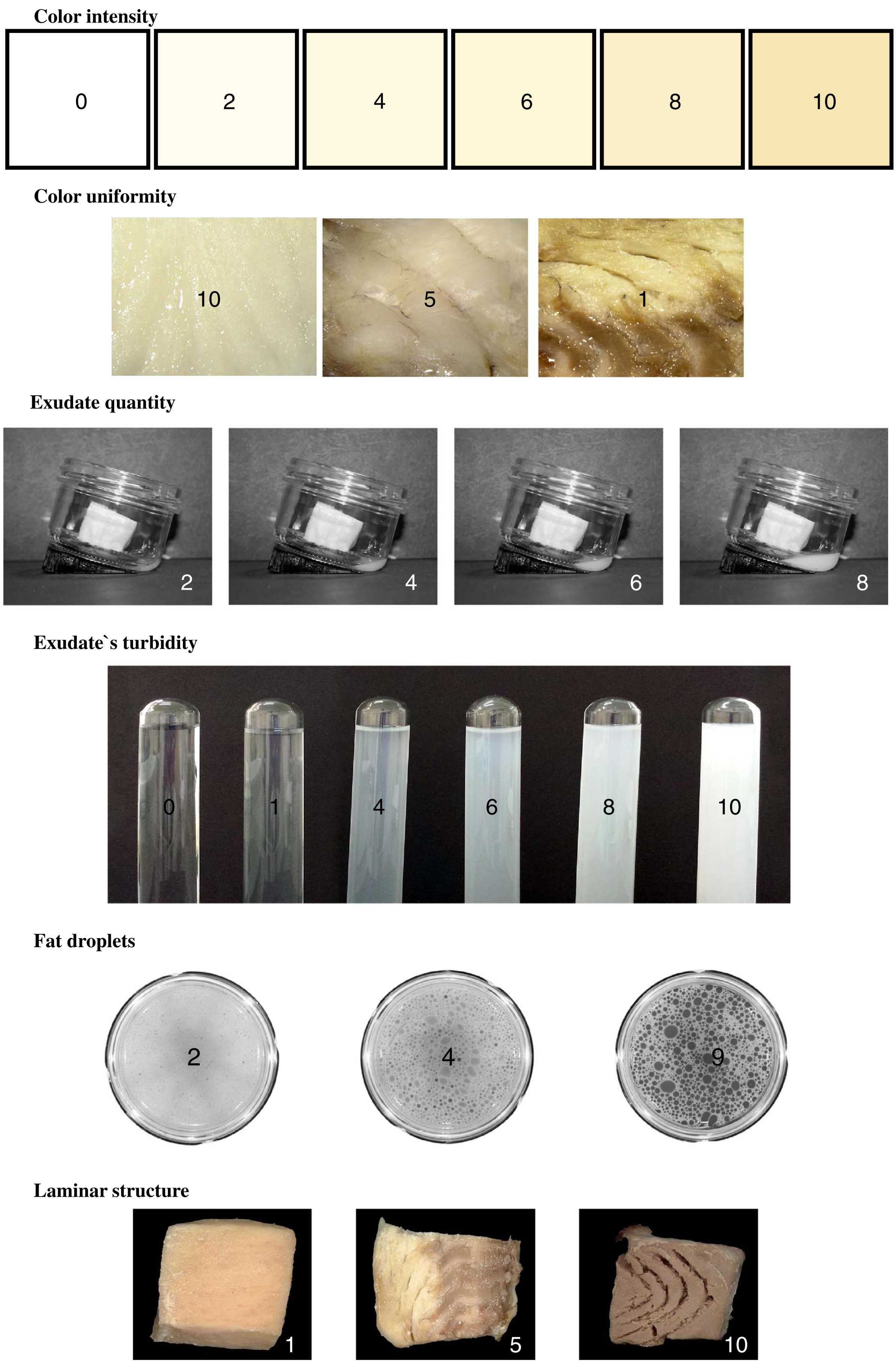

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Fig. 1. Appearance reference scales developed for sensory training.

Table 3
Odor, flavor and texture reference scales used for training in the sensory panel.

Sensory modality	Descriptor	Product used	% of product used	Part of the scale	Score
Odor	Butter	Melted butter (CADI Cat, Spain)	0%	Low	0–1
			4%	Medium	5
			6%	High	10
	Earthy	Geosmine solution 280 ng in 50 ml (AROXA Let. United Kingdom)	28%	Low	2
			33%	Medium	5
			41%	High	8
	Sardine	Omega cod capsules (nuaDHA1000) Vizcaya Spain)	5%	Low	2
			10%	Medium	5
			20%	High	10
	Sea food	Velvet crab (*Necora puber*)	25%	Low	2
			40%	Medium	5
			75%	High	10
Flavor	Sour	Citric acid solution 1 g:70 ml (ACS Panreac Cat Spain)	0%	Low	0–1
			10%	Medium	5
			20%	High	10
	Boiled vegetable	50% potato (*Solanum tuberosum*) 50% green beans (*Phaseolus vulgaris*)	60%	Low	2
			65%	Medium	5
			75%	High	9
	Butter	Melted butter (CADI Cat. Spain)	0%	Low	0–1
			4%	Medium	5
			10%	High	10
	Bitter	Proteolytic enzyme solution 1:1 (Delvolase DSM Delft, The Netherlands)	0%	Low	0
			5%	Medium	5
			10%	High	10
	Earthy	Geosmine solution 280 ng in 50 ml (AROXA United Kingdom)	23%	Low	2
			28%	Medium	5
			33%	High	9
	Seafood	Velvet crab (*Necora puber*)	15%	Low	2
			40%	Medium	5
			50%	High	10

Sensory modality	Descriptor	Reference used	Cooking time	Part of the scale	Score
Texture	Chewiness	Halibut	20 min	Low	1
		Seabream	20 min	Medium	5
		Tuna	60 min	High	10
	Crumbliness	Tuna	65 min	Low	0
		Seabream	20 min	Medium	5
		Halibut	20 min	High	10
	Firmness	Halibut	20 min	Low	1
		Seabream	20 min	Medium	6
		Tuna	65 min	High	10
	Juiciness	Tuna	75 min[a]	Low	0
		Salmon	15 min	Medium	6
		Halibut	20 min	High	10
	Pastiness	Halibut	20 min	Low	0
		Seabream	20 min	Medium	5
		Fish paste with proteolytic enzyme	20 min[b]	High	10
	Teeth adherence	Halibut	20 min	Low	1
		Seabream	20 min	Medium	5
		Salmon	20 min	High	8

[a] Cooked without lid to increase dryness.
[b] 10 g of fish paste with proteolytic enzyme (Delvolase DSM) solution during 20 min with additional 10 g of fish paste.

the descriptor, 10 = high intensity), to score all the selected descriptors. The scoring scale was based on the intensities defined during the training process. All panelists had water to drink as palate cleanser to drink between samples.

2.6. Statistical analysis

To analyze and visualize the CATA data, frequencies of each term were considered for each species. Only those descriptors being cited eight or more times (taking into account all assessors and the five fish species), 21 in total, were retained. The validity of these 21 descriptors together with sour attribute (added because of its presence in greater amberjack) was checked by means of a two way ANOVA (fish species and tasting session as fixed factors) for each assessor (made over the data set obtained from the two replicates performed before specifically training the panelist). All the descriptors were discriminant among species for each assessor and consequently all of them were retained for the final descriptive profile.

Descriptive data of the different animals were submitted to a one- (somatometric and compositional data), two- (instrumental texture) or three- (sensory profile) way ANOVA, including as fixed factors the fish species in all cases, the anatomic zone used of each fillet for the instrumental texture analysis, and the assessor and the tasting session for sensory data. A post-hoc Tukey HSD was computed for comparing the mean values of the different species.

A discriminant analysis was carried out in order to assess the ability of the non-destructive instrumental texture test to differentiate between species both in raw and cooked fish samples.

An additional Principal Component Analysis (PCA) was performed over the mean values of somatometric, compositional, instrumental texture and sensory data in order to examine the main relationship between all the information available. The Pearson moment correlation matrix was also retained from this analysis.

All statistical analyses were performed using XLSTAT 2017 software (Addinsoft, Paris, France).

3. Results and discussion

3.1. Somatometric analysis of the five fish species

Somatometric results of all five fish species are shown in Table 4. Wreckfish was the species with the highest CI, probably due to its generally plumper shape. In particular, wreckfish is a big species, individuals may reach a body length of 2 m, and weigh up to 100 kg, although on average individuals reach 45–55 cm body length (Roncarati et al., 2014). The CI is related to the body geometry of each species and can be indicative of the feeding condition of the fish when individuals of the same species are compared (Grigorakis, 2017). CI has been shown to increase in well-fed fish, e.g. in the intensive farming-originated fish in comparison with extensively farmed and wild fish (Flos, Reig, Oca, & Ginovart, 2002; Grigorakis, 2007; Martelli et al., 2013; Piccolo et al., 2008). Fish shape could act as an additional intrinsic cue affecting consumers' choices. In general, consumers have substantial difficulties in forming quality expectations, especially for fresh products for which little information about the product is normally provided. The formation of quality expectations in these cases is based on a few key cues, principally labeling (including price) and appearance (Font-i-Furnols & Guerrero, 2014).

Dressing yields for all species were quite similar, slightly exceeding 90% except for grey mullet who showed the lowest value. Dressing yield is relevant because it determines the yield when fish is sold as gutted, without further processing, which is a common way of commercialization in the EU for fresh and frozen fish (European Commission Fisheries, 2013).

The highest filleting yields were observed for greater amberjack and for wreckfish, in both cases exceeding 49%. For pikeperch, grey mullet and meagre the filleting yield was found to be similar and slightly lower than 40%. Filleting yield in pikeperch was slightly lower than the

Table 4
Mean values and standard deviation (SD) of somatometric analysis of wreckfish (N = 5) greater amberjack (N = 8), grey mullet (N = 10), meagre (N = 10) and pikeperch (N = 10).

Somatometric parameter	Wreckfish		Greater amberjack		Grey mullet		Meagre		Pikeperch	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total weight (g)	13,028.2[a]	13,716.7	13,000.0[a]	1629.2	748.9[b]	154.29	1834.58[b]	140.40	1096.64[b]	217.25
Condition I (%)	2.48[a]	0.26	1.50[b]	0.07	1.09[c]	0.06	0.86[d]	0.05	0.71[e]	0.13
Dressing yield (%)	91.06[b]	1.64	94.71[a]	1.39	87.77[c]	2.12	91.12[b]	0.62	93.45[a]	1.26
Filleting yield (%)	50.62[a]	6.87	49.64[a]	2.58	36.19[b]	3.00	38.40[b]	2.36	36.19[b]	4.42
Hepatosomatic I (%)	1.66[a]	0.85	1.14[ab]	0.26	1.45[a]	0.22	1.16[ab]	0.19	0.80[b]	0.18
Gonadosomatic I (%)	0.29[b]	0.39	0.77[a]	0.28	0.45[ab]	0.09	0.20[b]	0.14	0.22[b]	0.26
Viscerosomatic I (%)	8.47[a]	1.70	2.84[c]	0.33	10.31[a]	2.08	5.74[b]	0.44	5.72[b]	1.30

Different letters in the same row indicate statistically significant differences ($p \leq 0.05$) between the mean values of each species.
I: Index.

values reported by Zakęś et al. (2012) (40% for females, 42% for males). This could be attributed to a lower fillet mass in the fish of the present study, as was also indicated by the lower observed condition index, since fish in both studies had similar weights. Grey mullet and greater amberjack's filleting yields were also lower than those reported in the literature (Ali, Shams, Imran, Khanom, & Sarower, 2013; Öksüz, 2012), although in this case, differences in fish weight existed. Meagre, on the other hand, showed similar yields to those provided by Grigorakis, Fountoulaki, Vasilaki, Mittakos, & Nathanailides, 2011. Regarding wreckfish not published data were found about filleting yields. Filleting yield is an important parameter, especially for species where filleting is among their usual processing, because it describes their actual edible part. In fact, filleting yield provides a good index of what percentage of the total fish body weight is available for consumption (Nathanailides et al., 2013). Filleting yield depends on several factors such as size, structural anatomy of the fish, sex, species and feeding conditions (Rodríguez, Fountoulaki, Grigorakis, Alexis, & Flos, 2010), and is frequently used as fish selection criterion in order to improve its value (Bosworth, Libely, & Notter, 1998; Cibert, Fermon, Vallod, & Meunier, 1999). Since species with higher filleting yield can give higher profit in a filleted form, greater amberjack and wreckfish should be regarded as the most advantageous species.

Hepatosomatic index (HSI) is associated with the liver energetic reserves and metabolic activity. An increase in the HSI in any given species is associated with elevated feed abundance. HSI is also related to fish health as there are several studies that relate the liver size to a well-developed animal with lower pollution ratings (Pait & Nelson, 2003; Sadekarpawar & Parikh, 2013). Wreckfish was the species with the highest HSI values. The technical significance of HSI is rather indirect, since liver is not within the edible parts of the fish, and therefore the higher the HSI the higher the losses.

The low gonadosomatic indexes (GSI) found for all species are a clear indication that they have not started maturing at the time when sampling occurred. For instance, GSI close or higher than 1.0 indicate meagre entering maturation process, even for male individuals (Schiavone, Zilli, Storelli, & Vilella, 2012). Maturation can largely affect the biochemical quality of muscle tissues, and thus of fish edible parts, since it often uses part of the muscle energy depots (Love, 1992). The viscerosomatic index of the greater amberjack was found significantly lower than those of all species, the meagre and pikeperch showed intermediate values, while the grey mullet and wreckfish exhibited the highest ones (Table 4). The viscerosomatic index largely represents the losses during fish gutting (Grigorakis, 2010).

3.2. Fillet proximate composition

The fillet proximate composition of the studied species is shown in Table 5. In general, fillet protein content of all fish species was quite similar, nearing a 20% of total fillet constituents in agreement with previous studies (Grigorakis, 2010; Grigorakis et al., 2011). Fillet protein has been generally believed to be stable in adult fish and not to be influenced by external parameters (Grigorakis, 2010; Love, 1992). However, there have been some cases where seasonal protein changes have been reported for wild fish populations (Gökçe, Taşbozan, Çelik, & Tabakoglu, 2004; Patrick Saoud, Batal, Ghanawi, & Lebbos, 2008). Reduction of muscle protein in adult fish has been mentioned in cases of mobilization under prolonged fasting (Love, 1992).

Greater amberjack fillets had the highest lipid content which explains its lower water content. The total lipid content for fat fish species affects the percentage of moisture, since fat and water normally constitute around 80% of the fillet (FAO, 1995; Stead & Leard, 2002). All the other species exhibited fillet fat of < 1%, which would categorize them into low-fat species (Huynh & Kitts, 2009). In fact, meagre and pikeperch have been described as lean species (Kowalska, Zakęś, Jankowska, & Demska-ZakĘŚ, 2011; Sinanoglou, Proestos, Lantzouraki, Calokerinos, & Miniadis-Meimaroglou, 2014). Grey mullet on the other hand was supposed to contain higher fat levels in the fillet, and is normally described as a medium to high fat species (Özogul, Özogul, Çiçek, Polat, & Kuley, 2009) as opposed to what was found in this study. Nevertheless, it must be taken into account that all species except pikeperch were obtained during the winter period when lipid depots are generally reduced, and especially in wild specimens like the grey mullet. This seasonal effect has been observed for both wild and farmed populations (Grigorakis, 2010). Lipid content along with fatty acids profile in fish flesh directly affects odor and flavor intensity (Rincón et al., 2016). Thus, sensory differences could be expected among species depending on the fat content since most of the volatile compounds in fish are derived from the oxidative breakdown of unsaturated fatty acids (Grigorakis, 2007; Sérot, Regost, & Arzel, 2002).

3.3. Instrumental texture analysis

Texture is an important variable of the fish flesh and is of increasing concern in the aquaculture industry (Bjørnevik, Karlsen, Johnston, & Kiessling, 2003), especially for those animals to be submitted to an industrial process. As observed in Table 6, wreckfish was the species with the highest area and lowest slope value for both raw and cooked samples, thus indicating its more pronounced elastic nature. These elastic properties may be influenced by the amount and strength of the collagen cross-links in the raw flesh (Li et al., 2005) and the thermal-induced structural changes (Castro et al., 2015; Dunajski, 1979).

Grey mullet was the fish species where most noticeable differences in the mechanical properties (Maximum force and Area) between raw and cooked samples were observed. It exhibited the highest maximum force and slope values for cooked samples, suggesting that it was the hardest of all five species when using a non-destructive compression method. Texture is strongly affected by protein and water content. Provided that there were no significant differences between protein and moisture content among all the species in this study (Table 5), one

Table 5
Mean values and standard deviation (SD) of fillet proximate composition of wreckfish (N = 3) greater amberjack (N = 3), grey mullet (N = 3), meagre (N = 3) and pikeperch (N = 3).

Proximate composition parameter	Wreckfish		Greater amberjack		Grey mullet		Meagre		Pikeperch	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Moisture (%)	78.35[a]	0.53	69.46[b]	2.74	76.53[a]	1.07	77.17[a]	0.29	76.58[a]	1.07
Protein (%N)	19.27[b]	0.30	22.21[a]	1.58	21.37[ab]	0.72	20.65[ab]	0.20	21.80[a]	0.72
Fat (%)	0.70[b]	0.17	6.28[a]	4.04	0.58[b]	0.02	0.52[b]	0.36	0.06[b]	0.02
Ash (%)	1.15[b]	0.05	1.44[a]	0.13	1.27[ab]	0.16	1.35[ab]	0.01	1.30[ab]	0.16

Different letters in the same row indicate statistically significant differences ($p \leq 0.05$) between the mean values of each species.

plausible explanation for these findings could be the protein type that may be present in this species. In this vein, Lin, Zeng, Zhu, and Song (2012) stated that the type of proteins (myofibrillar, sarcoplasmic, stromal) and their functional status tend to affect muscle hardness. Generally speaking, the thermal denaturation temperature of proteins is strongly related to their amino acid composition and protein structure. In consequence, the observed different behavior under low compression forces compared to the rest of the species might be explained by different denaturation processes when samples were cooked. It is important to remark, that these statements are merely possible hypothesis according to the literature review, since no actual measurements of protein denaturation took place in this study. Nevertheless, this issue should be addressed in further studies.

There was, however, a tendency for most species and retained parameters to exhibit higher mean values when samples were cooked. When heating, the collagen responsible for maintaining the structure of the fish fillet is gelatinized by thermal action (Castro et al., 2015), whereas the actomyosin complex (intracellular contractile proteins) changes from a soft gel to a firmer denatured complex, thus making fish samples harder (Dunajski, 1979). These changes explained the observed increase in various texture parameters, however, it is worth referring these results to a non-destructive compression. According to the discriminant analysis carried out and the results of the confusion matrix, texture variables were more discriminant between species in raw samples (data not shown). Therefore, the different fish samples were correctly classified in their respective species in 77.78% and 68.89% of the cases for raw and cooked samples respectively. According to Thorarinsdottir, Arason, Geirsdottir, Bogason, and Kristbergsson (2002); Badii and Howell (2002), each fish species has a different thermal denaturation point, which could suggest that the observed differences among species might be partially masked when samples were submitted to the same cooking procedure. Although, at 115 °C all samples should have reached the denaturation point, differences in protein and water content among species might have led to the formation of gels with a different strength (Sun & Holley, 2011).

Table 7 shows the results of the TPA performed over the cooked samples. Hardness was significantly higher for wreckfish, suggesting a stronger contractile protein complex in this species (Dunajski, 1979). Moreover, since wreckfish was also the species that released more exudate (water) among the species, it is likely that the tissue was dryer, hence resulting in an increased hardness. These animals also showed the highest cohesiveness. This particular textural property depends on the strength of protein binding (Christensen, 2012; Szczesniak, 1963), which indicates the existence of cross-links between collagen molecules. In addition, it has been demonstrated that pelagic fish like wreckfish, tend to have higher amount of sarcoplasmic proteins than other types of fishes. These proteins tend to contribute to the increasing of the cohesiveness in the fish tissue (Farouk, Wieliczko, Lim, Turnwald, & Macdonald, 2002). Resilience values (how well a product "fights to regain its original height" (Rosenthal, 2010) were also the highest for wreckfish. This parameter describes the ability of the muscle to recover from deformation and the offered resistance to this deformation. Resilience is affected by the elasticity of the muscular fibers and by the connective tissue (Veland & Torrissen, 1999). Consequently, wreckfish seems to have higher elastic character in its tissue, although no significant differences between species were observed for the springiness (elasticity). One plausible explanation could be related to the big size of the animal. Thicker fillets tend to present more elastic deformation (Ando, Toyohara, & Sakaguchi, 1992; Cheng, Sun, Han, & Zeng, 2014), indeed wreckfish was among the largest animal in this study. In addition to the highest mean value for hardness observed in this species, gumminess (hardness x cohesiveness) and chewiness (gumminess x springiness) were also significantly higher than in the remaining species accordingly.

Contrary to what was expected, adhesiveness values for greater amberjack were the highest among the species despite its higher fat content. Normally, fat presence around the muscle fibers acts as lubricant, since it can be released during the compression test reducing the stickiness between the compression plates and the sample (Carpenter, 1962). However, the internal released juice during fish compression could also contain other substances different from melt fat. These substances could be fiber proteins, such as elastin or fibronectin, which have both structural and adhesive functions, and solubilized collagen (Koolman & Heinz-Roehm, 2005) which could act as an organic glue increasing the adhesiveness of the sample. Greater amberjack was also the species with lower resilience and higher fracturability (lower force needed to fracture the sample). Since greater amberjack is a fat fish species, the existing intramuscular fat between myomeres

Table 6
Mean values and standard deviation (SD) of nondestructive instrumental texture parameters (spherical probe compression) for cooked (C) and raw (R) fish samples: wreckfish (N = 5), greater amberjack (N = 5), grey mullet (N = 5), meagre (N = 5), and pikeperch (N = 5).

Inst. texture parameters	Wreckfish		Greater amberjack		Grey mullet		Meagre		Pikeperch	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Area R (gf/s)	1029.16[a]	437.09	965.35[a]	177.28	382.29[b]	220.54	620.09[ab]	423.72	734.36[ab]	499.61
Max. force R (gf)	368,02	122.03	383.88	78.48	365.19	180.64	332.21	190.96	394.43	235.62
Slope R (gf/mm)	64.35[b]	29.39	67,65[b]	14.94	166.73[a]	74.85	80.90[b]	40.20	98.56[b]	53.99
Area C (gf/s)	1604.29[a]	956.91	1147.35[ab]	275.06	1043,07[ab]	563.37	806.27[b]	254.65	698.37[b]	333.56
Max. force C (gf)	430.60[ab]	178.80	383.88[b]	74.74	607.73[a]	247.80	376.17[b]	54.22	315.17[b]	93.89
Slope C (gf/mm)	65.99[b]	26.69	69.39[b]	12.32	192.83[a]	86.93	92.87[b]	15.90	73.49[b]	20.08

Different letters in the same row indicate statistically significant differences ($p \leq 0.05$) between the mean values of each species.

Table 7
Mean values and standard deviation (SD) of texture profile analysis (TPA) parameters of cooked samples of wreckfish (N = 5), greater amberjack (N = 5), grey mullet (N = 5), meagre (N = 5), and pikeperch (N = 5).

TPA parameters	Wreckfish		Greater amberjack		Grey mullet		Meagre		Pikeperch	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Hardness (gf)	7032.00^{a}	3977.10	3985.74^{ab}	1181.17	3328.62^{b}	598.20	4402.66^{ab}	835.18	2251.51^{b}	246.97
Fracturability (gf)	2692.45^{a}	890.79	842.08^{b}	189.57	2120.97^{a}	808.28	2411.79^{a}	398.19	1552.62^{ab}	200.35
Cohesiveness	0.42^{a}	0.05	0.32^{ab}	0.09	0.27^{b}	0.08	0.33^{ab}	0.04	0.37^{ab}	0.04
Springiness	0.8	0.05	0.70	0.20	0.75	0.14	0.80	0.02	0.78	0.01
Adhesiveness (gf/s)	− 164.10^{ab}	122.17	− 204.83^{b}	148.66	− 43.00^{a}	48.40	− 14.34^{a}	7.21	− 9.56^{a}	9.82
Resilience	0.08^{a}	0.02	0,03^{d}	0.01	0.04^{cd}	0.01	0.07^{ab}	0.01	0.05^{bc}	0.01
Gumminess (gf)	3119.95^{a}	1960.95	1354.29^{b}	711.63	926.25^{b}	373.47	1512.62^{ab}	443.12	837.86^{b}	144.00
Chewiness (gf)	2553.38^{a}	1633.85	1040.99^{b}	668.06	726.36^{b}	378.77	1222.76^{ab}	377.59	655.03^{b}	114.51

Different letters in the same row indicate statistically significant differences ($p \le 0.05$) between the mean values of each species.

probably caused changes in the muscle firmness, resulting on a weakening of its cellular binding force (Thakur & Morioka, 2016).

It is worth mentioning that texture differences observed among the studied species were strongly affected by the instrumental method applied. According to Bouton and Harris (1972) compression values seem to be more influenced by the strength of the materials holding the muscular fibers together than by the strength of the muscular fibers themselves. Thus, depending on the level of the applied compression, i.e. the conducted test, the contribution of the muscular fibers or the surrounding collagen network to the final force values will vary (Ogawa et al., 2003). Spherical probe compressed the samples only at 30% of its height (non-destructive) and mainly measures the texture on the more external part of the fillet (Jonsson, Sigurgisladottir, Hafsteinsson, & Kristbergsson, 2001), while TPA compressed samples twice at 75% of its initial height involving the whole muscular structure (destructive measurement) (Rehbein & Oehlenschlager, 2009).

3.4. Sensory analysis

Results from quantitative analysis performed on the five fish species are shown in Table 8. Only those descriptors showing significant differences between species are discussed.

Wreckfish was distinguished for having the highest presence of exudate among the samples. The differences between species for this descriptor could be explained by specific biochemical mechanisms that control protein denaturation when cooking (Sotelo, Aubourg, Perez-Martin, & Gallardo, 1994; Sun et al., 2006) and also by the different content of connective tissue that these species might have (Batista, 1999). A higher content in connective tissue will favor the exudate release during cooking as a result of higher muscle contraction (Mc Gee, 1984). Wreckfish also presented the highest sensory firmness and chewiness in agreement with the instrumental texture parameters.

Greater amberjack was described as having laminar structure. This attribute is related to the separation of myomeres (muscle blocks attached to collagen septa) in the fish (Helfman, Collete, Facey, & Bowen, 2009). The myomeres structure connection (myocommata) in high fat fish species is based on collagen and the presence of adipocytes (Zhou, Ackman, & Morisson, 1995). According to Thakur and Morioka (2016) greater amberjacks lipids are deposited between its myomeres thus favoring the development of a laminar structure. Greater amberjack also showed sour flavor as a defining characteristic. No plausible explanation has been found on the literature to justify the presence of this sensory descriptor. In addition, greater amberjack also exhibited higher teeth adherence than the other species. As previously mentioned,

Table 8
Mean values and standard deviation (SD) of descriptors intensity for the five fish species obtained by quantitative sensory analysis of wreckfish (N = 5), greater amberjack (N = 5), grey mullet (N = 5), meagre (N = 5), and pikeperch (N = 5).

Descriptors	Wreckfish		Greater amberjack		Grey mullet		Meagre		Pikeperch	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
OButter	3.36^{a}	2.18	2.21^{b}	1.74	1.95^{b}	1.86	3.90^{a}	1.94	1.85^{b}	1.57
OSeafood	1.21^{ab}	1.26	1.12^{ab}	1.18	0.65^{b}	0.65	1.32^{a}	1.03	0.72^{ab}	1.06
OSardine	2.10^{a}	1.77	1.30^{ab}	1.75	2.20^{a}	2.01	1.53^{ab}	1.77	0.91^{b}	1.02
OEarthy	0.62^{c}	0.89	0.92^{bc}	1.50	1.78^{ab}	1.96	0.63^{c}	1.12	2.38^{a}	2.00
Color	4.57^{a}	1.62	3.65^{bc}	1.12	3.98^{ab}	1.91	3.10^{c}	1.22	2.03^{d}	0.90
Color uniformity	6.86^{bc}	2.12	8.10^{a}	1.62	6.68^{bc}	2.23	6.51^{c}	1.81	7.66^{ab}	1.52
Exudate	8.42^{a}	1.72	6.85^{b}	1.99	2.06^{d}	1.88	5.90^{bc}	2.32	4.81^{c}	1.73
Turbidity	6.66^{b}	2.81	1.36^{c}	1.29	1.83^{c}	1.74	6.17^{b}	2.29	7.97^{a}	2.17
Fat drops	6.08^{a}	2.76	5.28^{a}	2.47	0.87^{b}	1.15	5.71^{a}	2.62	0.98^{b}	1.09
Laminar structure	4.33^{b}	2.33	6.13^{a}	2.44	4.70^{b}	2.07	4.62^{b}	2.14	4.75^{b}	2.35
Sour	0.81^{b}	1.24	4.03^{a}	1.88	0.92^{b}	1.32	0.65^{b}	1.08	0.65^{b}	0.95
Bitter	1.68^{b}	1.63	1.91^{b}	2.40	3.10^{a}	2.36	1.70^{b}	1.83	1.51^{b}	1.30
Butter	1.87^{ab}	1.63	2.08^{a}	1.89	0.87^{c}	1.26	2.39^{a}	1.73	1.13^{bc}	1.10
Sea food	1.00^{ab}	1.01	0.98^{ab}	1.00	1.01^{ab}	1.05	1.30^{a}	1.47	0.48^{b}	0.69
Vegetables	2.51^{a}	1.91	1.37^{b}	1.87	2.0^{2ab}	1.27	2.26^{ab}	2.15	2.20^{ab}	1.62
Earthy	0.51^{c}	0.93	1.06^{bc}	2.05	1.64^{ab}	2.08	0.27^{c}	0.52	2.37^{a}	2.10
Firmness	6.66^{a}	1.49	5.96^{a}	1.68	5.88^{a}	1.76	4.85^{b}	1.31	4.36^{b}	1.40
Crumbliness	4.13^{d}	1.40	5.20^{c}	1.51	5.41^{bc}	1.75	6.15^{ab}	1.44	6.77^{a}	1.41
Juiciness	4.83^{bc}	1.65	5.50^{ab}	1.61	4.31^{c}	1.47	5.96^{a}	1.00	5.16^{ab}	1.12
Chewiness	6.38^{a}	1.25	5,83^{ab}	1.65	5.25^{b}	1.49	4.01^{c}	1.25	3.77^{c}	1.35
Pastiness	2.96^{ab}	1.99	3.80^{a}	2.38	2.65^{b}	2.09	3.85^{a}	2.46	3.88^{a}	2.35
Teeth adherence	3.66^{b}	1.98	6.83^{a}	1.15	3.82^{b}	2.06	3.82^{b}	1.78	2.95^{b}	2.00

Different letters in the same row indicate statistically significant differences ($p \le 0.05$) between the mean values (descriptor's intensity) of each species.

adhesive proteins are likely to be released while chewing the fish, therefore clinginess is likely to be produced between molar teeth (Koolman & Heinz-Roehm, 2005).

Grey mullet was principally characterized for its bitter taste. According to Cayhan and Selli (2011), grey mullet has low antioxidant activity compared to other species, which possibly allows higher lipid oxidation producing short-chain volatile compounds such as aldehydes that also elicit characteristic bitter flavors (Eskin & Shaidii, 2013). (Z)-4-heptenal and E-2 Nonenal, are two aldehydes that have been found among the aroma components in grey mullet (Cayhan & Selli, 2011), and have been related to rancid and bitter taste in fish (Cha & Cadwallader, 1998).

Meagre showed among the highest values measured between species for butter odor and flavor attributes. According to Giogios et al. (2013) meagre volatiles have been characterized by the presence of different compounds including 2, 3-butanedione. This aldehyde is a natural product that contributes to the taste of butter (Peterson & Reineccius, 2003), therefore it is likely that this descriptor might be related to the presence of this compound.

Pikeperch was mainly characterized by "earthy" odor and flavor. These sensory attributes seem to be related with the fish origin and/or environment. Pikeperch is normally reared in freshwater recirculating tank systems. Tank systems often contain actinomycetes which could be responsible for muddy odor by producing compounds such as geosmine and 2-methylisoborneol usually associated to the earthy odor/flavor (Persson, 1980; Selli, Prost, & Serot, 2009).

3.5. Relationship between the parameters assessed

Fig. 2 shows the results of the PCA performed over the whole data set (including somatometric, composition, instrumental texture, and sensory parameters). The first two dimensions of the PCA explained 67.34% of the variance. The first component was positively influenced by instrumental texture (hardness, gumminess, chewiness and area) and parameters such as CI and HSI indexes. Area values for cooked samples were positively correlated with the CI of the animals ($r = 0.98$) and with hardness (instrumental texture) ($r = 0.87$). Sensory firmness was also located together to instrumental hardness, chewiness and gumminess.

The second principal component contained descriptors positively correlated to fat content (laminar structure ($r = 0.95$), teeth adherence ($r = 0.98$), GSI ($r = 0.92$) and sour taste ($r = 0.99$)). According to Venugopal and Shahidi (1996), lipid content is an important chemical basis for flesh texture forming, thus creating the laminar structure. Regarding the connection of GSI with the lipid content, Ando, Hatano, and Zama (1985) found that lipid stores are necessary when building up fish gonads, thus suggesting a relation between the fat presence and the GSI of the fish. In addition, high fat content in other fish species like salmon have been reported to have sourness as a descriptive characteristic in its profile (Cardinal et al., 2004), thus the free fatty acid content might have contributed to the presence of this descriptor in this study too, although further research would be needed to prove such hypothesis. According to Montreuil, Vliegenthart, and Schachter (1997), fatty fish species often have a high content of glycoproteins with adhesive properties, whose presence translates into higher force required to separate teeth after biting the fish samples (Maldo de Paula & Conti-Silva, 2014). Accordingly, teeth adherence descriptor might be related to fat content as well.

PC 3 and PC4 explained 32.66% of the variance. In PC3, a positive correlation between maximum force and slope values ($r = 0.89$) of cooked samples were observed. According to Casas, Martinez, Guillen, Pin, and Salmeron (2006), high values of slope could be regarded as an index of stiffness, therefore higher force should also be required when compressing the fish sample. In the case of grey mullet, samples were placed close to these properties in the plot, thus having the higher slope and maximum force values.

Seafood flavor was one of the most representative attributes in PC4. According to Josephson (1991), seafood flavor is strongly related to lipid-derived aroma compounds, which are produced by the enzymatic oxidation of the polyunsaturated fatty acids (arachidonic, eicosapentatenoic and docosahexaenoic fatty acids) present in fish (Reineccius, 1994).

In general, the agreement between instrumental and sensory data reported in the present paper seems to indicate the appropriateness and usefulness of the sensory references developed during the training process of the assessors. As Rainey (1986) stated, sensory references are the most convenient way to transform in objective and comparable those scores provided by a sensory panel. Accordingly and as stated by Muñoz and Civille (1998) a common criteria for scoring intensities should be established in order to have more uniform and calibrated panel ratings.

The species herein presented a wide range of physicochemical and

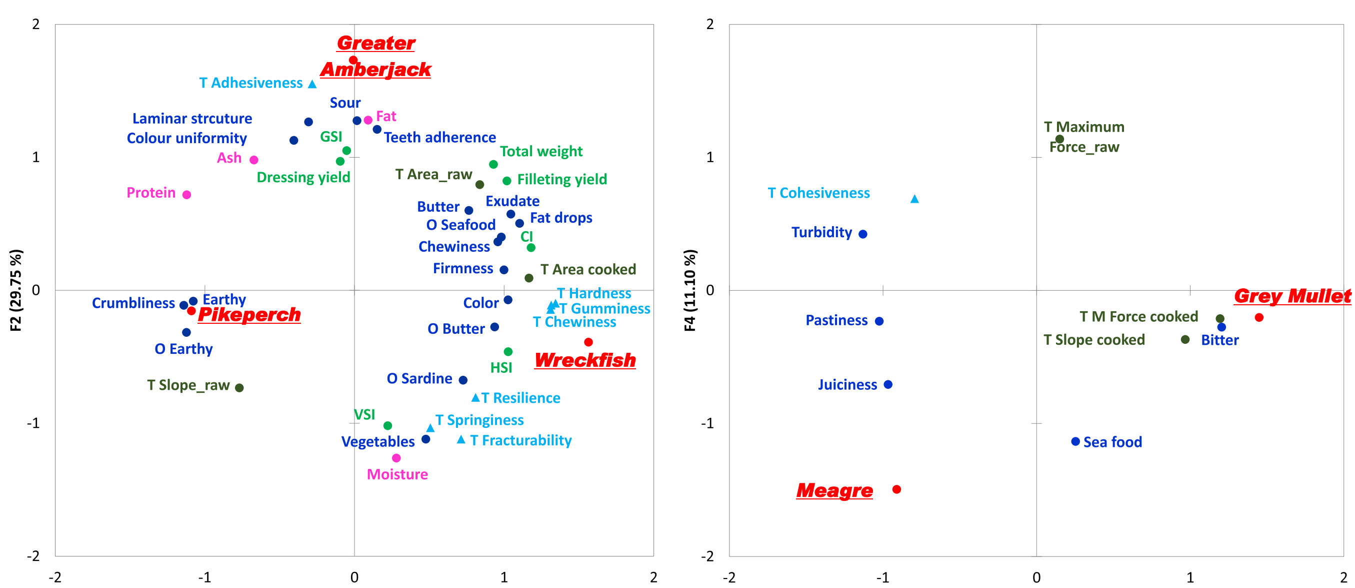

Fig. 2. Sensory somatometric, compositional and instrumental texture correlations of the five fish species. Only those attributes and samples being well projected on the graphs (sum of square cosines higher than 0.5) are shown.

sensory characteristics that show their potential for product development, thus increasing the variety of options for consumers and probably favoring the demand for farmed fish. The information reported in the present paper could be further exploited when designing new products by providing reliable guidelines about the most convenient applications and uses for each of the species under study. Species like pikeperch (characterized by "earthy" odor and flavor) or grey mullet (described with bitter flavor), could be used in products that come with dressing, spices or sauces that can mask their peculiar characteristics, probably undesirable for some consumers in some specific markets.

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