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Farmed and wild common sole (*Solea solea* L.): comparative assessment of morphometric parameters, processing yields, selected nutritional traits and sensory profile

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Abstract

Recent important developments in sole aquaculture have increased the availability of the farmed product on the market. The aim of this research was to characterize and compare for the first time in common sole (*Solea solea*) morphometric parameters, nutrients and sensory traits of cultured and wild specimens. Farmed sole, while maintaining the characteristics of a lean fish species (2% of lipid content), displayed a EPA+DHA fillet content more than twice as high as its wild counterpart. Sensory traits of “potato”, “boiled fish”, sweet, firmness, astringency, chewiness, were correlated to farmed origin while whiteness, briny, “octopus”, “crab”, salty, acid, bitter, umami, intensity and juiciness were linked to wild origin. Intensive farming conditions improved the nutritional value of common sole in terms of lipid content and fatty acid profile and led to sweeter sensory traits particularly associated with a terrestrial vegetable perception.

Keywords

Farmed and wild common sole, *Solea solea*, flesh quality, morphometric parameters, fatty acid profile, sensory analysis

1. Introduction

In terms of value, sole (*Solea solea* and *Solea senegalen*sis) is one of the top finfish species landed in Europe, where it is highly esteemed by consumers for its valuable nutritional and sensory characteristics. Despite an increasing demand, fisheries’ landings of sole have decreased in recent years due to overexploitation of stocks

(Morais et al., 2016). At the same time, in the most recent decades the scientific community has made great efforts to solve the principal bottlenecks of its farming (Morais et al., 2016). As a result, recently there has been an expansion in sole aquaculture production and there are ambitious plans for further growth facilitating the availability of the farmed product on the market. Traditionally, in aquaculture production Spain and Portugal have focused on Senegalese sole (*S. senegalensis*) while Northern European countries and Italy have focused on common sole (*S. solea*). The two species are really almost indistinguishable to consumers and are often combined in production and most market statistics (Bjørndal et al., 2016). Regarding common sole, the main investigation areas have been devoted to exploring larval rearing, nutrition of juveniles, egg quality and genetics (Bonvini et al., 2015; Ferraresso et al., 2016; Parma et al., 2013, 2015) while no data on fish flesh quality from farmed specimens are available. The flesh quality of fish is determined by a combination of multiple characteristics including extrinsic factors such as freshness, pre- and post-slaughter handling procedures, (Johnston, 1999; Jonhston et al., 2006) and intrinsic traits such as morphometric characteristics, chemical composition of the flesh and sensory profile attributes (Fuentes et al., 2010; Johnston et al., 2006). These parameters may be affected by several factors including season, fish size, maturation stage and water quality; however the nutritional values and sensory characteristics of fish are especially affected by rearing conditions so that differences between wild and farmed fish are usually expected (Borrensen, 1992; Fuentes et al., 2010). Thus, farmed versus wild quality assessments and reporting are essential in order to correctly inform the consumer on true nutritional and sensory variation thereby facilitating knowledge-based rather than belief-based choices (O'Neill et al., 2015). A comparison between wild and farm fish

concerning flesh quality has been proposed in several cultured species (Bhouri et al., 2010; Busetto et al., 2008; Drake et al., 2006; Farmer, et al., 2000; Frank et al., 2009; Fuentes et al., 2010; González et al., 2006; Guy and Nottingham, 2014; Martinez et al., 2010; Olsson et al., 2003; O'Neill et al., 2015; Rincón et al., 2016) while no data are available for common sole.

To characterize and identify the effect of farming conditions on the flesh quality of common sole, we evaluated differences in morphometric parameters, processing yields, selected nutritional traits between wild and farmed common sole at commercial size with particular emphasis on the proximate composition and fatty acid profile in raw and cooked fillets. In addition, a quantitative descriptive sensory analysis (QDA) was developed and applied to distinguish between wild and farmed fish. To the best of our knowledge this is the first report comparing nutrients and sensory traits of farmed and wild common sole.

2. Materials and methods

2.1. Morphometric and nutritional traits

2.1.1. Fish rearing and sampling

Wild common sole (WS) at first commercial size (n = 220, average length = 24.2 ± 1.19 cm) from the northern Adriatic Sea (FAO zone 37.2.1, GFCM GSA 17, according to Reg. EU 1343/2011) were sampled during the winter months, through a local supplier (MARR Battistini), at the wholesale fish market of Cesenatico. During the same period farmed common sole (FS, n = 220) were collected at first commercial size (20.4 ± 1.13

cm) from a farm located in south-eastern Italy (Panittica Italia, Fasano, BR). Fingerlings were produced from common sole breeders with northern Adriatic origin maintained at the Aquaculture Laboratory of the Department of Veterinary Medical Sciences at the University of Bologna according to Parma et al. (2015). Fingerlings were transferred to the farm at a size of 0.5 g and then on-grown for 18 months in intensive conditions (density, 5-20 kg/m^2) in a concrete outdoor tank (40 m^2, 60 m^3) supplied by natural seawater (salinity 35 ‰, temperature 20 ± 2 °C). Fish were daily fed using commercial feed (Aller Futura Ex, Aller Aqua A/S, Table 1) which was provided close to satiation by automatic belt feeder 12 h day^{-1}.

Both FS and WS specimens were delivered on ice to the Cesenatico Laboratory of Aquaculture, Italy, where they were processed within 24 hours from capture. Twenty FS and 20 WS randomly selected specimens were subdivided into 4 batches of 5 fish each and then homogenized using a TCF-12 refrigerated table-top grinder (Scozzoli, Montaletto di Cervia, Italy) for carcass proximate composition analysis.

2.1.2. Morphometric traits

Two hundred FS and 200 WS specimens were equally and randomly allocated into 10 batches (20 fish each) per typology (both FS and WS). All specimens were measured, filleted and skinned by hand. The morphometric traits measured on each specimen included total body length (TBL), total body weight (TBW), gutted weight (GW), viscera weight (VW), liver weight (LW), skinned fillet weight (SFW), eyes side fillet weight (ESFW), blind side fillet weight, (BSFW), frame weight (FrW) and skin weight (SW). Data registered were used to compute several biometric indices as follows: Condition factor (CF) = 100 × TW × TBL^{-3}; GW (%) = 100 × GW × TBW^{-1};

Viscerosomatic index (VSI, %) = 100 × VW × TBW $^{-1}$; Hepatosomatic index (HSI, %) = 100 × LW × TBW $^{-1}$; Skinned fillet yield (SFY, %) = 100 × SFW × TBW $^{-1}$; Eyes side fillet yield (ESFY, %) = 100 × ESFW × TBW $^{-1}$; Blind side fillet yield (BSFY, %) = 100 × BSFW × TBW $^{-1}$; Skin (%) = 100 × SW × TBW $^{-1}$; Frame (%) = 100 × FrW × TBW $^{-1}$.

2.1.3. Sample preparation and cooking

Within each typology (both WS and FS) and each batch, fillets were finely deboned, diced, thoroughly mixed and homogenized in three 3-s bursts using a Multiquick System ZK100 food processor (Braun GmbH, Kronberg, Germany). The ensuing flesh was divided into two portions to be analyzed either in the raw (RW) or cooked (CK) state. The flesh to be cooked was prepared as 30-g-patties, each patty being placed in the middle of a 12-cm-diameter glass Petri dish, three patties at a time being microwaved at 750 W (Sfornatutto De'Longhi oven, Treviso, Italy) for 70 s, so as to reach a final core temperature center around 70°C. Core temperature was checked upon removal from the oven with a needle thermometer. Within each typology and batch an average cooking yield (CY) was obtained as the percentage ratio between the weight of each cooked and cooled patty and the corresponding weight before cooking. Both raw flesh, subdivided in 30-g-patties, and cooked patties (around 12 pieces per batch) were vacuum packed and stored at –20 °C until analyzed, within the following two months.

2.1.4.Chemical analyses

Homogenized carcasses, as well as raw and cooked patties, were analyzed in duplicate for moisture, ash and total nitrogen, according to the AOAC methods No.

950.46B, 920.153 and 928.08, respectively (AOAC, 2010). Energy values, expressed in kiloJoules (kJ), were derived by multiplying the amounts of protein and fat by the factors 17 and 37, respectively (USDA, 2016).

Total lipids (TL) were extracted in duplicate according to Bligh and Dyer (1959) with some modification. Each sample (4 g of flesh homogenate, precisely weighed) was placed in a test tube immersed in an ice bath and again homogenized twice with an Ultra-Turrax mod. T25 (IKA-Werke GmbH & Co., Staufen, Germany) for one minute, the first time with 6 mL of chloroform + 12 mL of methanol, the second time with 6 mL of chloroform + 6 mL of deionized water. After centrifugation (10 min at 4000 rpm and at 4°C), both the upper aqueous phase and the intermediate solid phase were eliminated, while the lower phase containing chloroform together with TL was filtered through a layer of anhydrous sodium sulfate. One mL of the lipid extract was made to evaporate on a hotplate at 50°C and the lipid residue was weighed to calculate the TL percentage according to the following formula:

$$TL\% = 100 \times (g\ lipid \times mL^{-1}) \times (12 \times g\ sample^{-1}),$$

where the number 12 refers to the mL of chloroform used for the extraction.

Lipid extracts were directly trans-methylated according to Ichihara et al. (1996).

2.1.5. Fatty acid methyl esters (FAME) composition

FAME were analyzed on a Varian 3380 gas chromatograph (Varian Inc., Palo Alto, CA, USA) equipped with an Agilent J&W DB-23 fused silica capillary column (30 m × 0.32 mm i.d., 0.25 µm coating thickness; Agilent Technologies, Palo Alto, CA, USA), a split injector at 230°C and a flame ionization detector at 300°C. The carrier gas was nitrogen at a flow rate of 1.2 mL / min. The oven temperature was set in a programmed

mode from 150°C to 230°C at 5°C / min and final isotherm. Data were processed using a Varian Star Chromatography Workstation. Fatty acid identification was accomplished by comparing the retention times of unknown FAME with those of known FAME standard mixtures (Sigma-Aldrich Corp., St. Louis, MO, USA; PUFA No. 1, Marine Source, and PUFA No. 3, Menhaden Oil, SUPELCO, Inc., Bellefonte, PA, USA).

Selected fatty acid contents were quantified by transforming each area percentage to g / kg edible portion, through the finfish conversion factor according to USDA, (2016).

2.1.6. True Retention Values (TRVs)

Proximate composition and selected fatty acids contents, combined with relevant cooking yields, were used to calculate true retention values (TRVs) as outlined by USDA (2016).

The following equation was adopted:

TRV (%) = 100 × (nutrient content per g of cooked flesh × g of cooked flesh) × (nutrient content per g of raw flesh × g of raw flesh) $^{-1}$.

2.2. Sensory profiling

2.2.1. Animals and experimental samples

The wild specimens of common sole used as control (average total length = 22.1 ± 0.11 cm) had been caught by rapido trawling in the northern Adriatic sea off the Emilia-Romagna coast (GFCM GSA 17) on a single occasion during the winter season. Upon arrival at the Cesenatico laboratory packed in melting ice and within 24 hours from catch, they were immediately gutted, washed, patted dry and vacuum-sealed in plastic

bags, to be finally frozen at -20 ± 2 °C. During the same period farmed specimens (average total length = 23.5 ± 0.24 cm) from the fish farm Panittica Italia (same farming tank and source as described at *2.1.1*), were obtained in ice through refrigerated carriage and processed using the same methodology as the wild specimens.

Sensory profiling activities started after six weeks from fish sampling. While initially searching for useful descriptors, wild and farmed sole were evaluated along with several portion-size flatfish species, such as European flounder (*Platichthys flesus*), plaice (*Pleuronectes platessa*), turbot (*Scophthalmus maximus*), brill (*Scophthalmus rhombus*).

The former and the latter were eventually retained as references for the minimum and the maximum intensity, respectively, of both odor and aroma found in either wild or farmed sole. Whenever necessary, i.e. for the training of the panel, the development of the ballot, and also during the proper activity of sensory profiling, the number of wild and farmed specimens deemed necessary for the work of that day were previously defrosted by putting them at 0 ± 1°C for about 12 hours, then individually wrapped in polyethylene film and microwaved at 750 W for 3.0-3.5 min, depending on the fish size, up to a core temperature of 70°C using a Sfornatutto De'Longhi oven (De'Longhi Italia, Treviso, Italy). Afterwards, each fish was dressed and the fillets obtained were placed in a large glass Petri dish (12 cm in diameter), identified with a three-digit random number. All the fish to be evaluated in each session, once cooked, were kept warm (at 45-50°C) until served, within 20 min, by placing all the relevant Petri dishes in lunch box warmers.

2.2.2. The sensory panel and its work

A sensory panel was composed of volunteer faculty, staff and students active in the Degree Course in Aquaculture and Hygiene of Fishery Production in Cesenatico (northern Italy), for a total number of 10 people inclusive of the panel leader who was not engaged in the final evaluations. The gender ratio, panel leader excluded, was M:F = 4:5, and the age range was 23 : 63 years. Most panelists had several years' experience in finfish and shellfish sensory evaluation, both from marine and freshwater environments. All of them had previously undergone a 20-hour course aimed at confirming their being normosensitive (ISO 8586:2012; Jellinek, 1985) as well as their competence in discriminant tests (mainly triangle test) (ISO 4120:2004) and descriptive tests (Quantitative Descriptive Analysis, QDA) according to Stone and Sidell (1993). In addition, 4 hours were spent familiarizing with the main sensory traits of several flatfish species, farmed and wild common sole included. In any case, the differences between wild and farmed sole were so numerous and obvious that it was deemed unnecessary, if not improper, to submit these matrices to any preliminary discriminant test (Jellinek, 1985). Panelists were requested to identify, within each modality, all the descriptors useful for distinguishing amongst samples, each of which had been previously identified with three-digit random codes. Overall, 144 descriptors were generated according to Civille and Lyon (1996) and Hyldig (2012) an then they were reduced to 26 according to ISO (ISO 11035:1994). Supplementary Table 1-2 lists these descriptors together with definitions and selected references, as derived from the panel's work during three dedicated sessions. In these sessions, the initial work on naming and definition of descriptors was individually performed in temporary booths, placed within an odorless room provided also with a large round table. This was afterwards used by the panel to convene and compare individual responses to finally attain a single set of broadly

agreed descriptors, i.e. the ballot (Supplementary Table 1-2**)**. Once the definitive ballot had been assembled, it was used to evaluate the effective samples within the same week, but on three different occasions and always in the morning (from 10 to 12 o'clock), using still mineral water at room temperature and the soft inside of unsalted Tuscan bread loaves as neutralizing mediums. Panelists had been instructed to evaluate odor first, followed by all the other elements of the flavor profile, and then appearance traits, to end with textural characteristics. The panelist's tray contained the Petri dishes with the two types of sole, European flounder and brill (all placed in random order), as well as the fish texture references introduced by Carbonell et al. (2002) all identified with three-digit random numbers, and the neutralizing mediums.

2.3. Statistical analyses

In order to check if the morphometric traits and true retention of wild and farmed common sole were significantly different, Student's t test has been applied. The effect of origin and treatments on proximate composition of carcass and fillets, fatty acids composition and content as well as sensory attributes was analyzed by a two-way ANOVA and in case of significant interaction ($P \leq 0.05$) Tukey's post hoc test was performed. Normality and homoscedasticity were validated for all data preceding ANOVA. Principal component analysis (PCA) was applied to the multivariate sensory attributes in order to synthesize the multivariate structure in relevant and meaningful components. Data were analyzed using the software R version 2.0.

3. Results and discussion

3.1. Morphometric traits

Morphometric indices of WS and FS are summarized in Table 2. FS showed a higher ($P \leq 0.0001$) CF, GW, HSI and skin percentage compared to the wild specimens, while VSI and Frame were significantly lower. No significant differences in fillet yields (SFY, ESFY and BSFY) were observed among treatments. External characteristics in farmed fish are affected by culture conditions, such as stocking density and feeding strategy (Grigorakis, 2007). CF acts as a good indicator of dietary condition and was found to be higher in farmed sea bream and sea bass compared to wild fish. In agreement with our findings farmed sea bream were shown to have thicker skin (Grigorakis et al., 2002). In addition the differences in HSI may also be related to the tendency of sole to store lipids in the liver in relation to a high dietary lipid level under farming condition (Gatta et al., 2011).

3.2. Proximate composition

Carcass proximate composition is presented in Table 3. Farmed fish showed a higher lipid content compared to wild fish while no significant differences were detected in moisture, protein, ash and energy content. Proximate composition of raw and cooked fillet was significantly affected by the origin of the fish (except for protein content $P = 0.474$) and by the treatment (raw vs cooked) Table 3. Focusing on fish origin, fillet lipid and energy content were significantly higher in farmed sole while moisture and ash were lower. No significant differences in fillet protein content related to fish origin were

observed. The fillet lipid content observed in wild sole is in agreement with that found by Ozogul et al. (2011) in wild specimens of common sole from the Mediterranean. A higher fat and energy content and lower moisture is commonly expected from farmed fish sources and is mainly due to a higher dietary fat level, higher feed intake and the reduced activity of the cultured fish (Martinez et al., 2010; Rincón et al., 2016). Focusing on the preparation method, moisture was lower in cooked fillets for both farmed and wild compared to raw fillets, while protein, lipid, ash and energy were higher in cooked fillets compared to raw fillets.

3.3. Flesh fatty acid composition and content

The fatty acid composition of raw and cooked fillets in wild and farmed common sole is shown in Table 4. Most of the FAs profile was affected by fish origin. Saturated fatty acids (SFA) were significantly higher in WS compared to FS. Palmitic acid (C16:0) was the most common SFA followed by stearic acid (C18:0) and their relative content was significantly higher in WS compared to FS. Interestingly, the level of SFA reported here in FS is lower than that reported in several farmed Mediterranean species (usually > 20 % on total FAs) such as turbot, sea bass and sea bream (Grigorakis, 2007; Martinez et al., 2010). The total monounsaturated fatty acid (MUFA) level was higher in FS compared to WS. Oleic acid (C18:1n-9) was the predominant MUFA and was higher in FS than WS. This is in general agreement with several previous studies comparing wild and farmed marine fish species and reflects the presence of terrestrial vegetable oils in aquafeed (Fuentes et al., 2010; Rincón et al., 2016).

No significant differences were found in the total polyunsaturated fatty acid of the n-6 series (PUFA n-6) between WS and FS. Linoleic (LA, C18:2n-6) and arachidonic acid (ARA, C20:4n-6) were the most common PUFA n-6 in FS and WS respectively, and showed a significant difference between the two origins. Furthermore LA was 6 times higher in FS than WS, while ARA was 4 times higher in WS compared to FS. Similarly, pronounced differences between wild and farmed marine fish species with respect to LA and ARA have been found in sea bass and sea bream in several studies as reviewed by Arechavala-Lopez et al. (2013) and recently reported by Farabegoli et al. (2018). LA, which similarly to MUFA derives from terrestrial vegetable oils, is accumulated largely unchanged in the lipids of marine fish due to their reduced capacity for chain elongation and desaturation (Fuentes et al., 2010). FS displayed higher PUFA n-3 level compared to WS (42.3 ± 2.14 % and 36.2 ± 3.84 %, respectively) with particular relevance for docosahexaenoic acid (DHA, 22:6n-3) which was the predominant PUFA n-3 and was significantly higher in FS compared to WS (26.7 ± 1.48 % and 21.9 ± 2.09 %, respectively). No significant differences were found in the relative content of eicosapentaenoic acid (C20:5n-3, EPA) and docosapentaenoic acid (C22:5n-3, DPA) between WS and FS. In general there were no significant effects of the cooking treatment on the FA level among the most common FAs except for the C18:0 and C18:2n-6 levels which slightly decreased and increased respectively after cooking (Table 4). Table 5 shows the fillet fatty acid content (mg/100g) of selected FAs. FS displayed a significant higher content in all the FAs considered compared to WS except for the ARA content. In particular in raw FS fillets, DHA was 54% higher than in WS (487 ± 45.9 mg and 225 ± 31.5 mg/100 g, in FS and WS respectively) as well as for DHA+EPA (587 ± 57.4 mg and 283.3 ± 40.5 mg/100g in FS and WS respectively). One

popular misconception among consumers is that farmed fish are inferior in terms of quality and nutritional content than wild fish. In reality, farmed fish have been found to contain as many as or, in most instances, more grams of EPA + DHA per serving than their wild-caught counterparts (Sprague et al., 2016). In general sole is a lean species and the content of polyunsaturated fatty acids is therefore lower compared to fattier species such as salmon. However the present results showed that under culture conditions sole, while maintaining the characteristics of lean fish (2% of fat content), displayed an EPA+DHA fillet content more than twice as high as its wild counterpart. Considering that The European Food Safety Authority (EFSA, 2005) suggests that all adults should be consuming 250 mg EPA+DHA per day respectively through fish consumption, based on 130g edible portions (as advised by EFSA), two portions of farmed sole will almost satisfy the weekly EPA+DHA requirement. It is known that the tissue content in EPA+DHA reflects the dietary composition of teleost species. At this regard, natural dietary regime of sole, such as Polychaeta species, is generally poor in lipid and proportionally high in EPA with only residual amount of DHA. In addition, the DHA tissue levels of the present study may be also related to the possible capability of sole species for a selective tissue retention of DHA or biosynthesis of DHA from EPA as recently highlighted in egg quality and lipid metabolism studies of sole species (Morais et al., 2016; Parma et al., 2015). Commercial aquafeed is expected to contains higher lipid and DHA level (depending on the fishmeal and fish oil dietary level) then the natural sole's diet, thus leading to a higher content in the flesh of fish under farming condition.

Environmental factors such as temperature may affect fish body composition as an indirect effect on feeding intake or direct consequences affecting the lipid content and

composition of fish tissues in a process known as homoviscous adaptation. In fact decreasing in water temperature has been associated with an increase of lipid content in muscle and increase body DHA and PUFA in fish species such as Atlantic salmon and carp (Jobling and Bendiksen 2003; Olsen and Skjervold 1995; Ruyter et al., 2006). In the present study wild fish have been caught in early winter at a water temperature on the seabed ranged approx. between 13-15 °C (Arpa Emilia Romagna, Cesenatico, Italy) which was lower than that of farmed specimens 18-20 °C. Despite the higher lipid, DHA and PUFA level occurred in the sole reared at higher temperature, we cannot exclude the influence of water temperature differences on the lipid body composition. In addition, a lower feeding activity of wild sole compared to farmed fish due to a lower temperature should also expected since feeding intake was observed to increase up to 22.7 °C in this species (Schram et al., 2013).

No significant effect of cooking method on any FAs content was detected. A similar finding was obtained in sea bream where the majority FAs remained stable after steaming and grilling compared to those observed in raw wild and farmed fish (Bhouri et al., 2010).

3.4. True nutrient retention values

True retention values of proximate composition and fatty acid content for cooked FS and WS are presented in Table 6. Nutrient retention ranged between 80.8 % and 100.6 % for both fish groups in proximate and FA content. Protein retention was around 100 % in both wild and farmed specimens as expected for this nutrient as it is not prone to leaching or degradation (Badiani et al., 2013). Average lipid retention ranged from 89.6

% to 100.6% in WS and FS respectively and are in agreement with those reported by Bognár (2002) for boiled or steamed lean fish species. Lipid was also significantly highly retained in WS compare to FS. The differences in lipid retention between WS and FS may be related to the differences in lipid content. FS showed a higher lipid content than WS and this may suggest a higher proportion of storage lipids than structural lipid which results in a higher tendency to post-cooking leaching. TRVs for fatty acids in FS and WS (82.5-99.9%) were higher than those reported by Badiani et al. (2013) for microwaved sea bass fillet (73.8-83.6%) but comparable to those produced by Pirini et al. (2010) for oven-baked medium-oil blue-back fish. No significant differences between FS and WS were detected in the retention of any FAs considered (Table 6).

3.5. Quantitative descriptive sensory analysis

Results of sensory scores of FS and WS based on the list of sensory attributes developed for common sole QDA (Supplementary Table 1, 2) are reported in Table 7. All the attributes considered, except for the odor associated with boiled rice, were significantly affected by fish origin. WS fillets presented a higher level of whiteness compared to FS. On the subject of odor, FS reported a higher level of intensity and a higher perception of “potato”, “courgette”, and “chard” compared to WS, which resulted higher in the anchor of “briny”, “octopus” and “boiled fish” compared to FS. Regarding taste, WS reported a higher score for the attributes of “salty”, “acid”, “bitter” and “umami” while in FS the attribute of ”sweet” was very common. Flavor attributes for WS were characterized by higher scores in “intensity”, “crab”, “octopus” and

"briny" compared to FS which was higher in "potato", "boiled fish", "chard" and "mushroom". Regarding texture, the attributes mainly associated with FS were astringency, firmness and chewiness while WS was perceived more juicy than FS. Sensory data obtained from QDA was further subjected to PCA (Supplementary Table 3). The first two principal components explained 80.4 % and 4.4 % of the total variation presented in the data (Fig. 1). Fig. 2 showed the correlation loading of PC1 and PC2 sensory attributes. Attributes of "potato" (odors and flavor), "boiled fish" (flavor), "sweet" (taste), firmness, astringency, chewiness, were very highly correlated for PC1 (> 0.8) and linked to farmed origin. Otherwise attributes of whiteness, briny (odor and flavor), "octopus" (odor and flavor), salty, acid, bitter, umami, intensity (flavor), crab and juiciness were very highly correlated for PC1 (> 0.8) and linked to wild origin (Fig. 2). A clear distinction could therefore be inferred between the comprehensive flavor profile for wild and farmed sole, much in the way already outlined for several white-flesh fish species, such as southern flounder (Drake et al., 2006), barramundi (Frank et al., 2009), gilthead sea bream (Grigorakis et al., 2003) and blackspot sea bream (Rincón et al., 2016). More in detail, the flesh of saltwater farm-raised flounder had a more intense sweet taste and a stronger fresh fish aroma compared to wild flounder, which turned out to be higher in sea complex, as well as more metallic, acidic and salty (Drake et al., 2006). Remarks by Frank et al. (2009) on wild and farmed barramundi pointed in the same direction, in that the flesh from farmed specimens was perceived as having significantly higher scores for fishy odor, flavor and aftertaste, whereas the flesh from wild subjects was reported to have higher levels of the descriptor prawn and, occasionally, seawater. Wild gilthead sea bream, as studied by Grigorakis et al. (2003) were found to have juicier flesh than that of their cultured counterparts, which, in turn,

sported a whiter appearance together with softer flesh. Wild and farmed blackspot seabream, recently studied by Rincón et al. (2016) clearly differed as to appearance with wild specimens having whiter and more shiny fillets and some textural features (farmed specimens being fattier, chewier and more adhesive than wild ones), although no differences emerged between the two typologies as to firmness. The most remarkable differences between wild and farmed specimens, though, emerged in odor and flavor, farmed specimens having a more intense, oily and acidic flavor, as against wild specimens, which, once more, were characterized by much more intense seafood notes. Rincón et al. (2016) went further to examine the average fatty acid composition of the two typologies of *Pagellus*, where farmed lipid content was three times higher than in the wild one. Part of the sensory differences between wild and farmed specimens as found by Grigorakis et al. (2003) in gilthead sea bream, as well as those observed by Rincón et al. (2016) in blackspot seabream, could be more or less directly ascribed to differences in fatty acid profiles. In both papers different specimens were necessarily examined as to chemical and sensory traits, as was the case for the wild and farmed sole described in the present study. These specimens differed as to fat content (Table 3) and fatty acid composition, most notably 18:2n-6, 18:3n-3, 20:4n-6, and 22:6n-3 (Table 4), hence the presence of a whole host of different deriving carbonyl compounds could be inferred. A different train of reasoning had to be developed around texture, in that farmed sole emerged as being much more astringent (+ 429%), firm (+ 251 %) and chewy (+ 158 %) than the wild fish, which in turn proved to be much juicier (+ 348%). This is in contrast to what is expected from farmed and wild fish. The flesh of wild fish is usually firmer, which could be attributed to its lower fat content and the higher level of swimming activity. In the case of sole, our comparison in fillet composition between

wild and farmed origin showed that the lipid content in FS was less than 1% higher than WS and this may not be sufficient to give an effect on firmness perception. Feeding sources might also have an effect on flesh texture, however Valente et al. (2016) investigating the effect of dietary plant protein on flesh texture in Senegal sole, did not find significant differences up to 75% plant protein replacement. Other factors that could explain differences in flesh texture are related to the collagen content of the flesh, pH and the number and size of distribution of muscle fibres (Periago et al., 2005). In addition the swimming activity of sole farmed at high density condition should be also taken into account: in the present study we observed a continuous swimming activity at farm level and this often occurs when common sole are raised at a high density without sand bottom (personal comment). This continuous swimming activity might be even higher than in the wild specimens which spend most of their life burrowing in the sand or crawling on the sea bed searching for prey. The high swimming activity could also explain the lower level of whiteness we found in FS compared to WS. Dark muscle tissue is used for continuous swimming in contrast to white muscles that are used for rapid-burst swimming (Arechavala-Lopez et al., 2013).

4. Conclusions

In conclusion, a comparative assessment of quality traits including morphometric characteristics, yields, nutritional and sensory profile was carried out for the first time between farmed and wild common sole. Farmed sole displayed higher condition factor and higher gutted weight but did not differ in fillet yields compared to wild sole. Farmed sole, while maintaining the characteristics of a lean fish species (2% of lipid

content) was particularly rich in PUFA n-3 displaying a EPA+DHA fillet content more than twice as high as the wild fish. Sensory evaluation clearly discriminated farmed from wild. “Potato”, “boiled fish”, “sweet”, firmness, astringency, chewiness, were the attributes linked to farmed origin while whiteness, briny, octopus, salty, acid, bitter, umami, intensity, crab and juiciness were linked to wild origin. Intensive farming conditions improved the nutritional value of common sole in terms of lipid content and FAs profile and led to sweeter sensory traits more associated with a terrestrial vegetable perception than the wild specimens.

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Figure captions

Fig. 1. Principal coordinate analyses showing distribution of sensory attributes of common sole fillet in relation with the origin: farmed or wild.

Fig. 2. Correlation loadings of PC1 vs. PC2 of sensory attributes of common sole fillet. Red = very highly correlated (> 0.8) for PC-1; green = very highly correlated (> 0.8) for PC-2; black = medium/highly correlated (< 0.8).

Table 1. Proximate composition (as given by the manufacturer) of the commercial diet (Aller Futura Ex) used for the farmed common sole (*Solea solea*)

Proximate composition, % as it is	
Protein	64
Lipid	12
Ash	11
NFE	5
Fiber	0.5
Gross energy (MJ)	20.8

Table 2. Morphometric traits of wild and farmed common sole

	Wild	**Farmed**	***P*-value**
CF	0.81 ± 0.11	1.13 ± 0.19	$P < 0.0001$
GW (%)	93.8 ± 10.09	96.7 ± 0.69	$P < 0.0001$
VSI (%)	4.03 ± 1.02	3.20 ± 0.51	$P < 0.0001$
HSI (%)	1.05 ± 0.39	1.45 ± 0.38	$P < 0.0001$
Skin (%)	10.3 ± 2.10	11.5 ± 1.55	$P < 0.0001$
SFY (%)	44.29 ± 3.73	44.45 ± 2.91	$P = 0.61$
ESFY (%)	24.9 ± 2.36	25.2 ± 1.83	$P = 0.16$
BSFY (%)	19.4 ± 1.86	19.2 ± 1.57	$P = 0.46$
Frame (%)	36.4 ± 2.69	35.5 ± 3.14	$P < 0.002$

Data are given as the mean (n=200) ± SD.
CF = Condition factor = 100 × total body weight (TBW) × total body lenght^{-3} (TBL) ;
GW, gutted weight = 100 × GW × TBW^{-1};
VSI, viscerosomatic index = 100 × visceral weight × TBW^{-1};
HSI, hepatosomatic index = 100 × liver weight × TBW^{-1};
Skin = 100 × Skin weight × TBW^{-1};
SFY, skinned fillet yield = 100 × Skinned fillet weight (SFW) × TBW^{-1};
ESFY, eyes side fillet yield = 100 × eyes side (SFW) × TBW^{-1};
BSFY, blind side fillet yield = 100 × blind side (SFW) × TBW^{-1};
Frame = 100 × frame weight × TBW^{-1}

Table 3. Proximate composition (%) of carcass, raw (RW) and cooked (CK) fillets of wild and farmed common sole.

	Wild		Farmed		*P*-value		
	Carcass				Origin	Treatment	Orig xTreat
Moisture	73.5 ± 0.5		73.2 ± 0.6		*P* = 0.45	n.a	n.a
Protein	17.7 ± 0.6		17.8 ± 0.3		*P* = 0.88	n.a	n.a
Lipid	7.41 ± 0.13		7.69 ± 0.13		*P* = 0.03	n.a	n.a
Ash	2.60 ± 0.19		2.48 ± 0.26		*P* = 0.48	n.a	n.a
Energy	138 ± 2		140 ± 1		*P* = 0.06	n.a	n.a
	Fillet						
	RW	CK	RW	CK			
Moisture	78.8 ± 0.3^{d}	75.8 ± 0.5^{b}	78.1 ± 0.4^{c}	74.5 ± 0.4^{a}	*P* < 0.0001	*P* < 0.0001	*P* = 0.225
Protein	19.5 ± 0.3^{a}	22.5 ± 0.6^{b}	19.4 ± 0.3^{a}	22.8 ± 0.3^{b}	*P* = 0.474	*P* < 0.0001	*P* = 0.135
Lipid	1.20 ± 0.13^{a}	1.41 ± 0.19^{a}	2.11 ± 0.30^{b}	2.21 ± 0.23^{b}	*P* < 0.0001	*P* = 0.0369	*P* = 0.472
Ash	1.32 ± 0.06^{b}	1.43 ± 0.06^{c}	1.24 ± 0.02^{a}	1.29 ± 0.03^{ab}	*P* < 0.0001	*P* < 0.0001	*P* = 0.071
Energy	89 ± 2^{a}	103 ± 2^{c}	97 ± 4^{b}	111 ± 3^{d}	*P* < 0.0001	*P* < 0.0001	*P* = 0.726

Data are given as the mean ± SD. N=4 for carcass composition, n=10 for fillet composition. In each line, different superscript letters indicate significant differences among treatments ($P \leq 0.05$). N.a = not applicable.

Table 4. Fatty acid composition (% of total fatty acid methyl esters, FAME) of raw (RW) and cooked (CK) fillets in wild and farmed common sole.

	Wild		Farmed		*P*-Value		
	RW	***CK***	***RW***	***CK***	**Origin**	**Treatment**	**Orig x Treat**
C14:0	1.57 ± 0.28^{a}	1.60 ± 0.20^{a}	1.99 ± 0.23^{b}	1.89 ± 0.07^{b}	$P < 0.001$	$P = 0.584$	$P = 0.321$
C15:0	0.53 ± 0.08^{b}	0.58 ± 0.07^{b}	0.27 ± 0.04^{a}	0.25 ± 0.01^{a}	$P < 0.001$	$P = 0.329$	$P = 0.089$
C16:0	14.5 ± 2.06^{b}	14.9 ± 1.10^{b}	13.4 ± 0.74^{ab}	12.8 ± 0.41^{a}	$P = 0.0002$	$P = 0.7351$	$P = 0.2026$
C18:0	4.48 ± 0.23^{b}	4.99 ± 0.32^{c}	3.36 ± 0.10^{a}	3.42 ± 0.18^{a}	$P < 0.001$	$P = 0.0002$	$P = 0.0023$
∑ *SFA*	21.1 ± 2.53^{b}	22.1 ± 1.32^{b}	19.0 ± 1.03^{a}	18.3 ± 0.56^{a}	*P < 0.001*	*P = 0.7890*	*P = 0.0957*
C16:1 n-7	4.63 ± 0.95^{b}	5.01 ± 0.84^{b}	3.12 ± 0.26^{a}	3.03 ± 0.11^{a}	$P < 0.001$	$P = 0.482$	$P = 0.268$
C18:1 n-9	10.4 ± 0.95^{a}	10.5 ± 0.61^{a}	13.8 ± 0.44^{b}	13.5 ± 0.41^{b}	$P < 0.001$	$P = 0.617$	$P = 0.390$
C18:1 n-7	3.42 ± 0.28^{b}	3.66 ± 0.22^{c}	2.51 ± 0.09^{a}	2.42 ± 0.07^{a}	$P < 0.001$	$P = 0.234$	$P = 0.008$
C20:1 n-9	1.37 ± 0.20^{a}	1.43 ± 0.28^{a}	2.53 ± 0.20^{b}	2.45 ± 0.12^{b}	$P < 0.001$	$P = 0.815$	$P = 0.291$
C20:1 n-7	0.52 ± 0.20^{c}	0.38 ± 0.05^{b}	0.13 ± 0.01^{a}	0.14 ± 0.02^{a}	$P < 0.001$	$P = 0.052$	$P = 0.040$
C22:1 n-11	1.10 ± 0.17^{a}	1.19 ± 0.30^{a}	2.24 ± 0.33^{b}	2.10 ± 0.14^{b}	$P < 0.001$	$P = 0.702$	$P = 0.145$
C22:1 n-9	0.39 ± 0.25^{b}	0.18 ± 0.04^{a}	0.32 ± 0.03^{ab}	0.29 ± 0.01^{a}	$P = 0.613$	$P = 0.005$	$P = 0.040$
∑ *MUFA*	21.8 ± 2.34^{a}	22.3 ± 1.27^{ab}	24.7 ± 1.05^{c}	24.0 ± 0.58^{bc}	*P < 0.001*	*P = 0.803*	*P = 0.203*
C16:2 n-4	0.98 ± 0.12^{b}	1.11 ± 0.07^{c}	0.53 ± 0.03^{a}	0.51 ± 0.02^{a}	$P < 0.001$	$P = 0.024$	$P = 0.002$
C16:3 n-4	0.85 ± 0.07^{b}	0.86 ± 0.05^{b}	0.52 ± 0.05^{a}	0.54 ± 0.04^{a}	$P < 0.001$	$P = 0.312$	$P = 0.839$
∑ *PUFA n-4*	1.83 ± 0.18^{b}	1.98 ± 0.12^{c}	1.05 ± 0.06^{a}	1.05 ± 0.05^{a}	*P < 0.001*	*P = 0.065*	*P = 0.058*
C18:2 n-6	1.01 ± 0.22^{a}	0.85 ± 0.07^{a}	6.01 ± 0.21^{c}	5.80 ± 0.12^{b}	$P < 0.001$	$P = 0.001$	$P = 0.593$
C20:2 n-6	0.41 ± 0.07^{b}	0.39 ± 0.04^{b}	0.36 ± 0.01^{a}	0.36 ± 0.01^{a}	$P = 0.004$	$P = 0.640$	$P = 0.452$
C20:3 n-6	0.32 ± 0.06^{b}	0.28 ± 0.02^{b}	0.13 ± 0.01^{a}	0.13 ± 0.01^{a}	$P < 0.001$	$P = 0.224$	$P = 0.115$
C20:4 n-6	4.37 ± 0.42^{b}	4.35 ± 0.53^{b}	1.10 ± 0.08^{a}	1.13 ± 0.03^{a}	$P < 0.001$	$P = 0.963$	$P = 0.810$
C22:4 n-6	2.11 ± 0.24^{b}	1.95 ± 0.12^{b}	0.18 ± 0.01^{a}	0.19 ± 0.01^{a}	$P < 0.001$	$P = 0.100$	$P = 0.042$
C22:5 n-6	0.14 ± 0.04^{a}	0.18 ± 0.21^{a}	0.46 ± 0.02^{b}	0.50 ± 0.03^{b}	$P < 0.001$	$P = 0.278$	$P = 0.919$
∑ *PUFA n-6*	8.37 ± 0.76	8.00 ± 0.71	8.23 ± 0.16	8.12 ± 0.10	*P = 0.950*	*P = 0.159*	*P = 0.463*
C18:3 n-3	0.51 ± 0.22^{a}	0.48 ± 0.07^{a}	0.94 ± 0.07^{b}	0.91 ± 0.03^{b}	$P < 0.001$	$P = 0.454$	$P = 0.917$
C18:4 n-3	0.30 ± 0.11^{a}	0.28 ± 0.05^{a}	1.00 ± 0.05^{b}	0.99 ± 0.07^{b}	$P < 0.001$	$P = 0.421$	$P = 0.932$
C20:4 n-3	0.23 ± 0.06^{a}	0.20 ± 0.03^{a}	0.82 ± 0.05^{b}	0.82 ± 0.03^{b}	$P < 0.001$	$P = 0.192$	$P = 0.396$
C20:5 n-3	5.74 ± 1.15	5.46 ± 0.44	5.47 ± 0.88	4.98 ± 0.26	$P = 0.132$	$P = 0.125$	$P = 0.673$
C22:5 n-3	7.52 ± 0.76^{ab}	7.15 ± 0.44^{a}	7.37 ± 0.34^{ab}	7.90 ± 0.43^{b}	$P = 0.078$	$P = 0.631$	$P = 0.008$
C22:6 n-3	21.9 ± 2.09^{a}	20.3 ± 0.98^{a}	26.7 ± 1.48^{b}	28.3 ± 0.62^{b}	$P < 0.001$	$P = 0.945$	$P < 0.001$
∑ *PUFA n-3*	36.2 ± 3.84^{a}	33.8 ± 0.82^{a}	42.3 ± 2.14^{b}	43.9 ± 1.14^{b}	*P < 0.001*	*P = 0.643*	*P = 0.010*
∑ *PUFA*	46.4 ± 4.08^{a}	43.8 ± 1.25^{a}	51.6 ± 2.06^{b}	53.1 ± 1.12^{b}	*P < 0.001*	*P = 0.513*	*P = 0.012*
Not identified	11.0 ± 1.96^{b}	11.4 ± 0.76^{b}	4.75 ± 0.18^{a}	4.76 ± 0.33^{a}	$P < 0.001$	$P = 0.598$	$P = 0.606$
PUFA/SFA	2.24 ± 0.46^{a}	1.99 ± 0.12^{a}	2.72 ± 0.23^{b}	2.90 ± 0.14^{b}	$P < 0.001$	$P = 0.678$	$P = 0.018$
MUFA/SFA	1.04 ± 0.10^{a}	1.02 ± 0.10^{a}	1.30 ± 0.04^{b}	1.31 ± 0.03^{b}	$P < 0.001$	$P = 0.758$	$P = 0.473$
n-3/n-6	4.34 ± 0.46^{a}	4.26 ± 0.37^{a}	5.14 ± 0.30^{b}	5.41 ± 0.16^{b}	$P < 0.001$	$P = 0.383$	$P = 0.108$
n-6/n-3	0.23 ± 0.03^{b}	0.24 ± 0.02^{b}	0.20 ± 0.01^{a}	0.18 ± 0.01^{a}	$P < 0.001$	$P = 0.596$	$P = 0.292$
EPA+DHA	27.6 ± 3.02^{a}	25.7 ± 0.89^{a}	32.1 ± 1.99^{b}	33.3 ± 0.82^{b}	$P < 0.001$	$P = 0.562$	$P = 0.017$
EPA/DHA	0.26 ± 0.04^{c}	0.27 ± 0.03^{c}	0.20 ± 0.03^{b}	0.18 ± 0.01^{a}	$P < 0.001$	$P = 0.220$	$P = 0.029$
DHA/EPA	3.88 ± 0.48^{a}	3.74 ± 0.38^{a}	4.97 ± 0.67^{b}	5.69 ± 0.22^{c}	$P < 0.001$	$P = 0.057$	$P = 0.005$
C20:1 + C22:1	3.37 ± 0.58^{a}	3.17 ± 0.63^{a}	5.22 ± 0.53^{b}	4.97 ± 0.20^{b}	$P < 0.001$	$P = 0.163$	$P = 0.878$
ARA/EPA	0.78 ± 0.12^{b}	0.80 ± 0.13^{b}	0.20 ± 0.02^{a}	0.23 ± 0.01^{a}	$P < 0.001$	$P = 0.395$	$P = 0.986$
EPA/ARA	1.31 ± 0.23^{a}	1.28 ± 0.23^{a}	4.96 ± 0.63^{c}	4.39 ± 0.22^{b}	$P < 0.001$	$P = 0.014$	$P = 0.030$

Data are given as the mean (n=10) ± SD. In each line, different superscript letters indicate significant differences among treatments ($P \leq 0.05$). SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; ARA: arachidonic acid; PUFA: polyunsaturated fatty acids; EPA: eicosapentaenoic acid; DHA: docosahexaenoic acid.

Table 5. Fatty acid content (mg/100 g) of raw (RW) and cooked (CK) fillet in wild and farmed common sole.

	Wild		Farmed		*P*-Value		
	RW	**CK**	**RW**	**CK**	**Origin**	**Treatment**	**Orig x Treat**
C18:2 n-6	10.4 ± 2.7[a]	9.6 ± 1.9[a]	110 ± 19.6[b]	111 ± 13.4[b]	$P < 0.001$	$P = 0.979$	$P = 0.896$
C20:4 n-6	44.9 ± 5.9[b]	48.2 ± 5.8[b]	20.1 ± 2.0[a]	19.9 ± 5.4[a]	$P < 0.001$	$P = 0.360$	$P = 0.273$
∑ *PUFA* n-6	86.0 ± 12.1[a]	95.1 ± 28.8[a]	152 ± 24.1[b]	154 ± 16.3[b]	$P < 0.001$	$P = 0.408$	$P = 0.612$
C18:3 n-3	5.3 ± 2.4[a]	5.4 ± 1.6[a]	17.6 ± 3.2[b]	17.5 ± 2.4[b]	$P < 0.001$	$P = 0.85$	$P = 0.95$
C20:5 n-3 (EPA)	58.7 ± 11.7[a]	61.6 ± 13.2[a]	99.9 ± 17.1[b]	95.4 ± 11.0[b]	$P < 0.001$	$P = 0.870$	$P = 0.391$
C22:5 n-3	77.2 ± 9.6[a]	80.7 ± 17.4[a]	135 ± 20.1[b]	151 ± 18.3[b]	$P < 0.001$	$P = 0.078$	$P = 0.249$
C22:6 n-3 (DHA)	225 ± 31.5[a]	228 ± 40.0[a]	487 ± 45.8[b]	542 ± 59.2[c]	$P < 0.001$	$P = 0.050$	$P = 0.078$
∑ *PUFA* n-3	371 ± 51.8[a]	381 ± 71.2[a]	773 ± 85.3[b]	841 ± 94.3[b]	$P < 0.001$	$P = 0.124$	$P = 0.244$
EPA+DHA	283.3 ± 40.5[a]	289.2 ± 51.6[a]	587.0 ± 57.4[b]	637.3 ± 69.6[b]	$P < 0.001$	$P = 0.051$	$P = 0.079$

Data are given as the mean (n=10) ± SD. In each line, different superscript letters indicate significant differences among treatments ($P \leq 0.05$). PUFA: polyunsaturated fatty acids; EPA: eicosapentaenoic acid; DHA: docosahexaenoic acid.

Table 6. True retention values (%, TRV) of proximate composition and fatty acid content in wild and farmed common sole fillet

	Wild	**Farmed**	***P*-Value**
Moisture	82.6 ± 2.9	80.8 ± 1.0	$P = 0.092$
Protein	99.8 ± 3.4	99.0 ± 1.6	$P = 0.517$
Lipid	100.6 ± 9.8	89.6 ± 11.6	$P = 0.034$
Ash	93.9 ± 4.9	88.4 ± 3.6	$P = 0.011$
C18:2 n-6 (LA)	82.5 ± 23.8	85.9 ± 13.2	$P = 0.691$
C20:4 n-6 (ARA)	93.6 ± 16.7	83.4 ± 23.4	$P = 0.272$
∑ *PUFA n-6*	95.6 ± 25.7	86.7 ± 11.6	$P = 0.333$
C18:3 n-3 (ALA)	99.9 ± 39,1	85.5 ± 14.7	$P = 0.298$
C20:5 n-3 (EPA)	94.5 ± 30.2	83.1 ± 19.5	$P = 0.331$
C22:5 n-3 (DPA)	91.4 ± 24.2	95.3 ± 13.2	$P = 0.652$
C22:6 n-3 (DHA)	88.7 ± 21.2	94.3 ± 11.8	$P = 0.485$
∑ *PUFA n-3*	90.1 ± 23.0	92.4 ± 12.7	$P = 0.785$

Data are given as the mean (n=10) ± SD. PUFA: polyunsaturated fatty acids; ARA: arachidonic acid; EPA: eicosapentaenoic acid; DHA: docosahexaenoic acid. LA: linoleic acid; ALA: α-Linolenic acid; DPA: docosapentaenoic acid.

Table 7. Average sensory scores for the attributes evaluated in farmed and wild common sole fillet and effect of factor origin and panel. Values are expressed as means ± SD, n=14

		Wild	Farmed	*P*-value		
				Origin	Panel	Org x Pan
Appearance	Whiteness_A	81.3 ± 4.8	11.3 ± 9.9	0.000	1.000	1.000
Odor	Intensity_O	41.4 ± 15.5	55.6 ± 16.2	0.129	1.000	0.073
	Briny_O	43.1 ± 7.1	9.5 ± 6.0	0.000	0.237	0.355
	Octopus_O	41.4 ± 9.0	4.3 ± 6.7	0.000	1.000	1.000
	Potato_O	7.5 ± 8.5	44.9 ± 8.2	0.000	0.130	1.000
	Boiled fish_O	42.6 ± 17.2	14.2 ± 14.8	0.007	1.000	1.000
	Courgette_O	2.14 ± 4.5	25.1 ± 18.2	0.001	0.569	1.000
	Chard_O	3.8 ± 7.9	20.3 ± 16.3	0.008	1.000	0.581
	Rice_O	16.3 ± 12.7	13.4 ± 16.3	1.000	1.000	0.621
Basic taste	Sweet_T	6.6 ± 9.8	58.2 ± 8.7	0.000	1.000	1.000
	Salty_T	71.9 ± 14.7	27.3 ± 11.5	0.000	1.000	1.000
	Acid_T	34.6 ± 8.6	0.43 ± 1.6	0.000	1.000	1.000
	Bitter_T	38.6 ± 10.1	3.6 ± 11.3	0.000	1.000	1.000
	Umami_T	77.9 ± 10.3	17.1 ± 8.7	0.000	1.000	1.000
Flavor	Intensity_F	64.9 ± 7.3	25.3 ± 6.2	0.000	1.000	1.000
	Crab_F	44.9 ± 5.1	0.43 ± 1.6	0.000	1.000	1.000
	Octopus_F	44.8 ± 12.4	6.2 ± 5.5	0.000	1.000	1.000
	Briny_F	51.6 ± 11.0	7.3 ± 6.6	0.000	1.000	1.000
	Potato_F	1.3 ± 2.7	39.6 ± 12.7	0.000	1.000	1.000
	Boiled fish_F	2.0 ± 4.8	56.6 ± 12.6	0.000	0.015	0.124
	Chard_F	1.8 ± 4.7	23.8 ± 16.6	0.001	1.000	0.497
	Mushrooms_F	1.9 ± 6.2	24.2 ± 16.0	0.002	1.000	1.000
Texture	Astringency_Tx	14.1 ± 5.5	60.5 ± 11.9	0.000	1.000	1.000
	Firmness_Tx	26.5 ± 5.1	66.6 ± 7.3	0.000	0.327	1.000
	Chewiness_Tx	17.4 ± 3.8	27.5 ± 4.0	0.000	0.000	1.000
	Juiciness_Tx	57.1 ± 10.7	16.4 ± 6.7	0.000	0.486	1.000

A: appearance; O: odor; T: taste; F: flavor; Tx: texture

Figure 1

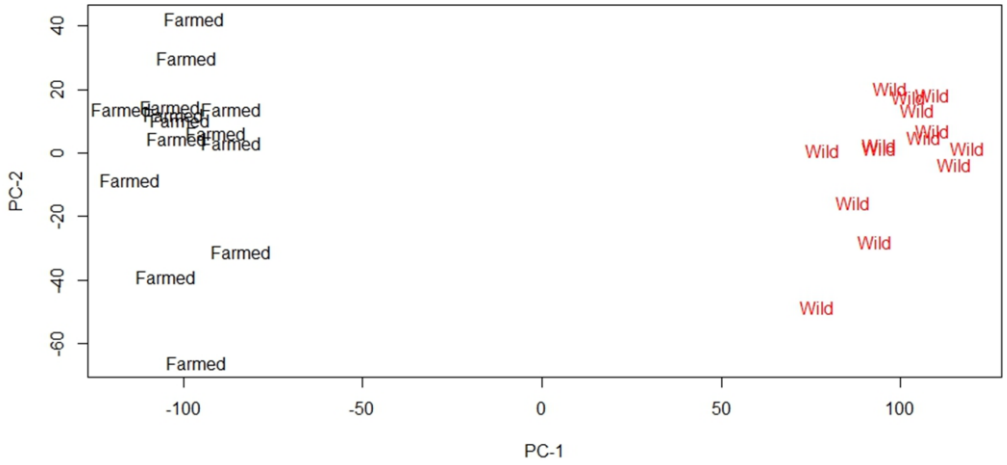
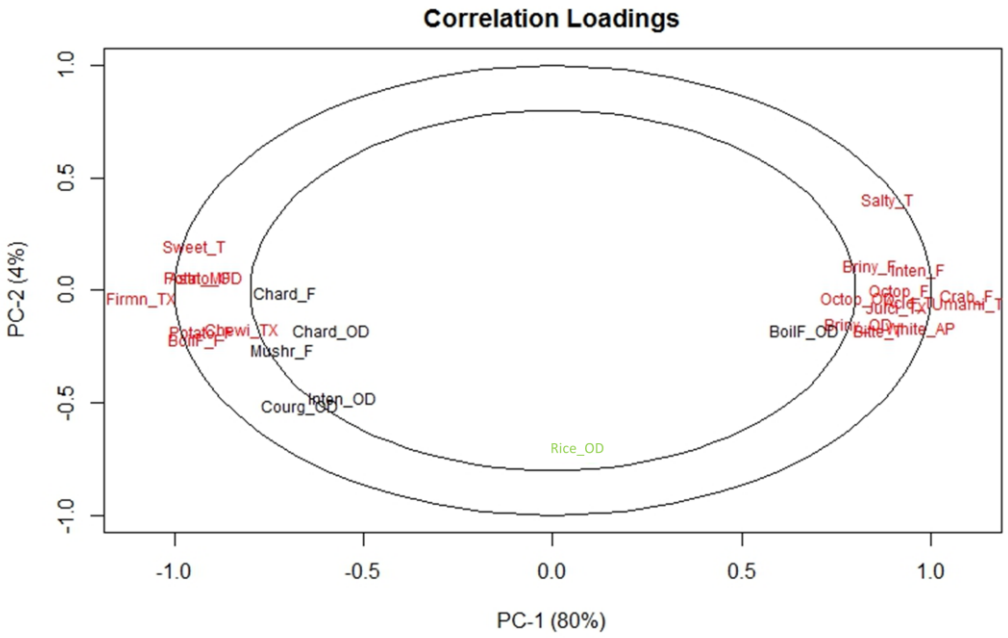


Figure 2


Correlation Loadings
PC-2 (4%)
PC-1 (80%)
1.0
0.5
0.0
-0.5
-1.0
Sweet_T
Firmn_TX
Chard_F
Chard_OD
Mushr_F
Courg_OD
Rice_OD
Salty_T
Briny_F
Inten_F
Crab_F
BoilF_OD

Supplementary Table 1. List of descriptors for appearance, odors and basic taste developed by a 10-member trained sensory panel for common sole Quantitative Descriptive Analysis

			Anchor Points	
			Minimum	**Maximum**
Appearance	Whiteness_A	Visual evaluation of the degree of fullness of white as perceived under CIE standard illuminant D65 with the aid of Pantone® chips of the whitish series	Pantone® chips: Antique white 11-0105TCX / White alyssum 11-1001TCX	Pantone® chips: Snow white 11-0602TCX / Star white 11-4202TCX
Odors	Intensity_O[1]	The global strength of the aromatics as perceived through orthonasal olfaction at the opening of the glass Petri dish containing the warm[2] product	As in microwaved (MW) flounder (*Platychthys flesus*)	As in MW brill (*Scophthalmus rhombus*)
	Briny_O	Aromatics characteristic of ocean air, salt water, pickling salts (Civille and Lyon, 1996)	No stimulus	Pan-opened mussel shells with intervalval liquor
	Octopus_O	Aromatics associated with the flesh of boiled octopus (*Octopus vulgaris* Cuvier, 1797)	No stimulus	Boiled octopus kept duly warm
	Potato_O	Aromatics associated with the core of a yellow potato boiled without skin	No stimulus	The warm core of a yellow potato boiled without skin
	Boiled fish_O	Aromatics associated with the flesh of boiled hake (either *Merluccius capensis* or *M. paradoxus)*	No stimulus	Boiled hake kept warm
	Courgette_O	Aromatics associated with the flesh of boiled light green courgettes	No stimulus	Boiled light green courgettes kept warm
	Rice_O	Aromatics associated with Arborio rice boiled *al dente* well drained and with a knob of unsalted butter added, while still hot	No stimulus	Boiled Arborio rice plus a small amount of unsalted butter
	Chard_O	Aromatics associated with Swiss chard leaves boiled in a tiny amount of water for 5-6 minutes and chopped after squeezing out any excess water	No stimulus	Boiled chard leaves slightly chopped and kept warm
Basic taste	Sweet_T	Taste on the tongue stimulated by sugars and high potency sweeteners (Civille and Lyon, 1996)	No stimulus	A 0.6% solution of sucrose in water (Jellinek, 1985)
	Salty_T	Taste on the tongue stimulated by sodium salts, especially sodium chloride (Civille and Lyon, 1996)	No stimulus	A 0.15 % solution of sodium chloride in water (Jellinek, 1985)
	Acid_T	Taste on the tongue stimulated by acids (Civille and Lyon, 1996)	No stimulus	A 0.04 % solution of citric acid in water (Jellinek, 1985)
	Bitter_T	Taste on the tongue stimulated by solutions of caffeine, quinine, and certain other alkaloids (Civille and Lyon, 1996)	No stimulus	A 0.03 % solution of caffeine in water (Jellinek, 1985)
	Umami_T	Specific chemical feeling factor stimulated by monosodium glutamate (MSG) and certain other nucleotides (Civille and Lyon, 1996)	No stimulus	A 0.15 % solution of MGS in water (Jellinek, 1985)

[1]A 12-cm unstructured line scale was adopted, anchored respectively at 1.0 and 11.0 cm from the beginning of the scale itself (Stone et al., 1980). [2]Here and whenever serving temperature is mentioned, 45-50°C was selected for both fish samples and reference materials (Hyldig, 2012). A: appearance; O: odor; T: taste.

Supplementary Table 2. List of descriptors for flavors, mouthfeels and texture developed by a 10-member trained sensory panel for common sole Quantitative Descriptive Analysis

			Anchor Points	
			Minimum	**Maximum**
Flavors	Intensity_F[1]	The global strength of the aromatics as perceived through retronasal olfaction at the opening of the glass Petri dish containing the warm product	As in microwaved flounder (*Platychthys flesus*)	As in microwaved brill (*Scophthalmus rhombus*)
	Crab_F	A delicate flavor typical of fresh crabmeat, including a very mild fresh fish note (Civille and Lyon, 1996)	No stimulus	Freshly cooked crab meat
	Octopus_F	Aromatics associated with the flesh of boiled octopus (*Octopus vulgaris* Cuvier, 1797)	No stimulus	Boiled octopus kept duly warm
	Briny_F	Aromatics characteristic of ocean air, salt water, pickling salts (Civille and Lyon, 1996)	No stimulus	Pan-opened mussel shells with intervalval liquor
	Potato_F	Aromatics associated with a boiled yellow potato without skin	No stimulus	The warm core of a yellow potato boiled without skin
	Boiled fish_F	Aromatics associated with the flesh of boiled hake (either *Merluccius capensis* or *M. paradoxus*)	No stimulus	Boiled hake kept warm
	Mushrooms_F	Aromatics generally associated with butter sautéed button mushrooms (*Agaricus bisporus*) (Civille and Lyon, 1996)	No stimulus	Just sautéed button mushrooms
	Chard_F	Aromatics associated with Swiss chard leaves boiled in a tiny amount of water for 5-6 minutes and chopped after squeezing out any excess water	No stimulus	Boiled chard leaves slightly chopped and kept warm
Mouthfeels	Astringent_M	The chemical feeling factor on the tongue or other skin surfaces of the oral cavity described as puckering/dry and associated with tannins or alum (Civille and Lyon, 1996)	No stimulus	Strong black tea (5 bags of tea steeped for 1 h in 500 ml water)
Texture[2]	Firmness_TX	Mechanical textural attribute relating to the force required to achieve a given deformation or penetration of a product (Carbonell et al., 2002 modified; ISO 11036:1994).	Soft as microwaved cooked plaice (*Pleuronectes platessa*)	Firm as microwaved cooked swordfish (*Xiphias gladius*)
	Chewiness_TX	Mechanical textural attribute related to cohesiveness and to the number of chews required to masticate a solid product into a state ready for swallowing (Carbonell et al., 2002 modified; ISO 11036:1994)	Microwaved cooked plaice (*P. platessa*)	Microwaved cooked swordfish (*X. gladius)*
	Juiciness_TX	Surface textural attribute relating to the perception of the amount of water released from a product (Carbonell et al., 2002 modified)	Microwaved cooked swordfish (*X. gladius*)	Microwaved cooked plaice (*P. platessa*)

[1]A 12-cm unstructured line scale was adopted, anchored respectively at 1.0 and 11.0 cm from the beginning of the scale itself (Stone et al., 1980). [2]Attributes referred to a "Standard bite size" (cm 1.5 × 1.5 × natural thickness of the product, up to a maximum of 1.5 cm). F: flavor; M: mouthfeels; Tx: texture.

Supplementary Table 3. Factor loadings of Principal Coordinate Analyses for sensory evaluation of farmed and wild common sole.

		PC-1	PC-2
Appearance	Whiteness_A	0.35	-0.13
Odor	Intensity_O	-0.07	-0.35
	Briny_O	0.17	-0.12
	Octopus_O	0.19	-0.03
	Potato_O	-0.19	-0.02
	Boiled Fish_O	0.14	-0.23
	Courgette_O	-0.12	-0.44
	Chard_O	-0.09	-0.17
	Rice_O	0.01	-0.49
Taste	Sweet_T	-0.26	0.13
	Salty_T	0.23	0.36
	Acid_T	0.17	-0.10
	Bitter_T	0.18	-0.22
	Umami_T	0.31	-0.09
Flavor	Intensity_F	0.20	0.01
	Crab_F	0.22	-0.02
	Octopus_F	0.19	0.07
	Briny_F	0.23	0.11
	Potato_F	-0.20	-0.09
	Boiled fish_F	-0.27	-0.17
	Chard_F	-0.11	0.05
	Mushrooms_F	-0.12	-0.13
Texture	Astringency_Tx	-0.23	0.15
	Firmness_Tx	-0.20	-0.03
	Chewiness_Tx	-0.05	-0.07
	Juiciness_Tx	0.20	-0.15

A: appearance; O: Odor; T: taste; F: flavor; Tx: texture; PC: principal coordinate