A sensory and nutritional comparison of mussels (*Mytilus* sp.) produced in NW Iberia and in the Armona offshore production area (Algarve, Portugal)

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**ABSTRACT**

A biometric, nutritional and sensory analysis of raw and cooked mussels comparing *Mytilus* sp. from the north-west coast of Portugal and Spain (Minho and Galicia, respectively) and the new offshore production site of Armona (Algarve, south Portugal) was carried out. In addition, multiple factorial analysis was performed to explore potential relationships between sensory attributes and nutritional content properties between the different mussels. Results showed that, at similar times of sale, biometrics of mussels from Armona and Vigo were similar and bigger than the remaining. Nonetheless, despite some similarities in proximate composition, mussels presented differences in lipid classes, fatty acid content and free amino acids profiles. These differences were not fully reflected in the sensory assessment by the panel, which were able to distinguish different production sites in raw specimens but displayed problems in discrimination these in cooked mussels. Some nutritional components were related to specific sensory sensations.

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**1. Introduction**

The culture of marine molluscs represented 75.5% (13.9 million ton) of world's aquaculture production in 2010, with mussel production reaching approximately 13% (1.8 million ton: FAO, 2014). Mussels' popularity has increased over the past decades due to the presence of bioactive compounds in their meat, which have positive effects on human health (Grienke, Silke, & Tasdemir, 2014). Spain is the top producer of mussels (*Mytilus* sp.) in Europe and second worldwide, with a production of nearly
200,000 ton year\(^{-1}\) (FAO, 2014). However, the European mussel production has stalled at the end of the XX century due to a reach of the full carrying capacity in traditional locations (Smaal, 2002). This led to an increase in imports by Europe up to nearly 40% of EU production in 2010 (189,700 tons; FAO, 2014) and a loss in revenues for the EU trade balance. Nonetheless, aquaculture production technology has evolved and offshore areas are now being considered as new grounds for production of traditional species.

Portugal does not have a tradition of mussel culture, and its production has been negligible, with relative low commercial demand and value. However, according to Kapesky, Aguilar-Manjarrez, and Jenness (2013), the country has 2130 km\(^2\) of offshore area with potential for mussel culture due to its hydrographic conditions, wherein the recently established Armona production area in the Algarve is located.

Most of the Spanish mussels’ production is carried out in enclosed areas, the ‘rias’. On the other hand, the lower temperature fluctuations and higher hydrodynamics conditions in the offshore area of Armona (Relvas et al., 2007) favour high food availability as well as a good removal of excretion products. Therefore, different productions sites, with different conditions and culture technologies (rafts in the rias vs. longlines in offshore) should promote changes in the growth and nutritional composition of mussels, which will in turn reflect in their quality as evaluated by consumers. Moreover, mussel’s quality is assessed by the consumer as the result of not only its chemical and biological characteristics, but also its organoleptic properties, such as the appearance of the muscle, the intrinsic flavour and absence of undesirable components (Vernocchi, Maffei, Lanciotti, Suzzi, & Gardini, 2007). Together with biometric parameters and chemical composition, sensory characteristics are expected to define the qualities and distinguish mussels produced in different locations (Fuentes, Fernández-Segovia, Escrche, & Serra, 2009).

Thus, it makes the more sense to compare mussels from traditional production in Spain with the new offshore production in Portugal. Given this, the main goal of this work was to characterise and compare the biometric parameters (size, weight and meat yield), nutritional content (moisture, ash, total protein and free amino acids, total lipid, lipid class and fatty acids as well as carbohydrates) and sensory aspects (appearance, odour, flavour and texture) of mussels (Mytilus sp.) produced in the Armona’s Aquaculture Production Pilot Area (APAA) in the Algarve coast (south of Portugal) to mussels from Galicia and North of Portugal.

2. Materials and methods

2.1. Samples

Mussels, Mytilus sp., from five different locations were studied herein. The offshore (OFF) mussels were cultured in the APAA area (North 37° 01.7692’ N 007° 42.2652’ W; East 37° 00.7677’ N 007° 41.7555’ W; South 36° 59.2953’ N 007° 46.2478’ W; West 37° 00.2960’ N 007° 46.7587’ W), which is located off the Algarve coast (South of Portugal). Individuals were collected in June and July 2011 by the staff of the concessionaire, Companhia de Pescarias do Algarve (Faro, Portugal). Additionally, mussels from 3 sites in Galicia (NW Spain) – unspecific locations in Galicia (SPG), Vigo (VIG) and Pontevedra (PTV) – and from Vila Praia de Âncora, North of Portugal (PTN), were purchased in local markets (Faro, Portugal) between April and July 2011.

Mussels from Galicia and North of Portugal were collected 24–48 h before purchase. Samples analysed herein were randomly selected from two 1 kg bags of the same origin/supplier purchased on the sampling day. On the other hand, the offshore mussels were randomly sampled from different longlines 24 h before the assessments. Samples were immediately transported to the laboratory in cooling boxes with ice packs, washed with tap water and stored in a refrigerating chamber at 5 ± 1 °C. Following recommendations in the Codex Alimentarius STAN 292-2008 (FAO/WHO, 2008), only mussels without visible damage (e.g. open valves or broken shell) and exceeding the legal/minimum commercial size (50 mm) were analysed herein.

2.2. Biometric parameters

Biometric parameters were assessed in a total of 234 specimens (OFF, n = 48; PTN, n = 24; PTV, n = 60; SPG = 78; VIG, n = 24). Length (maximum measure along the anterior–posterior axis), width (maximum lateral axis), and height (maximum dorsum-ventral axis) of randomly selected mussels were measured using a digital precision calliper to the nearest 0.1 mm. The animal whole weight (WW) as well as edible fraction (WT) were weighed in a Sartorius U6100 scale (Data Weighing Systems, Inc., U.S.A.). Meat yield (MY) was calculated as MY = (WW/WT) × 100 (Okumus & Stirling, 1998).

2.3. Nutritional content

Determinations were performed in triplicate using pooled samples. Fifty individuals from each batch/origin were collected and minced in a food processor (Phillips HR 1396, Royal Philips Electronics, The Netherlands).

Fresh samples were collected for moisture and ash determinations, according to the methods described by AOAC (1995), in a Memmert oven (Memmert GmbH & Co. KG, Germany) and a Thermolyne Type 6000 Furnace (Barnesteath/Thermolyne Corporation, U.S.A.). The remaining mass was immediately frozen in liquid nitrogen to avoid degradation and later lyophilized before being used in determinations.

Total protein was determined according to the Kjeldahl method (AOAC, 1995), with a conversion factor of 6.25. Samples were digested in a Gerhardt Kjeldatherm and distilled in a Gerhardt Vapodest 1 (C. Gerhardt GmbH & Co. KG, Germany). Free amino acids (FAA) were extracted with 0.1 M hydrochloric acid (HCl) and the homogenate was centrifuged by ultrafiltration (10 kDa, 2500 g, 20 min, 4 °C). Derivatization using phenylisothiocyanate (PITC) was conducted according to the PicoTag™ method described by Cohen, Meys, and Tarvin (1989). The derivatized amino acids and standard solutions were analysed by reverse-phase high pressure liquid chromatography (HPLC-RP) in a Waters™ LC system with a PicoTag™ column (3.9 × 300 mm), a column heater (at 46 °C), two pumps, an auto-sampler and a variable wavelength UV/VIS detector, according to the conditions described by Cohen et al. (1989). The chromatograms were monitored at a wavelength of 254 nm. Identification and quantification of the peaks was carried out with the Breeze software (Waters Corp., U.S.A.). Amino acid standard solutions with the internal standard (norleucine) were prepared and derivatized following the same procedure described for the samples.

Total carbohydrates were determined according to the method described by Dubois, Gilles, Hamilton, Rebers, and Smith (1956). Sample readings were performed in a Hitachi U-2000 spectrophotometer, at 490 nm. Total lipid (TL) was extracted with chloroform:methanol (2:1 v/v) containing 0.01% of butyldihydroxytoluene (BHT) as antioxidant (Christie, 1982). Lipid classes (LC) and fatty acids (FA) were determined at IFAPA – Agua del Pino (Huelva, Spain). Total lipid samples were separated into classes by one-dimensional double-development high-performance thin-layer chromatography (HPTLC) using methyl acetate/ isopropanol/ chloroform/ methanol/ 0.25% (w/v) potassium chloride (KCl; 25:25:25:10:9
by vol.), as the polar solvent system and hexane/diethyl ether/glacial acetic acid (80:20:2 by vol.), as the neutral solvent system. Lipid classes were quantified by charring with a copper acetate reagent followed by calibrated scanning densitometry using a CAMAG TLC Scanner 3 dual wavelength flying spot scanner (Muttten, Switzerland) dual wavelength flying spot scanner (Olsen & Henderson, 1989). Total lipid extracts were subjected to acid-catalysed transmethylation for 16 h at 50 °C, using 1 mL of toluene and 2 mL of 1% sulphuric acid (v/v) in methanol. The resulting fatty acid methyl esters (FAME) were purified by thin-layer chromatography (TLC), and visualised with iodine in chloroform:methanol (2:1 v/v) 98% (v/v) containing 0.01% BHT (Christie, 1982). Prior to transmethylation, heptacosanoic acid (21:0) was added to the TL as an internal standard. FAME were separated and quantified using a SHIMADZU GC 2010 (Kyoto, Japan) gas chromatograph equipped with a flame-ionisation detector (250 °C) and a fused silica capillary column Tecnokroma — Suprawax-280TM (15 m × 0.1 mm i.D.). Helium was used as a carrier gas and the initial oven temperature was 150 °C, followed by an increase at a rate of 30 °C min-1 to a final temperature of 250 °C for 7 min. Individual FAME were identified by reference to authentic standards and to a well-characterised fish oil.

BHT, KCl, potassium bicharbonate, and iodine were supplied by SIGMA CHEMICAL Co (St. Louis, USA); TLC (20 × 20 cm × 0.25 mm) and HPTLC (10 × 10 cm × 0.15 mm) plates, pre-coated with silica gel (without fluorescent indicator) were purchased from MACHER-EN-NAGEL (Düren, Germany). All organic solvents used for gas chromatography (GC) were of reagent grade and were purchased from PANREAC (Barcelona, Spain).

2.4. Sensory analysis

All sensory analysis sessions were performed according to ISO standards (ISO 2001, 2008) in a sensory analysis room (in the Department of Food Engineering, DEA-ISE, University of the Algarve) compliant with ISO (2007), by a panel of 12 people co-opted from the staff of DEA-ISE with previous experience in sensory analysis of food products. Nonetheless, in order to familiarise the panel with the sensory assessment of mussels and to optimise the tables used for sensory evaluation, five training sessions were conducted. Initially, considering the specific characteristics to be assessed (FAO/WHO, 2001), panelists freely used terms from a pre-determined vocabulary set (Gökoglu, 2002). Results were used to elaborate a preliminary version of the tables for sensory evaluation based on Torry Sensory Assessment schemes (Archer, 2010). These tables were optimised in terms of descriptors and assessment criteria during the following training sessions.

The sensory analysis comprised fresh and cooked mussel samples. The sensory attributes evaluated, using a 0–5 point category scales, were: (a) odour, muscle/meat appearance and texture for fresh mussel; and (b) odour, flavour and texture for cooked mussel, as shown in Table 1. Twenty-four individual mussels were randomly selected from each batch of different origin and kept on ice until assessment. Two mussels (one fresh and one cooked) of each batch were presented sequentially to each panellist in 7 × 7 × 2 cm white, equal-sized dishes, properly coded. Fresh mussels were shocked immediately before testing while the cooked mussels were steamed at 400 W in a Moulinex FM 2535 microwave (Moulinex, France) for 1.5 min without seasoning.

2.5. Data analysis

Results are reported as means ± standard deviation or estimates ± standard error (where appropriate). The significance level was set at 5%.

The relationship among length, width, height and weight variables was analysed through multiple linear regression. Differences in biochemical compositions of mussels originated from distinct locales where tested using one-way ANOVA per parameter. Values expressed as relative percentage were arcsine square-root transformed prior to analysis. Significant differences in ANOVA were further studied using Fisher’s least significant difference (LSD) post hoc test. Whenever homogeneity of variances could not be met (viz. FAA, LC and FA), Welch ANOVA and the Games-Howell post hoc test were used instead. IBM® SPSS® Statistics 19 (IBM® Co., USA) was used in all the previous statistical calculations.

Sensory panel performance was assessed using three-way ANOVA per parameter and considering the distinct origins (factor Product) and session-to-session differences (factor Session) in panellists’ results (factor Panellist). At this stage, data pertaining to mussels from PTN and VIG were excluded since they were analysed once. The interactions of factors Product × Panellist and Panelist × Session were used to assess panellists’ discriminating power and consistency, respectively. A multivariable principal component analysis (PCA)-based approach was used to compare mussels’ sensory profiles (Husson, Lê, & Pagès, 2010). The descriptors/sensory attributes that in the initial ANOVA were found not statistically significant i.e. p > 0.05 were not considered herein. Results were augmented via bootstrap (R = 500), that allowed the estimation of 95% confidence ellipses around products’ average points. Finally, products were compared using T2 Hotelling test. The interest of implementing the PCA on these data was assessed using Bartlett’s sphericity test and Keiser-Mayer-Olkin measure of sampling adequacy (KMO MSA). The procedures described above were carried out for fresh and cooked mussels’ results of sensory analysis using the package SensomineR (Lê & Husson, 2008) for the R software version 2.14.0.

A multiple factorial analysis (MFA) was carried out, using the package FactoMineR for the R software version 2.14.0 (Husson et al., 2010), to explore the potential relations between sensory attributes and physical–chemical properties among the distinct mussels (PTN, OFF and VIG). The MFA, derived from PCA and canonical correlation analysis (CCA), was carried out using average data for odour, flavour and texture parameters of cooked mussels.
and the corresponding averages of the most relevant FAA and FA (viz. volatile essential amino acids and fatty acids that were found significantly different between mussel batches).

3. Results

3.1. Biometric data

Differences were found in all the parameters being assessed, except for the meat yield. In general, the PTV and SPG mussel were smaller and lighter than mussel from the remaining batches. Regarding length, VIG presented the larger individuals (83.13 ± 1.29 mm) followed by OFF mussel. Both OFF and VIG presented the highest width, height and weight, while SPG and PTV included the individuals with the smallest measurements, respectively (p < 0.05). Interestingly, OFF and VIG mussels were quite similar in size and weight. No significant correlations were found between length and width versus weight (p > 0.01). However, height was found to be significantly correlated to weight (p < 0.01). No significant differences (p > 0.05) were found between OFF and PTN mussels in spite of the differences found in shell morphology.

3.2. Nutritional content

The proximal composition of the edible portion of PTN, OFF and VIG mussels is presented in Table 2. Differences were found in all the parameters being assessed, except moisture and ash. Moisture and ash were higher (p < 0.05) in PTN mussel. PTN and VIG mussels presented the higher content in carbohydrates (28 and 32%, respectively; Table 2). No significant differences (p < 0.05) regarding protein and lipid content were found between mussel batches.

As for LC, PTN mussel displayed the highest value of polar lipids, while no differences (p > 0.05) were found regarding neutral lipids between all the sites. This was due to the slightly higher content in phosphatidylcholine (PC), phosphatidylethanolamine (PS) and phosphatidyl-ethanolamine (PE) measured in PTN mussel (p < 0.05; Table 2). The biggest differences between production sites were observed in the neutral lipids classes, where PTN mussel and VIG displayed the highest cholesterol (CHO) content (p < 0.05). On the other hand, the OFF mussel displayed the highest (p < 0.05) content in triglycerides (TG) and FFA.

Of the 56 FA identified, palmitic acid (16:0), stearic acid (18:0), dimethyl acetal stearic acid (DMA 18:0), palmitoleic acid (16:1n7), eicosapentaenoic acid (EPA; 20:5n3), and docosahexaenoic acid (DHA; 22:6n3) totally around 70% of the total FA content (Table 3). No significant differences (p > 0.05) were observed regarding the sum of unsaturated fatty acids (PUFA) between sites. However, the sum of saturated fatty acids (SFA) was higher in OFF (p < 0.05) and OFF increased in monounsaturated fatty acids (MUFA) was observed in VIG mussels (p < 0.05). It is also interesting that the highest values of the PUFA n6 group were composed by arachidonic acid (ARA; 20:4n6) and linoleic acid (LA; 18:2n6), both in the VIG mussels (p < 0.05). VIG specimens displayed the highest content in EPA, while OFF mussel had the highest content in DHA (p < 0.05).

On the other hand, MUFA displayed the lowest content in all the city mussel analysed and was mainly composed by palmitoleic acid (16:1n7), being higher in VIG mussels (p < 0.05). As regards the FAA content, differences (p < 0.05) were noted between the three production sites. The highest content in total essential amino acids was observed in the VIG mussel, while both OFF and VIG specimens displayed similar but higher values of total non-essential amino acids respect to PTN (Table 4). Lysine was the most abundant essential amino acid found in mussels from all production sites. As for non-essential amino acids, taurine was the most abundant, displaying the highest content in VIG mussel (1648.65 µmol g⁻¹ DW) that of the remaining mussels (p < 0.05; Table 4). Differences were also registered for leucine, valine, phenylalanine, tyrosine asparagine and ornithine contents between the 3 different origins (p < 0.05).

3.3. Performance of the sensory analysis panel

Globally, panellists’ performance during and between sensory analysis sessions was good, i.e. stable and consistent. Regarding

<table>
<thead>
<tr>
<th>Lipid classes</th>
<th>PTN</th>
<th>OFF</th>
<th>VIG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (%)</td>
<td>87.59 ± 0.27*</td>
<td>83.94 ± 0.27*</td>
<td>81.71 ± 0.31*</td>
</tr>
<tr>
<td>Ash (%)</td>
<td>23.22 ± 0.54b</td>
<td>16.41 ± 0.40a</td>
<td>15.29 ± 0.14a</td>
</tr>
<tr>
<td>Total protein</td>
<td>39.17 ± 2.99</td>
<td>42.94 ± 2.30</td>
<td>37.85 ± 0.86</td>
</tr>
<tr>
<td>Total carbohydrates</td>
<td>27.71 ± 1.06b</td>
<td>20.37 ± 0.69a</td>
<td>23.93 ± 2.37b</td>
</tr>
<tr>
<td>Total lipids</td>
<td>10.54 ± 1.04</td>
<td>11.71 ± 0.74</td>
<td>9.09 ± 0.88</td>
</tr>
</tbody>
</table>

Proximal composition values are expressed in % DW, except moisture. Lipid classes are expressed in relative percentage of total lipids (equivalent to g.100 g⁻¹ DW). Samples signalled with * correspond to n = 2 by removal of outlier. Different letters indicate significant differences for p < 0.05 (LSD post hoc test; * Games-Howell post hoc test).
Free amino acids profiles of North Portugal (PTN), Offshore (OFF) and Vigo (VIG) mussels.

Values are expressed in mg eq. contribution (%) lipids PTN OFF VIG

Table 3

Free fatty acids (% lipids) PTN OFF VIG

<table>
<thead>
<tr>
<th>Component</th>
<th>PTN</th>
<th>OFF</th>
<th>VIG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>42.83 ± 0.50 a</td>
<td>43.72 ± 0.50b</td>
<td>44.37 ± 0.50c</td>
</tr>
<tr>
<td>PUFA</td>
<td>31.19 ± 0.50 a</td>
<td>33.57 ± 0.50b</td>
<td>34.52 ± 0.50c</td>
</tr>
<tr>
<td>SFA</td>
<td>11.64 ± 0.50 c</td>
<td>8.79 ± 0.50a</td>
<td>9.30 ± 0.50b</td>
</tr>
<tr>
<td>MUFA</td>
<td>9.90 ± 0.50 b</td>
<td>9.39 ± 0.50c</td>
<td>9.55 ± 0.50a</td>
</tr>
<tr>
<td>n-6</td>
<td>19.75 ± 0.50 b</td>
<td>18.64 ± 0.50a</td>
<td>20.12 ± 0.50c</td>
</tr>
<tr>
<td>n-3</td>
<td>7.51 ± 0.50</td>
<td>9.18 ± 0.50</td>
<td>11.13 ± 0.50</td>
</tr>
<tr>
<td>EPA</td>
<td>1.41 ± 0.05 a</td>
<td>1.52 ± 0.05b</td>
<td>1.66 ± 0.05c</td>
</tr>
<tr>
<td>DHA</td>
<td>2.63 ± 0.05 a</td>
<td>2.76 ± 0.05b</td>
<td>2.98 ± 0.05c</td>
</tr>
<tr>
<td>n-3/n-6</td>
<td>1.84 ± 0.05 a</td>
<td>1.93 ± 0.05b</td>
<td>2.00 ± 0.05c</td>
</tr>
</tbody>
</table>

Table 4

Free amino acids (% lipids) PTN OFF VIG

<table>
<thead>
<tr>
<th>Component</th>
<th>PTN</th>
<th>OFF</th>
<th>VIG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taurine (Tau)</td>
<td>1818.93 ± 46.95 a</td>
<td>1702.03 ± 88.72a</td>
<td>1950.68 ± 53.58b</td>
</tr>
<tr>
<td>Glutamic acid (Glu)</td>
<td>107.49 ± 4.06 a</td>
<td>174.38 ± 8.67a</td>
<td>205.94 ± 8.28b</td>
</tr>
<tr>
<td>Aspartic acid (Asp)</td>
<td>13.96 ± 0.01 a</td>
<td>26.94 ± 0.02b</td>
<td>57.97 ± 0.03c</td>
</tr>
<tr>
<td>Alanine (Ala)</td>
<td>53.73 ± 1.01 b</td>
<td>57.97 ± 0.03a</td>
<td>57.97 ± 0.03b</td>
</tr>
<tr>
<td>Methionine (Met)</td>
<td>105.48 ± 0.01 a</td>
<td>174.92 ± 0.02b</td>
<td>32.73 ± 0.03c</td>
</tr>
<tr>
<td>Histidine (His)</td>
<td>11.54 ± 0.01 a</td>
<td>174.92 ± 0.02b</td>
<td>32.73 ± 0.03c</td>
</tr>
<tr>
<td>Leucine (Leu)</td>
<td>34.90 ± 0.01 a</td>
<td>174.92 ± 0.02b</td>
<td>32.73 ± 0.03c</td>
</tr>
<tr>
<td>Lysine (Lys)</td>
<td>13.96 ± 0.01 a</td>
<td>174.92 ± 0.02b</td>
<td>32.73 ± 0.03c</td>
</tr>
<tr>
<td>Threonine (Thr)</td>
<td>52.20 ± 1.01 b</td>
<td>26.94 ± 0.02b</td>
<td>57.97 ± 0.03b</td>
</tr>
</tbody>
</table>

4.3. Sensory analysis of fresh mussels

Values are expressed in mg g⁻¹ DW. Samples n = 3. Different letters indicate significant differences for p < 0.05 (LSD post hoc test; * Games-Howell post hoc test).
PC2, defined mostly by firmness (positive coordinate) and by elasticity (negative coordinate), further discriminated SPG and VIG mussels, both produced in Galicia, and, to a lesser extent, mussels from the Algarve (OFF). The Hotelling test confirmed significant differences ($p < 0.05$) between all mussels except those from PTN and PTV.

### 3.5. Sensory analysis of cooked mussels

Colour, glossiness and appearance of tissues’ surfaces of cooked samples were clearly altered during steaming. It was interesting to verify that OFF mussels were not readily distinguished from the other mussels’ production sites in terms of sensory attributes. In addition, cooked OFF mussels’ were clearly described by the panelists as more succulent and with the best characteristic flavour, followed by VIG specimens.

The first and second components of PCA (Fig. 1B) explained more than 96% of the total variance (85.03% for PC1 and 11.06% for PC2). However, since PC2 displayed an eigenvalue <1, PC1 solely could have been retained for interpretation. According to both Bartlett’s test ($\chi^2 = 396.9; p < 10^{-6}$) and KMO MSA (0.7215), PCA was judged efficient.

Only five sensory attributes effectively explained the majority of the differences between cooked mussels: fresh (FROD) and intrinsic odours (INTOD), characteristic flavour (CHFLV), succulence (SUCC) and smoothness (SMO). SMO showed comparatively high loadings on the positive dimension of both PC1 and PC2 (Fig. 1B), whereas the remaining attributes (particularly SUCC and CHFLV) had strong, positive loadings on the PC1. The overlapping confidence ellipses presented in Fig. 1D showed a less clear discrimination of production sites using cooked mussels’ data. The retained sensory attributes characterised mussels from SPG and OFF has having pronounced CHFLV and SUCC, FROD and INTOD, and being perceived as smooth in sharp contrast to VIG, PTV and PTN mussels. The Hotelling test confirmed the significant differences ($p < 0.05$) in sensory profiles between the OFF mussels and the ones from PTV and VIG, as well as between the SPG mussel and the ones from PTN and PTV. On the other hand, no differences were found between the OFF and SPG mussels ($p = 0.324$).

### 3.6. Combining sensory and nutritional content of cooked mussels

MFA, a PCA-based methodology on the merged (sensory and instrumental variables) data, enriched the interpretation of the sensory data by showing how the physical–chemical properties are reflected by specific sensations. In this study, the 18:0 SFA appeared to be related to the fresh odour attribute, and the DHA/EPA ratio related to the seaweedy odour. The FA 16:0 and DHA also appeared to contribute to the characteristic flavour of mussel (Fig. 2). The FAA were greatly correlated to the firmness of mussel’s meat (Fig. 2), particularly alanine (Ala), cysteine (Cys), taurine (Tau) and tyrosine (Tyr). In addition, glycine was closely related to the smoothness (SMO) and toughness (TOUGH).
were available to the customer at similar times so a comparison condition indices and meat yield. This is due to the fact that the of mussels based on methods such as mantle colours observation, no way to reliably obtain data on sex nor precise the maturity stage gametogenic cycle (Okumus temperature and salinity but, more importantly, food supply and will influence their nutritional profile. While OFF mussels from the warmers waters of the Mediterranean (e.g. Valencia or Ebro delta), which in turn display higher DHA content and a DHA/EPA ratio near 1 (Fuentes et al., 2009), similar to what was observed for the OFF mussels. The higher percentage of EPA, ARA and 18:1n7 and lower percentage of DHA and DHA/EPA ratios verified in the VIG mussels might be related to the higher diatom content which is normally verified in estuarine areas, such as the Vigo ria.

Still, it needs to be considered that in the present study PTN and VIG mussels were depurated prior to being marketed, which most probably interfered with their nutritional profile. While OFF mussels are cultured in a class A area, the remaining specimens are grown in class B areas and are, therefore, subjected to depuration in order to reduce faecal bacterial contamination. During depuration, shellfish are fasted, which results in excretion of waste products of metabolism (Lee, Lovatelli, & Ababouch, 2008), and forced to expend their energy reserves in their metabolic processes. This will influence their nutritional quality and organoleptic characteristics (Ruano, Ramos, Quaresma, Bandarra, & Fonseca, 2012). In fact, the VIG mussels displayed lower TG and higher FA than those of Freites, Fernández-Reiriz, and Labarta (2002a), which were collected in a nearby geographical location (ria Arosa) but not subjected to depuration.

The FAA profiles of VIG were similar to those reported by Fuentes et al. (2009), with a higher taurine content followed, in decreasing order, by arginine, glycine, and alanine. Taurine plays an important role in human physiology (Huxtable, 1992) but no important effect on the formation of aroma active components (Fuke, 1994). On the other hand, the glycine value registered in the OFF mussels was extremely high, reaching values similar to those of taurine, which were not registered by Fuentes et al. (2009) in any geographical location of the Iberian Peninsula. Differences in the contents of some of the FAA, e.g. leucine, valine, phenylalanine, tyrosine, asparagine or ornithine, among locations can

Fig. 2. Biplot of the two principal components resulting from the multifactorial analysis (MFA), considering the relevant variables in the sensory and biochemical analysis, of mussels from the different origins studied. Legend: Sens. – sensory attributes; CHEW – chewiness; CHFLV – characteristic flavour; CONS – consistency; FIRM – firmness; FROD – fresh odour; INTOD – intrinsic odour; SAFLV – salty flavour; SEAWOD – seaweedy odour; SMO – smoothness; SUCC – succulence; SWFLV – sweet flavour; TOUGH – toughness. FFA – free fatty acids; ALA – alpha-linolenic acid; ARA – arachidonic acid; C16:0 – saturated C16:0 fatty acid; C18:0 – saturated C18:0 fatty acid; DHA – docosahexaenoic acid; DHA:EPA – DHA/EPA ratio; EPA – eicosapentaenoic acid; EPA:ARA – EPA/ARA ratio; LOA – linoleic acid; n3.n6 – omega-3/omega-6 fatty acids ratio. AA – aminoacids; Ala – Alanine; Cys – Cystein; Glu – Glutamic Acid; Gly – Glycine; Ile – Isoleucine; Leu – Leucine; Met – Methionine; Phe – Phenylalanine; Tau – Taurine; Tyr – Tyrosine; Val – Valine. Dim 1 – dimension or principal component 1; Dim 2 – dimension or principal component 2.

4. Discussion

OFF and VIG mussels were quite similar in length, width and height to mussels from Galicia and the Ebro Delta, characterised by Fuentes et al. (2009), which were generally bigger than those from Valencia. As for MY, mussels from OFF and PTN probably had higher content than any of the mussels of the previous study. On the other hand, OFF and PTN mussels displayed higher MY than those of the Adriatic Sea (25.2%; Vernocchi et al., 2007). The differences found between different samples and results found in literature are easily justified by culture density-dependent effects (Cubillo, Peteiro, Fernández-Reiriz, & Labarta, 2012), temperature and season (Bayne & Worrall, 1980; Okumus & Stirling, 1998), availability of food (e.g. phytoplankton blooms) and spawning condition (Strohmeier, Duinker, Strand, & Aue, 2008), etc. As a matter of fact, MY depends on complex interactions including not only temperature and salinity but, more importantly, food supply and gametogenic cycle (Okumus & Stirling, 1998). However, there is no way to reliably obtain data on sex nor precise the maturity stage of mussels based on methods such as mantle colours observation, condition indices and meat yield. This is due to the fact that the reproductive cycle varies considerably between species and with geographical locations (Gabbott, 1976). Nevertheless, the samples were available to the customer at similar times so a comparison of products is justified and was established.

Proximate composition of mussels from three sampled locations (PTN, VIG and OFF) only showed differences in moisture, ash and carbohydrates. Since the technology of culture was similar (longlines/hanging ropes), the relatively low values of carbohydrates and the marginal differences in ash observed in the OFF mussels were most probably due to the different hydrodynamic conditions of this offshore culture area, which will interfere with mussel metabolism in a set of complex interactions between temperature, food availability, growth and reproduction cycle (Gabbott, 1976). The reproductive cycle of mussels in Galicia does not necessarily follow patterns described for other regions, since there are differences among mussel populations of different geographical areas, among populations from close locations and interannual differences at the same location (Villalba, 1995). According to data from Relvas et al. (2007), all the mussel production sites of samples used in the present study display upwelling, which promotes phytoplankton blooms, but its temperature profiles are different throughout the year. In fact, the temperature profile of the Armona site is characterised by higher seawater temperatures when compared to those of NW of the Iberian Peninsula, which might promote faster growth and possibly two peaks of reproduction (one in spring and another in summer), as reported by Villalba (1995) to sometimes occur in Vigo. Moreover, temperature will also affect the composition and availability of food and/or consequently the timing and duration of the reproductive cycle and number of spawnings per year (Gabbott, 1976), which will affect the nutritional content of mussels. For instance, mussels (M. galloprovincialis) from the Adriatic Sea, sampled at similar months, showed higher protein levels (between 46.98 and 52.66%), but lower lipids, ash and MY content (5.6–8.1%, 12.8–13.8% and 13.4–21%, respectively; Vernocchi et al., 2007), than those of OFF.

Moreover, the variations observed in the levels of total lipids, neutral lipids and fatty acids in mussels in the present study should be related to the nature of their local diet, which depends on the conditions already enumerated above. The samples showed a FA profile rich in both SFA and PUFA, which means that all the locations were probably rich in detritus, bacteria, nanozooplankton and phytoplankton (Freites, Labarta, & Fernández-Reiriz, 2002b). Nonetheless, typically mussels from Galicia (NW Spain) display higher levels of EPA when compared to those from the warmers waters of the Mediterranean (e.g. Valencia or Ebro delta), which

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be attributed to different environmental and feeding conditions of production areas as pointed out in other studies (Fernández-Reiriz Labarta, & Babarro, 1996; Orban et al., 2002; Fuentes et al., 2009). Moreover, differences in total FAA could in part be caused by proteolysis that might have occurred to a lesser extent in the samples from offshore area due to the shorter time from harvesting at origin to their arrival at the laboratory as proposed by Fuentes et al. (2009).

Results show that there were discrepancies in the assessment of some of the attributes by some panellists, either in fresh or cooked mussels. In spite of Caglak, Cakli, and Kilinc (2007) suggesting that a numeric acceptability scale from 0 to 5 points was suitable to evaluate fresh and cooked mussels, the lack of coherence in the assessment of some of the attributes observed herein may reflect some disagreement of the panellists regarding the use of the acceptability scale (Esteves, 2008). While the evaluation of “moist appearance” and “firmness” is directly related to panel sensory ability, the differences in the assessment of “orange colour” in fresh mussels has a biological explanation since, in this species, gonad colouration varies greatly between individuals (Mikhallow, Mario, & Mendez, 1995). Therefore, individual discrepancies of the panel might extend beyond sensory assessment and be related to biological factors. As for the difficulty in the assessment of “firmness”, “consistency” or “juiciness”, these are probably due to the fact that, according to Costell and Durán (2005), food texture is the result of different natures’ stimuli, and its assessment is a dynamic and complex process that implies visual perception of the products, their response to handling and the integration of the sensations experienced in the mouth during chewing and swallowing.

As in a previous study by Gómez-Sintes, Fuentes, Fernández-Segovia, Serra, and Escriche (2004), panellists were not able to find any differences between appearance and colour of cooked mussels; albeit, the heat treatment to which samples are subjected should have a minimum impact on their innate characteristics (Hyldig, 2010). On the other hand, the heat treatment allows the release of volatile compounds that enhance flavours (Ólafsdóttir & Jónsdóttir, 2010) and herein contributed to the distinction between mussels in terms of CHFLV, FROD and INTOD.

It was interesting to verify that OFF mussels were not readily distinguished from the other mussels’ production sites in terms of sensory attributes. It was expected that the lack of depuration in OFF mussels influenced the perception of sensory attributes due to already explained differences in terms of nutritional content.

The nutritional content was reflected in the sensory perception of mussels’ quality characteristics. For instance, the lipid conversions (mainly PUFA) into volatile compounds resulted in the variation of the specific characteristics of flavour, as described by Ólafsdóttir (2010) for other species. Fuentes et al. (2009) linked the high concentration of FAA found in mussels with the perception of intense odour and flavour attributes: aspartic acid (acidity), glutamic acid (flavour intensifier), arginine (bitterness), glycine and alanine (sweetness). Surprisingly, most panellists in this study had trouble evaluating sweetness, but this attribute could be subtly expressed in the salty/characteristic flavour of cooked mussel. In fact, the essential amino acids of ramified chain (valine, isoleucine and leucine), the ones containing sulphur (methionine and cysteine) and the aromatics (phenylalanine and tyrosine) are the most important amino acids contributing to odour and flavour (Aristoy & Toldrá, 2010).

5. Conclusions

The production site influenced the size and nutritional content of mussels. As for the sensory analysis, panellists were able to distinguish mussels of different origins to some extent. Flavour was the distinguishing characteristic that panellists used to favour OFF mussels. From a marketing point of view, both biochemical and sensory characteristics ensure that the offshore mussel produced in the Algarve coast (OFF) will have good acceptability by the final consumer, and will surely be able to compete with other mussels currently found in the market, namely the mussels produced in the Galician rias (Vigo, Arousa and others), seafood product that is registered in the EU as a Designated Origin of Origin (PDO).

Acknowledgements

A.V. Sykes wishes to thank Fundação para a Ciência e a Tecnologia (FCT) for his post-doctoral Grant (SFRH/BPD/36100/2007). Ismael Hachero-Cruzado’s post-doc contract is supported by INIA. This work was funded by Project SEPIAMETA (PTDC/MAR/102348/2008) granted by FCT. Lipid class and fatty acid determinations were funded by project INTERREG 0251_ECOAQUA_5_E.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.foodchem.2014.07.082.

References


