Variações na textura, conteúdo lipídico e fibras musculares de corvinas de três tamanhos comerciais diferentes, capturadas no inverno e no verão

Seasonal variations in texture, fat content and muscle cellularity in meagre, Argyrosomus regius, of three different commercial sizes

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ABSTRACT
Meagre is an emergent species with a high potential to be intensively farmed in the Mediterranean region. In this study, three different commercial sizes: 800, 1500 and 2500 g meagre were analysed in the winter and in the summer. The results showed that season affected the morphometric characteristics, especially in the 1500 g (skeleton and fillet yield) and in the HSI of all fish sizes. The fat content also increased from winter to summer in larger meagre possibly due to the increase of feeding activity and feed intake. On the other hand, the textural properties of the flesh were less affected and differences were found mainly for the 2500 g meagre which showed lower hardness and chewiness in the summer. Cohesiveness decreased in the summer, in 1500 g meagre, and was negatively correlated to the fat content. Fibre area did not seem to vary with the change of season although fibre density increased in the summer. This increase could be associated to an increase in fibre recruitment during the spring/ summer period. In conclusion, this study shows that season has an important impact on muscle cellularity and in the flesh quality of meagre.

Keywords: Meagre, muscle cellularity, texture, fat content.

RESUMO
A corvina é uma espécie com elevado potencial para aquacultura intensiva na região do Mediterrâneo. O consumo de alimento desta espécie é extremamente afetado pela temperatura da água e diminui nos meses de inverno. Neste estudo foi analisada a qualidade de corvinas com três tamanhos diferentes: 800, 1500 e 2500 g, capturadas no inverno e no verão. Os resultados obtidos indicam que a estação do ano afeta as caraterísticas morfométricas, conteúdo lipídico (2.5 para 4.3 % e 3.1 para 4.5 % em corvinas de 1500 e 2500 g, respetivamente, no inverno e no verão) e índice hepatossomático (1.3 para 2.8 % e 1.6 to 2.6 % em corvinas de 1500 e 2500 g, respetivamente, no inverno e no verão). As propriedades texturais do filete não foram afetadas mas foi encontrada uma correlação negativa entre a coesividade e o conteúdo de gordura do filete de corvinas de 1500 g. As fibras musculares também foram avaliadas e não foram encontradas diferenças na área das fibras embora a densidade de fibras tenha sido maior no verão do que no inverno (400 para 598 fibras/mm^2 e 287 para 413 fibras/mm^2 em corvinas de 1500 e 2500 g, respetivamente, no inverno e no verão). Esta diferença poderá estar associada a um aumento do recrutamento das fibras musculares durante o período de inverno, o que é sugerido pela distribuição das áreas das fibras medidas na corvina de 1500 g. Em conclusão, este estudo mostra que a época da captura da corvina pode afetar os diferentes atributos da qualidade do filete deste peixe.

Palavras-chave: Corvina, fibras musculares, textura e gordura.

1 INTRODUCTION

Seasonal variations in growth are commonly observed in fish species (Haugen *et al.*, 2006) and are usually reflected in the morphological characteristics such as weight/length relationship (Haug *et al.*, 1989; Bjornsson, 1995). These changes may be followed by variations in quality-related parameters such as fat content, colour and texture of the fillet (Nordgarden *et al.*, 2003; Bjornevik *et al.*, 2004; Espe *et al.*, 2004). White muscle cellularity (density and area of muscle fibres) is an important factor which may affect textural properties of the flesh (Fauconneau *et al.*, 1993; Hurling *et al.*, 1996). Several studies reported a relationship between muscle fibre size / density and flesh hardness and fat (Hatae *et al.*, 1990; Hurling *et al.*, 1996; Johnston *et al.*, 2000) suggesting that the presence of small fibres in the muscle tissue might contribute to the quality of the end product.

Muscle growth dynamics results from two different processes: fibre muscle hypertrophy and fibre muscle hyperplasia. The first is the growth of already existent fibres and occurs throughout fish life until the maximum fibre area is reached (Johnston, 1999). This maximum fibre area is constrained by the muscle aerobic capacity needed for diffusion of oxygen and metabolites (Kiessling *et al.*, 1991a; Johnston *et al.*, 2004). The second process is the recruitment of new fibres (Johnston *et al.*, 2003) and its ceasing varies according to the species. Fish species with large ultimate sizes recruit new fibres even when adult size is reached (Weatherley *et al.*, 1988; Kiessling *et al.*, 1991a,b; Koumans *et al*., 1993). On the contrary, small size species might have their fibre recruitment essentially during embryo development (Alami-Durante *et al.*, 1997; Johnston *et al.*, 1999).

Meagre, *Argyrosomus regius,* is an emergent species and a strong candidate for in intensive farming in the Mediterranean region (Duncan *et al*., 2013; Monfort, 2010). Its impressive growth rates compared to the already established species such as seabream and seabass as well as its good adaptation to captivity are the main incentives to farmers (Ribeiro *et al.*, 2013). Farmed meagre commercial sizes is generally between 1 and 2 kg because fish weighing less than 1 kg are thought to have lower quality essentially due to lower fillet hardness and less appealing commercially features (Monfort, 2010, Ribeiro *et al.*, 2013). Nevertheless, recent studies started analysing the quality of smaller meagre and considered there were not significant differences between smaller and larger meagre (Giogios *et al.*, 2013; Saavedra *et al.*, 2015, 2017).

The aim of this study was to investigate the changes in texture, fat content and muscle cellularity between meagre harvested in the winter and summer seasons.

2 MATERIAL AND METHODS

Fish origin and sampling

Fish used in this study was originated from a broodstock adapted to captivity and reared in the Aquaculture Research Station of Portuguese Institute of the Sea and Atmosphere (IPMA) located in the South of Portugal. Meagre was reared in indoor fibre glass tanks until they were 15 g and then moved to outdoor tanks. When fish reached the 300 g they were transferred to earthen ponds. Farmed meagre of approximately 800, 1500 and 2500 g were harvested in December and in July for winter and summer sampling, respectively. From each group eight specimens were sampled approximately 24 h after slaughtering by hypothermia. The winter group of fish weighed 802.9 ± 34.1 g, the second 1512.5 ± 91.6 g and the third 2737.5 ± 112.6 g. The summer group had a weight of 806.3 ± 44.1 g, 1568.8 ± 88.4 g and 2181.3 ± 162.4 g. Before processing the fish, weight and length were taken and then fish were scaled, washed and gutted. Two fillets (with skin) were taken from each fish and whole and trimmed (commercial fillet) fillets were weighed.

Texture

For the winter group only one fillet per fish was used to quantify the textural properties whereas in the summer group two fillets were used. This was done to reduce the variability observed in the winter group. A section of 4 x 4 cm (height ranged from 1.3 to 2.1 cm, according to fish size), with skin but no scales, was cut in the anterior region of the fillet, immediately after the first dorsal ray, and then used to measure instrumental texture in raw. The analysis was carried using a texture analyser (Stable Micro Systems, TA.XTPlus Texture Analyser) and the double compression test (Test Profile Analysis - TPA) with a load cell of 30 kg and a flat ended metal probe with 75 mm diameter (compression plate P75). A compression of 40% was applied to the fillet sections at a speed of 2 mm/s and once the test was over hardness, cohesiveness, adhesiveness and chewiness were quantified. Eight fish were used per group (total of 24 fish per season) and were analyzed at room temperature (approximately 20 ºC).

The remaining fillets (without skin) of each fish were cut into pieces, stored at -80ºC and then freeze-dried for chemical analysis.

Total fat content

Total lipid in the muscle was determined according to Folch *et al*. (1957). Lipid extraction was done using a solution of chloroform and methanol (2:1) and total lipid content was quantified after the chloroform fraction had evaporated through a nitrogen flow. Results are expressed in wet weight.

Muscle cellularity

Muscle cellularity was analysed by histology. A cross-section sample of approximately 1 cm width was cut in the region by the first ray of the dorsal fin. Two blocks of approximately 1.5 x 1 cm were taken from the section and fixed in 10 % buffered formalin, dehydrated and included in paraffin wax. From each block, two cuts (8 µm) were stained with haematoxylin and eosin. Quantification of fibre area and fibre density in the white muscle was done using the software ImageJ after the photos from the cuts were taken using an Image Analysis System (AxioVision Release 4.8.2. SP2), connected to a video camera (AxioCamER5s) and a light microscope (Zeiss-

Axioplan). From each cut (with a total of four cuts per fish, N= 5 fish per group) two sections were analysed in terms of number of fibres and fibre area.

Fibre density was calculated as total number of fibres / area.

Data management

Significant differences between fish were determined using a t-test (grouping variable: season) or one-way analysis of variance (ANOVA) (grouping variable: fish size). Scheffé test was used as the post-hoc test. All statistical tests and correlations were done using Statistica® (version 8.0).

3 RESULTS

The morphometric characterization of meagre of 800, 1500 and 2500 g sampled in the winter and summer is detailed in Table 1. The percentage allocated to the skeleton was significantly lower in meagre of 800 g compared to the remaining groups in the winter. Only the 1500 g meagre showed significant differences in the skeleton weight from winter to summer ($t=-7.44$, $p<0.001$), being higher in the former.

The hepatosomatic index (HSI) and visceral somatic index (VSI) showed significant differences for all groups between winter and summer ($p<0.001$ for all groups, except for HSI for 800 g meagre where $p=0.042$). HSI increased from winter to summer, especially in the 1500 g (1.28 ± 0.29 % *versus* 2.75 ± 0.49). VSI decreased in the summer, especially in 2500g meagre (7.81 ± 1.01 % *versus* 2.54 ± 0.39). In terms of fillet yield, significant differences were found for 800 g and 1500 g meagre between winter and summer ($t=-4.04$, $p=0.01$ and $t=.5.88$, $p<0.001$, respectively). The first showed a decrease in the whole fillet yield whereas in the second an increased was observed. Nevertheless, 800 g meagre showed the highest fillet yield in the winter and a higher trimmed fillet yield compared to the 1500 and 2500 g meagre, in the summer.

Table 1. Morphometric characterization of summer and winter meagre. Values are mean and standard deviation. Different letters represent significant differences for p‹0.05 within seasons. * Represent significant differences for p‹0.05 between sizes. HSI - hepatosomatic index; VSI - visceral somatic index.

	Fish Weight (g)	Winter	Summer
Skeleton Weight (%)	800	55.16 ±3.16**a**	56.61 ± 1.97**a**
	1500*	68.33 ± 1.25**b**	60.41 ± 2.74**b**
	2500	60.60 ± 1.47**c**	59.95 ± 3.30**ab**
HSI (%)	800*	1.61 ± 0.34	1.93 ± 0.23**a**
	1500*	1.28 ± 0.29	2.75 ± 0.49**b**
	2500*	1.62 ± 0.38	2.61 ± 0.36**b**
VSI (%)	800*	6.81 ± 1.45	4.21 ± 0.20**a**
	1500*	7.00 ± 0.69	2.91 ±0.42**b**
	2500*	7.81 ± 1.01	2.54 ± 0.39**b**
Whole Fillet (%)	800*	38.04 ± 2.04**a**	34.32 ± 1.74
	1500*	24.67 ± 1.15**b**	31.61 ± 3.13
	2500	31.60 ± 1.62**c**	32.40 ± 2.89
Trimmed Fillet (%)	800	25.44 ± 1.27**a**	26.80 ± 1.60**a**
	1500	19.49 ± 0.90**b**	20.84 ± 2.23**b**
	2500	25.52 ± 1.38**a**	23.75 ± 2.47**c**

Total fat content

Significant differences were found for the total fat content between summer and winter for 1500 and 2500 g meagre (t=2.73, p=0.18 and t=3.03, p=0.01, respectively) (Table 2). For these two groups the fat content was higher in the summer compared to the winter. In smaller fish, 800 g, the fat content remained approximately the same and significantly lower compared to the fat content obtained for larger fish ($F_{2,18}$=12.57, p<0.001 and $F_{2,18}$=21.69, p<0.001, for winter and summer respectively).

Table 2. Total fat content (% in wet weight) in summer and winter meagre. Values are mean and standard deviation. Different letters represent significant differences for p‹0.05 within seasons. * Represent significant differences for p‹0.05 between sizes.

	Fish Weight (g)	Winter	Summer
Total fat content (% w.w.)	800	1.40 ± 0.21**a**	1.37 ± 0.29**a**
	1500*	2.55 ± 0.67**b**	3.98 ± 1.21**b**
	2500*	3.00 ± 0.80**b**	4.59 ± 1.13**b**

Texture

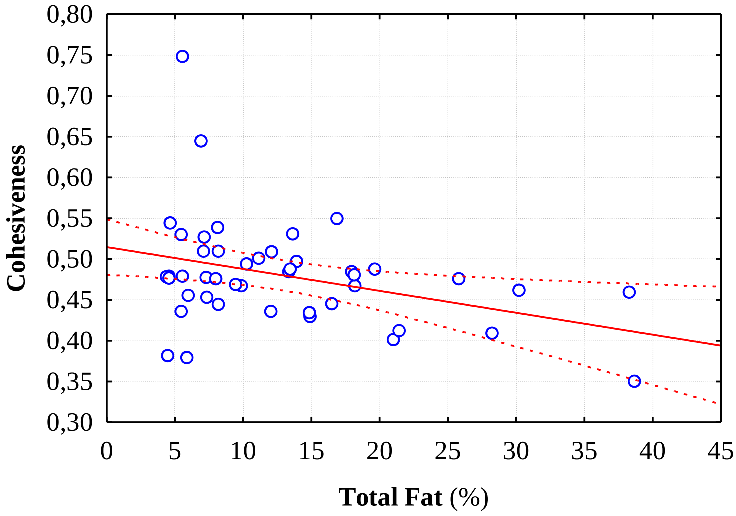
The textural properties of meagre were studied in raw fillets (Table 3). Hardness was the only textural attribute with significantly differences between meagre of different weights and only observed in the summer sampling ($F_{2,21}$=3.60, p=0.045). However, only in 2500 g fish hardness showed differences between seasons (t=-2.32, p=0.036). Significant differences between seasons were also observed for cohesiveness (t=2-68, p=0.018) and chewiness (t=-2.52, p=0.025) in 1500 and 2500g meagre, respectively.

Table 3. Texture properties of raw muscle of summer and winter meagre determined through texture profile analysis on fillet sections of 4x 4 cm. Values are mean and standard deviation. Different letters represent significant differences for p‹0.05 within seasons. * Represent significant differences for p‹0.05 between sizes.

	Fish Weight (g)	Winter	Summer
Hardness (N)	800	92.21 ± 27.42	79.85 ± 9.70**a**
	1500	100.63 ± 26.89	94.36 ± 11.95**b**
	2500*	107.41 ± 22.39	87.04 ± 10.69**ab**
Adhesiveness	800	-2.82 ± 0.50	-2.73 ± 0.48
	1500	-3.31 ± 0.69	-2.71 ± 0.35
	2500	-2.59 ± 1.68	-3.25 ± 0.74
Cohesiveness	800	0.48 ± 0.06	0.45 ± 0.04
	1500*	0.51 ± 0.03	0.45 ± 0.05
	2500	0.50 ± 0.06	0.46 ± 0.03
Chewiness (N.cm)	800	26.87 ± 8.59	24.19 ± 3.82
	1500	28.10 ± 3.84	28.27 ± 3.67
	2500*	33.73 ± 8.56	25.06 ± 4.62

When the fat content was compared to the textural properties of the fillets, a significant negative correlation was found between the fat content and cohesiveness (r=-0.35) where an increase of the fat content lead to a decrease in the flesh cohesiveness (Fig. 1).

Fig. 1. Correlation between cohesiveness and total fat content (%) in meagre of 800, 1500 and 2500 g.



Muscle cellularity

Muscle fibre area was significantly lower in the 800 g meagre compared to 2500 g meagre ($F_{2,12}$=4.05, p=0.045 and $F_{2,12}$=11.52, p=0.002, for winter and summer respectively) (Table 4). The 1500 g meagre showed an average fibre area between the smaller and larger meagre. When sampled in summer, 1500 g meagre had a significantly smaller fibre area than larger meagre ($F_{2,12}$=11.52, p=0.002). Fibre density was significantly lower in 800 and 1500 g meagre compared to 2500 g meagre in both winter and summer ($F_{2,12}$=12.68, p=0.001 and $F_{2,12}$=11.80, p=0.001, respectively).

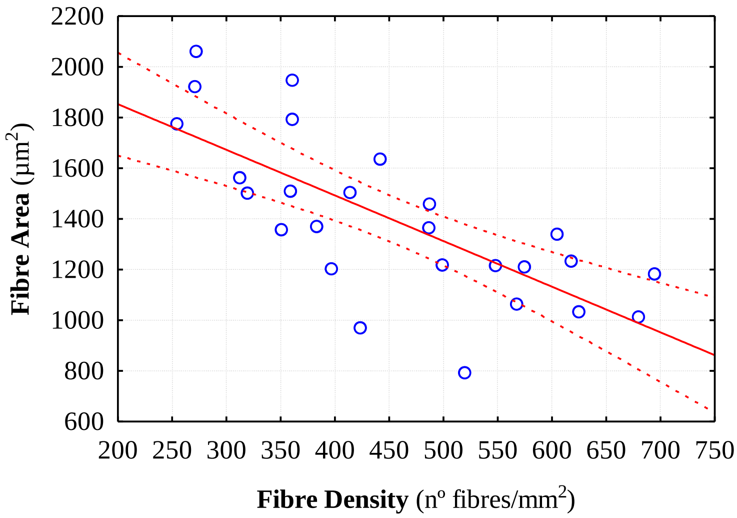
Fibre density changed significantly from winter to summer for the three weigh groups studied (t=-3.51, p=0.008; t=-5.75, p<0.001; and t=-4.40, p=0.002, for 800, 1500 and 2500 g meagre, respectively), being higher in the summer.

Table 4. Fibre area and fibre density for 800, 1500 and 2500 g meagre harvest in the winter and in the summer. Values are mean and standard error of the mean. Different letters represent significant differences between weight groups. * represent significant differences between seasons for p‹0.05.

	Fish weight (g)	Winter	Summer
	800 g	1140.9 ± 130.0**a**	1156.6 ± 83.4**a**
Fibre area	1500 g	1368.2 ± 117.3**ab**	1236.6 ± 27.1**a**
(μm^2)	2500 g	1691.5 ± 161.5**b**	1649.0 ± 102.5**b**
	800 g*	426.3 ± 29.5**a**	581.5 ± 32.9**a**
Fibre density	1500 g*	399.6 ± 13.7**a**	598.4 ± 31.7**a**
(fibres per μm^2)	2500 g*	286.8 ± 15.4**b**	412.9 ± 24.2**b**

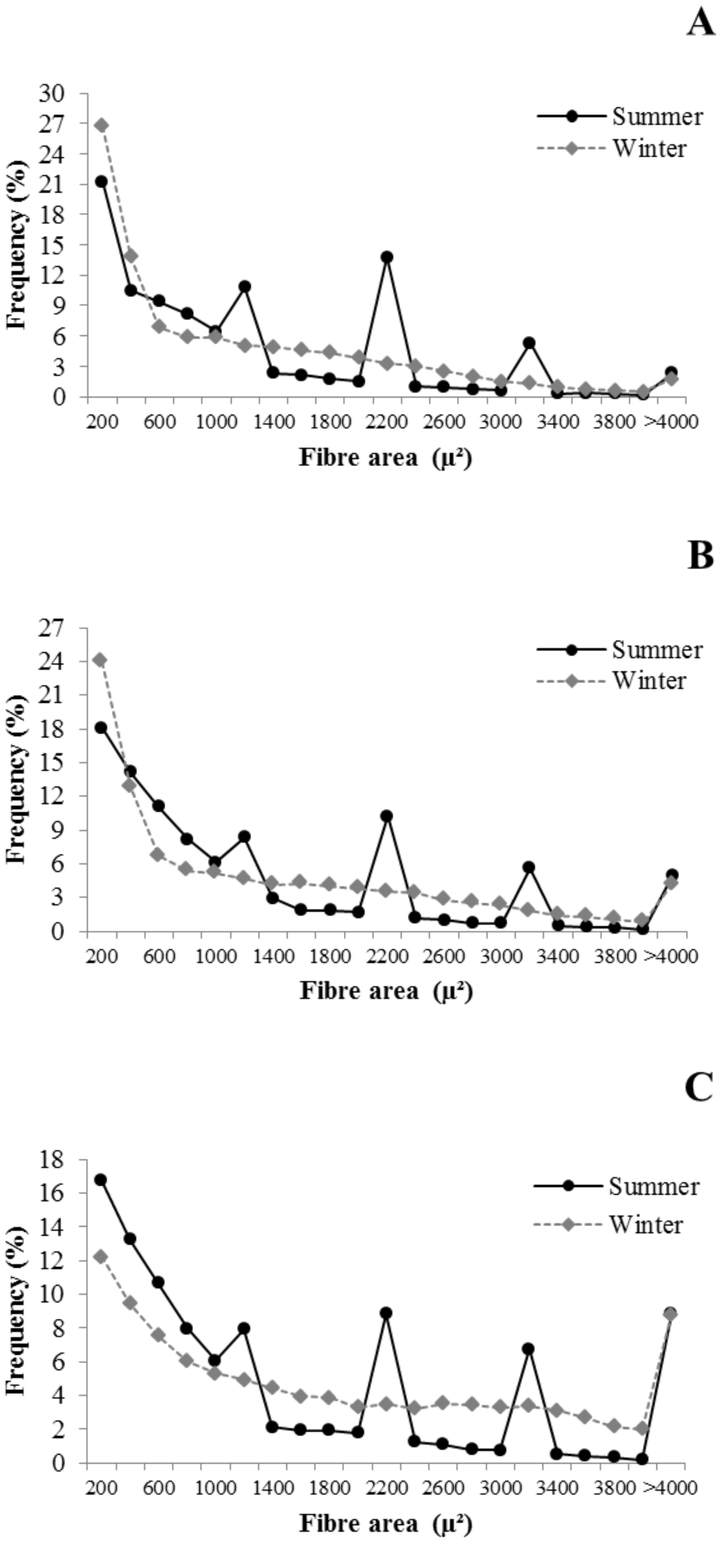
When fibre density and mean fibre area were compared, a significant negative correlation (r=-0.73) was found where fibre density decreased as fibre area increased (Fig. 2).

Fig.2. Correlation between fibre density and mean fibre area in meagre of three different commercial sizes.



When the different fibre areas were plotted in a graph, it was observed that the most frequent area fibre was between 200 and 400 μm^2 and that from that area forward the frequency of fibres decreased in all three fish weights studied (Fig. 1). In 800 g meagre, fibres with an area higher than 3000 μm^2 had a frequency lower than 2 %. On the contrary, in 2500 g meagre, approximately 10 % of the fibres had an area higher than 4000 μm^2. When comparing winter and summer sampling, it was observed that the reduction in the fibre area was gradually in the winter whereas in the summer there were three peaks of frequency occurring in 1200, 2200 and 3200 μm^2 and that three peaks were coincident in all the three weight groups studied (Fig. 3).

Figure 3. Frequency of fibre area (μ^2) frequency in 800 g (A), 1500 g (B) and 2500 g (C) meagre.



4 DISCUSSION

Meagre has an impressive growth rate and its first commercial size (approximately 800 g) can be reached one year after hatching (Ribeiro *et al.*, 2013), depending on rearing conditions. Meagre requires approximately two and three years to reach the weight of 1500 g and 2500 g, respectively. This enables farmers to adopt different strategies and release the fish to the market in specific times, avoiding market saturation. A possible constraint to this strategy might be the harvest season as it can affect fish quality and decrease its commercial appeal. In this study, the harvest season had a strong impact on the morphometric features of the 1500 g. When 1500 g meagre was sampled in the winter the percentage allocated to the skeleton was 68 %, which was reduced to 60%, in the summer. The same way, the whole fillets in the winter represented only 25 % of total body weight whereas in the summer this percentage was increased to nearly 32 %. Both skeleton and fillets percentages suggest that 1500 g meagre in the winter was considerably thinner and that the fillets were not very wide. In 800 and 2500 g meagre the impact of the season did not seem to significantly affect the skeleton and fillet yield.

Another biometric factor affected by the season was the HSI and VSI. The first increased in the summer while the latter decreased. The increase of the liver weight might be related to the increase of feed intake, which is very low in the winter periods, when the water temperature is low. Moreover, the liver of fish sampled during the summer was pale while in the fish sampled in the winter it was pinker. This is also supported by the increase of total fat from winter to summer in 1500 and 2500 g meagre. In these groups, the lipid content showed an increase above 50%. The same was not observed in the 800 g meagre, which had approximately 5 % of total fat in both winter and summer. The absence of significantly differences in the smaller meagre weigh could be related to its higher growth rate and lower fat accumulation. The increase of the VSI in the winter is difficult to explain, especially because it includes the liver weight, which had higher weight in the summer sampling. Nevertheless, it is possible to be associated to remains of feed left in the digestive tract, as this was often observed.

The total fat content obtained for the winter group is in agreement to other published studies which have reported a fat content bellow 3 % (Poli *et al.*, 2003; Hernández *et al.*, 2009; Grigorakis *et al.*, 2011; Giogios *et al.*, 2013; Costa *et al*., 2013; Sinanoglou *et al.*, 2014; Saavedra *et al.*, 2017). Smaller meagre showed a significantly lower lipid content in relation to 1500 and 2500 g, independently on the season. This is not uncommon as muscle lipids tend to increase with fish size (Aksnes *et al.*, 1996; Kiessling *et al.*, 1991a; Shearer *et al.*, 1994; Hemre and Sandnes 1999). In the summer group, except for the 800 g meagre, the fat levels reach a maximum of 4.6 %. Olsson *et al.* (2003) and Haugen *et al.* (2006) also observed an increase in the fat content of Atlantic halibut from winter to summer, when feeding activity was higher. This enhanced of feeding activity has been considered to be influence by the increased day length (Smith *et al.*, 1993; Forsberg, 1995; Mallekh *et al.*, 1998) and water temperature.

These changes in the fat content may have an impact in the textural properties of the flesh (Hérnandez *et al.*, 2009). In fact, in 2500 g meagre hardness and chewiness decreased from winter to summer, when the fat content increased. In 1500 g meagre, a decreased in the cohesiveness was observed in the summer. In 800 g meagre no significant differences were found between season and the fat content remained constant. Nevertheless, the only correlation found in this study was between the fat content and cohesiveness in 1500 g fish, suggesting that cohesiveness decreases when the fat content increases.

In terms of fillet hardness, significant differences were only found in the summer, where 1500 g meagre showed the highest value. However, only the 2500 g meagre showed a significant decreased from winter to summer. This decrease could have been associated with the fat content but no correlation was found. The values obtained for fillet hardness were in the range of other studies for meagre (60-80 N in Saavedra *et al*., 2014). Similar hardness was also registered for other species such as *Trachurus trachurus* (Torres *et al*., 2014), *Sparus aurata* (Fuentes *et al*., 2013) and *Salmo salar* (Fernández-Segovia *et al*., 2012) using the same methodology.

Several studies have highlighted the importance of muscle growth patterns and its effect on fish flesh quality (Johnston, 1999; Johnston *et al.*, 2000, 2002). In the current work, the mean fibre area increased with the size of the fish and was higher in 2500 g meagre, especially in the summer. Some studies showed that an increase in average fibre size resulted in a reduction of fibre density (Johnston *et al.*, 2000). This agrees with the current results where a negative correlation was obtained between fibre area and fibre density and where 2500 g meagre showed simultaneously the highest fibre area and the lowest fibre density. Fibre area did not seem affected by the season when the fish was sampled but fibre density was significantly lower when fish was sampled in the winter. This was observed for all fish weight groups. Fibre muscle density is an important quality trait that has previously shown to affect texture, the incidence of gaping and colour perception in farmed salmon (Johnston *et al.*, 2000, 2002). Johnston *et al.* (2000), found a positive correlation between muscle fibre density and firmness when assessed by a trained taste panel. Hurling *et al.* (1996) and Hatae *et al.* (1990) obtained a negative correlation between mean muscle fibre density and flesh hardness when analysed by a taste panel and instrumental methods, respectively. However, in the current work no correlations were found between textural properties and muscle cellularity.

In relation to muscle dynamics, it was observed for the 800 and 1500 g meagre that, in the winter, there was a higher frequency of fibres with an area lower than 400 μm^2, suggesting a higher fibre recruitment during the winter period. The mechanisms and timing of fibre recruitment are still unclear and some authors have reported controversial results. Kiessling et al. (1991) and Haugen et al. (2006) suggested that in rainbow trout and Atlantic halibut, periods of fast growth led to an increase of fibre hypertrophy whereas periods of slow growth favoured fibre recruitment. On the contrary, Higgins and Thorp (1990) observed that in Atlantic salmon, fibre hypertrophy occurred mainly during slow growth periods. The results obtained in the present study are more likely to be in agreement with the former authors as a higher percentage of smaller fibres occurred in the winter sampling. Moreover, in the summer sampling, three peaks of frequency were observed in 800, 1500 and 2500 g meagre for fibre areas of 1200, 2200 and 3200 μm^2. The higher frequency observed for this fibre areas could be related to peaks of fibre recruitment that should have had occurred between winter and summer, as they were not observed in the winter sampling. Once the water temperature increased and fish had a higher feeding intake, the newly recruited fibres might have grown through hypertrophy and achieved higher fibre areas. Since meagre growth rates are considerably high it is possible that fibre area could have increased considerably in a short period of time. Haugen et al. (2006) suggested that, in halibut, the fibres recruited in the winter could reach an area above the 500 μm^2 in a few months and, in the summer fish muscle were depleted of small fibres due to a growth spurt. In meagre, a higher frequency of small fibres was still observed in the summer. This is common in species that reach a large ultimate size (Kiessling et al,1991a). Such species may need to recruit new fibres to maintain their metabolic capacity when growing to larger sizes. This is the case of meagre, which can reach 50 kg, in the wild (Hernández *et al*., 2009).

In conclusion, season seems to affect both quality and muscle cellularity of meagre. Its effect was more pronounced in larger meagre (1500 and 2500 g) as some of the morphometric parameters and fat content varied substantially. In terms of muscle cellularity, fibre recruitment seemed to be enhanced in the winter when fish growth is low. Fibre density was strongly affected by the season, being higher in the summer.

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REFERENCES

Aksnes, A., Hjertnes, T. and Opstvedt, J. 1996. Effect of dietary protein level on growth and carcass composition in Atlantic halibut (*Hippoglossus hippoglossus* L). *Aquaculture* 145, 225– 233. https://www.sciencedirect.com/science/article/pii/S0044848696013476

Alami-Durante, H., Fauconneau, B., Rouel, M., Escaffre, A. M. and Bergot, P. 1997. Growth and multiplication of white skeletal muscle fibres in carp larvae in relation to growth rate. *J. Fish Biol.* 50, 1285–1302.

Bjornevik, M., Espe, M., Beattie, C., Nortvedt, R. and Kiessling, A., 2004. Temporal variation in muscle fibre area, gaping, texture, colour and collagen in triploid and diploid Atlantic salmon (*Salmo salar* L). *J. Sci. Food Agric.* 84, 530–540.
Bjornsson, B., 1995. The growth pattern and sexual maturation of Atlantic halibut (*Hippoglossus hippoglossus* L) reared in large tanks for 3 years. *Aquaculture* 138, 281–290. https://www.sciencedirect.com/science/article/pii/0044848695000313

Costa, S., Afonso, C., Bandarra, N., Gueifão, S., Castanheira, I., Carvalho, M.L., Cardoso, C. and Nunes, M.L. 2013. The emerging farmed fish species meagre (*Argyrosomus regius*): How culinary treatment affects nutrients and contaminants concentration and associated benefit-risk balance. *Food and Chemistry and Toxicology* 60, 277–285.

Duncan, N.J., Estévez, A., Fernández-Palacios, H., Gairin, I., Hernández-Cruz, C.M., Roo, F.J., Schuchardt, D., Vallés and R., 2013. Aquaculture production of meagre (*Argyrosomus regius*): hatchery techniques, ongrowing and market. In: Allan, G., Burnell, G. (Eds.), Advances in Aquaculture Hatchery Technology. Woodhead Publishing Limited, Cambridge, UK, 519–541.

Espe, M., Ruohonen, K., Bjornevik, M., Froyland, L., Nortvedt, R. and Kiessling, A., 2004. Interactions between ice storage time, collagen composition, gaping and textural properties in farmed salmon muscle harvested at different times of the year. *Aquaculture* 240, 489–504.
https://www.sciencedirect.com/science/article/pii/S0044848604002558

Fauconneau, B., Chmaitilly, J., Andre, S., Cardinal, M., Cornet, J., Vallet, J.L., Dumont, J.P. and Laroche, M., 1993. Characteristics of rainbow trout flesh: I. Chemical composition and cellularity of muscle and adipose tissues. *Sciences des Aliments* 13, 173–187.

Fernández-Segovia, I., Fuentes, A., Aliño, M., Masot, R., Alcañiz, M. and Barat, J.M. 2012. Detection of frozen-thawed salmon (*Salmo salar*) by a rapid low-cost method. *Jounal of Food Engineering* 113, 210–216.

Folch, T., Lees, M., and Sloane Stanley, G.H., 1957. A simple method for the isolation and purification of total lipids from animal tissues. *Journal of Biological Chemistry* 226, 497–509.

Forsberg, O.I., 1995. Empirical investigation on growth of post-smolt Atlantic salmon (*Salmo salar* L.) in land based farms. Evidence of a photoperiodic influence. *Aquaculture* 133, 235– 248. https://www.sciencedirect.com/science/article/pii/0044848695000292

Fuentes, A., Masot, R., Fernández-Segovia, I., Ruiz-Rico, M., Alcañiz, M. and Barat, J.M. 2013. Differentiation between fresh and frozen-thawed sea bream (*Sparus aurata*) using impedance spectroscopy techniques. *Innovative Food Science and Emerging Technology* 19, 210–217.

Giogios, I., Grigorakis, K. and Kalogeropoulos, N. 2013. Organoleptic and chemical quality of farmed meagre (*Argyrosomus regius*) as affected by size. *Food Chem.*141, 3153–3159.

Grigorakis, K., Fountoulaki, E., Vasilaki, A., Mittakos, I. and Nathanailides, C. 2011. Lipid quality and filleting yield of reared meagre (*Argyrosomus regius*). *International J. Food Sci.Techno.* 46, 711–716.

Hatae, K., Yoshimatsu, F. and Matsumoto, J.J., 1990. Role of muscle fibres in contributing firmness of cooked fish. *J. Food Sci.* 55, 693–696.

Haug, T., Huse, I., Kjorsvik, E. and Rabben, H., 1989. Observations on the growth of juvenile Atlantic halibut (*Hippoglossus-hippoglossus* L.) in captivity. *Aquaculture*, 80, 79–86.

Haugen, T., Kiessling, A., Olsen, R.E., Rora, M.N., Slinde, E. and Nortvedt, R., 2006. Seasonal variations in muscle growth dynamics and selected quality attributes in Atlantic halibut (*Hippoglossus hippoglossus* L.) fed dietary lipids containing soybean and/or herring oil under different rearing regimes. *Aquaculture*, 261, 565-579.
https://www.sciencedirect.com/science/article/pii/S0044848606006417

Hemre, G.-I. and Sandnes, K. 1999. Effect of dietary lipid level on muscle composition in Atlantic salmon, *Salmo salar*. *Aquacult. Nutr*., 5, 9–16.

Hernández, M.D., López, M.B., Álvarez, A., Ferrandini, E., García García, B. and Garrido, M.D. 2009. Sensory, physical, chemical and microbiological changes in aquacultured meagre (*Argyrosomus regius*) fillets during ice storage. *Food Chemistry* 114, 237–245.

Hurling, R., Rodell, J.B. and Hunt, H.D., 1996. Fibre diameter and fish texture. *J. Texture Stud.* 27, 679–685.

Johnston, I. A., Alderson, R., Sandham, C., Dingwall, A., Mitchell, D. and Selkirk, C. 2000. Muscle fibre density in relation to the colour and textural of smoked atlantic salmon (*Salmo salar* L.). *Aquaculture* 189, 335–349.
https://www.sciencedirect.com/science/article/pii/S0044848600003732

Johnston, I.A., Manthri, S., Alderson, R., Smart, A., Campbell, P., Mitchell, D., Whyte, D., Dingwall, A., Nickell, D. Selkirk, C. and Robertson, B., 2002. Effects of dietary protein level on muscle cellularity and flesh quality in Atlantic salmon with particular reference to gaping. *Aquaculture* 210, 259–283
https://www.sciencedirect.com/science/article/pii/S0044848601008626

Johnston, I.A., Manthri, S., Smart, A., Campbell, P., Nickell, D. and Alderson, R., 2003. Plasticity of muscle fibre number in seawater stages of Atlantic salmon in response to photoperiod manipulation. *J. Exp. Biol.* 206, 3425–3435.

Johnston, I.A., Manthri, S., Bickerdike, R., Dingwall, A., Luijkx, R., Campbell, P., Nickell, D. and Alderson, R., 2004. Growth performance, muscle structure and flesh quality in out-of-season Atlantic salmon (*Salmo salar*) smolts reared under two different photoperiod regimes. *Aquaculture* 237, 281–300. https://www.sciencedirect.com/science/article/pii/S0044848604002613

Kiessling, A., Storebakken, T., Asgard, T. and Kiessling, K.H., 1991a Changes in the structure and function of the epaxial muscle of rainbow-trout (*Oncorhynchus mykiss*) in relation to ration and age.1. Growth dynamics. *Aquaculture* 93, 335–356.

Kiessling, A., Asgard, T., Storebakken, T., Johansson, L. and Kiessling, K.H., 1991b Changes in the structure and function of the epaxial muscle of rainbow-trout (*Oncorhynchus mykiss*) in relation to ration and age. 3. Chemical composition. *Aquaculture* 93, 373–387.

Koumans, J.T.M., Akster, H.A., Booms, G.H.R. and Osse, J.W.M., 1993. Growth of carp (*Cyprinus carpio*) white axial muscle; hyperplasia and hypertrophy in relation to the myonucleus/sarcoplasm ratio and the occurrence of different subclasses of myogenic cells. . *Fish Biol.* 43, 69–80.

Mallekh, R., Lagarde´re, J.P., Bégout Anras, M.L. and Lafaye, J.Y., 1998. Variability in appetite of turbot, *Scophthalmus maximus* under intensive rearing conditions: the role of environmental factors. *Aquaculture* 165, 123– 138.

Monfort, M. C. 2010. Present market situation and prospects of meagre (*Argyrosomus regius*), as an emerging species in Mediterranean aquaculture. Studies and reviews Nº 89. General fisheries commission for the Mediterranean, FAO.
Nordgarden, U., Ornsrud, R., Hansen, T., Hemre and G.I., 2003. Seasonal changes in selected muscle quality parameters in Atlantic salmon (*Salmo salar* L.) reared under natural and continuous light. *Aquac. Nutr*. 9, 161–168.

Olsson, G.B., Olsen, R.L., Carlehog, M. and Ofstad, R., 2003. Seasonal variations in chemical and sensory characteristics of farmed and wild Atlantic halibut (Hippoglossus hippoglossus). Aquaculture 217, 191–205. https://www.sciencedirect.com/science/article/pii/S0044848602001916

Poli, B.M., Parisi, G., Zampacavallo, G., Iurzan, F.,Mecatti, M., Lupi, P. and Bonelli, A. 2003. Preliminary results on quality and quality changes in reared meagre (*Argyrosomus regius)*: body and fillet traits and freshness changes in refrigerated commercial-size fish. *Aquaculture International* 11: 301–311, 2003.

Ribeiro, L., Soares, L., Quental-Ferreira, H., Gonçaves, A. and Pousão-Ferreira, P. Portuguese research studies meagre production in earthen ponds. 2013. *Global Aquaculture Advocate* 16, 38-40.

Saavedra, M., Bandarra, N., Pereira, T., Radelytska, Pousão-Ferreira, P. and Gonçalves, A. 2014. Texture of meagre: what are the differences between wild and farmed fish? Oral communication. World Aquaculture Adelaide, 7-11 June. Austrália.

Saavedra, M., Pereira, T. G., Grade, A., Barbeiro, M., Pousão-Ferreira, P., Quental-Ferreira, H., Nunes, M. L., Bandarra, N. and Gonçalves, A. 2015. Farmed meagre, *Argyrosomus regius* of three different sizes: what are the differences in flesh quality and muscle cellularity? *Int. J. Food Sci Tech*, 50, 1311–1316.

Saavedra, M., Pereira, T.G., Carvalho, L. M., Pousão-Ferreira, P., Grade, Ana, Teixeira, B., Quental-Ferreira, H., Mendes, R. Bandarra, N. and Gonçalves, A. 2017. Wild and Farmed Meagre, *Argyrosomus regius*: A Nutritional, Sensory and Histological Assessment of Quality Differences *J. Food Compos Anal.* 63, 8-14.

Smith, I.P., Metcalfe, N.B., Huntingford, F.A. and Kadri, S., 1993. Daily and seasonal pattern in the feeding behaviour of Atlantic salmon (*Salmo salar* L.) in sea cage. *Aquaculture* 117, 165– 178.

Shearer, K.D., Åsgård T., Andorsdöttir G. and Aas, G.H. 1994. Whole body elemental and proximal composition of Atlantic salmon (*Salmo salar*) during the life cycle. *J. Fish Biol*., 44, 785–797.

Sinanoglou, V. J., Proestos, C., Lantzouraki, D. Z., Calokerino, A. C. and Miniadis-Meimaroglou, S. 2014. Lipid evaluation of farmed and wild meagre (*Argyrosomus regius*). *Eur. J. Lipid Sci. Technol.* 116, 134–143.

Torres, J.A., Saraiva, J.A., Guerra-Rodríguez, E., Aubourg, S.P. and Vázquez, M. 2014. Effect of combining high-pressure processing and frozen storage on the functional and sensory properties of horse mackerel (*Trachurus trachurus*). *Innovative Food Science and Emerging Technology* 21, 2–11.

Weatherley, A.H., Gill, H.S. and Lobo, A.F., 1988. Recruitment and maximal diameter of axial muscle-fibers in teleosts and their relationship to somatic growth and ultimate size. *J. Fish Biol*. 33, 851–859.