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Review article

Compositional and organoleptic quality of farmed and wild gilthead sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) and factors affecting it: A review

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Abstract

The term fish quality is a complex set of characteristics influenced by numerous endogenous and exogenous factors. The present review evaluates the quality of gilthead sea bream (*Sparus aurata*) and European sea bass (*Dicentrarchus labrax*) two of the most important farmed Mediterranean fish species. Based on pertinent literature, comparisons of wild and cultured fish have been carried out for proximate composition, fat and amino acid deposition, fatty acid contents, external appearance and organoleptic characteristics. Wild gilthead bream was found to have significantly lower muscle fat and higher muscle moisture contents compared to the cultured counterparts. Regarding their nutritional quality, farmed gilthead sea bream was found to have lower Atherogenic (0.323 vs. 0.577 in wild fish) and Thrombogenic indices (0.212 vs. 0.357 respectively). In sea bass, the only significant compositional difference found was the higher ash content of farmed fish. Differences in muscle structure and trace mineral contents have been observed for both species. External appearance differentiation is pronounced only in gilthead sea bream, while organoleptic differences regarding taste, flavour and texture were observed in the same species. The possibility of quality manipulation of the two studied species through dietary (fat level, feeding ratio, fasting, type of feed etc.) and other quality affecting factors is discussed based on literature data.

Keywords: Gilthead sea bream; Sea bass; Muscle composition; Fat; Fatty acids; Amino acids; Appearance; Sensory characteristics

Contents

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1. Introduction

Fish quality has been defined as "a combination of such characteristics as wholesomeness, integrity and freshness" (Martin, 1988). Within the former definition "wholesomeness" is the "quality of a food fit to eat, clean and uncontaminated, and packed and stored in a sanitary environment" and "integrity" is a "product being what it is supposed to be according to the suppliers claims". Finally "freshness" is a "quality of appearance, taste and texture". Organoleptic properties and nutritional value, are two sets of characteristics that together with freshness are those consisting fish quality as perceived by the consumer. Both characteristics strongly depend on the chemical composition of the fish, which in its turn depend on many quality affecting factors that include intrinsic characteristics of the fish (such as species, age, sex etc.), environmental factors (temperature, salinity etc.) and feeding history (diet composition, feeding ratio etc.) (Huss, 1988; Grigorakis, 1999). Additionally harvesting and post-harvesting procedures also interfere. Thus, a complex net of interactions is formed affecting what is generally termed as fish quality (Caggiano, 2000). Furthermore, the complexity of fish quality increase even more by the fact that in many cases quality terms and their understanding differ for the fish farmer, the processing industry and the consumer (Schwarz, 1997; Rasmussen, 2001).

The muscle quality characteristics of salmonids, catfishes (*Ictalurus punctatus*, *Silurus glanis*, *Clarias gariepinus*) and carp (*Cyprinus carpio*) have been previously reviewed (Fauconneau et al., 1995; Fauconneau and Laroche, 1996; Rasmussen, 2001), while also some general reviews occur on fish quality and its impacts (Huss, 1988; Haard, 1992; Love, 1992; Shearer, 1994). Regarding the commonly cultured Mediterranean fish species, some review exist for the nutrition and the growth characteristics of gilthead sea bream (*Sparus aurata*) and European sea bass (*Dicentrarchus labrax*) (Oliva-Teles, 2000), and some aspects of sea bream post-mortem changes have been reviewed (Howgate, 2006). However, no literature review exists on the quality of these two fish species respecting their muscle composition and sensory properties and the factors affecting them. The aim of the present study is to review and discuss the existing knowledge regarding the quality of gilthead sea bream and sea bass. Through that an attempt will be made to examine whether wild counterparts of these two species differ from the cultured ones with respect to their quality characteristics, and to find out in what extend manipulation of end product quality for these species is feasible.

2. Muscle composition, fat deposition and fatty acids profile

Skeletal muscle is the largest organ system in fish and corresponds actually to the edible part of it. In gilthead sea bream of commercial sizes the skeletal muscle represents the 34.3–48% of the total body weight (Grigorakis and Alexis, 2005; Testi et al., 2006) while in sea bass ranges from 44.2% (Boujard et al., 2004) to 57.5%, respectively (Nicolosi Asmundo et al., 1993).

Muscle composition is a major quality aspect in fresh fish. Changes in muscle composition of fish may have consequences for marketing. In fish species that do not store fat in their muscle (such as turbot, *Psetta maxima*, that have a muscle fat content of $<1\%$ on a fresh wet weight basis), even a small increase, of a rate of 2% can be altering the quality of the product considerably, while similar alterations in fish that tend to store fat in muscle, such as salmonids, would not affect its market acceptability (Love, 1992). The lipids in the edible part of the fish are important because they affect the sense of taste and the general sensation of cooked flesh in the mouth. For instance, herrings (*Cluppea* spp.) give a smooth and succulent ("juicy") mouth sensation when are well-fed and fat rich, but a dry and fibrous sensation after spawning (Love, 1992). Flesh lipid furthermore, is an important precursor of flavour compounds since fatty acid autoxidation produces volatile compounds characterising the fish flavour (German, 1990; Kawai, 1996). Muscle protein content may not have the prime importance of fat, but also contributes to the organoleptic quality in the cases of water-interacting proteins (Zayas, 1997), as well as in cases of long term fasting, reduction of the muscle connective tissue protein give to the cooked flesh an insubstantial texture (Love, 1992).

The concentration of fat in and around the peritoneal cavity (perivisceral and peritoneal fat respectively) is another important quality aspect. The perivisceral fat affects negatively the consumers' impression about the fish, i.e. it plays a role in the visual sense. For instance, a characteristic, strong, not very pleasant smell often

comes out of the perivisceral fat in well-fed aquaculture fish (Grigorakis, 1999). The peritoneal fat has a different significance for the consumer perception. When fish are consumed as fresh and gutted, the perivisceral fat is removed together with the intestines, but the peritoneal fat remains on the edible part since it is located behind the peritoneum. Thus, peritoneal fat contributes to the flavour and to the general taste of the fish although it remains unknown as to what the exact extend of this contribution is (Grigorakis, 1999).

The muscle proximate composition of gilthead sea bream and sea bass, as found in literature, are presented in Tables 1 and 2. Cultured gilthead sea bream was found to have significantly higher muscle fat and significantly lower muscle moisture compared to wild counterparts. These differences, pronounced by the comparisons of weighed means, have been also mentioned by numerous studies (Orban et al., 1996; Flos et al., 2002; Grigorakis et al., 2002; Mnari et al., 2007). Proximate composition of extensively cultured gilthead bream does not differ significantly to either wild or cultured fish (Table 1). Differences have been mentioned between intensively cultured fish and fish obtained from other rearing systems, mainly regarding gilthead sea bream (Flos et al., 2002), and sharpsnout sea bream (*Diplodus puntazzo*) (Orban et al., 2000).

In sea bass, unlike gilthead bream, no compositional differences were observed in their muscle fat and moisture (Table 2) (Nicolosi Asmundo et al., 1993; Amerio et al., 1996; Gatta et al., 2000; Poli et al., 2001; Alasalvar et al., 2002; Kyrana and Lougovois, 2002; Grigorakis et al., 2004; Ozogul et al., 2005; Ozyurt and Polat, 2006; Periago et al., 2005; Testi et al., 2006). The only proximate constituent that differed significantly between wild and cultured counterparts was the ash content, which was higher in the cultured fish.

In general, the existent data regarding perivisceral and peritoneal fat deposition of gilthead sea bream (Table 3) and sea bass (Table 4) is relatively limited. Significant differences have been observed in the perivisceral and peritoneal fat depots between wild and cultured fish (Krajnovic-Ozretic et al., 1994; Grigorakis et al., 2002). Although the different methods of fat depots estimation or different expression ways result into high differentiation among the various references, some conclusions can be made about the differences between wild and cultured fish. Deposit fat (both perivisceral and peritoneal) in farmed gilthead sea bream has always been found significantly higher than in wild fish (Grigorakis et al., 2002). In sea bass the deposit fat has been found significantly higher for cultured fish in one case (Krajnovic-Ozretic et al., 1994) while no significant differences were observed in another (Periago et al., 2005).

Regarding fatty acid differences of gilthead bream, the various fatty acid groups were not found to differ significantly among wild and cultured counterparts (Table 5, Amerio et al., 1996; Orban et al., 1996; Almansa et al., 2001; Grigorakis et al., 2002; Saglik et al., 2003; Ibarz et al., 2005; Izquierdo et al., 2005; Ozyurt et al., 2005; Vasiliadou et al., 2005; Mnari et al., 2007; Senso et al., 2007; Testi et al., 2006). Although the *n*-3 polyunsaturated fatty acids weighed mean value for cultured fish appears to be much higher and the weighed means for EPA/DHA and *n*-3/*n*-6 ratios much lower than those of wild counterparts, significant differences were not established. In sea bass, EPA/DHA ratio has a lower weighed average value for cultured fish. On the other hand, the weighed average for *n*-3 total amount seems to be lower in cultured counterparts (Table 6). Similarly to that found in gilthead bream, both differences were not found statistically significant, although average values differ remarkably (Nicolosi Asmundo et al., 1993; Krajnovic-Ozretic et al., 1994; Delgado et al., 1994; Amerio et al., 1996; Lanari et al., 1999; Pirini et al., 2000; Alasalvar et al., 2002; Saglik et al., 2003; Passi et al., 2004; Mourente et al., 2005; Montero et al., 2005; Ozyurt and Polat, 2006; Periago et al., 2005; Testi et al., 2006).

The reason explaining the lack of significant differences in the fatty acid groups between wild and cultured counterparts for either species is the high standard deviations that reflect the high variability found within the literature. Fatty acid composition in gilthead bream (Grigorakis et al., 2002; Ozyurt et al., 2005, Mnari et al., 2007; Senso et al., 2007) and in sea bass (Krajnovic-Ozretic et al., 1994; Alasalvar et al., 2002; Ozyurt and Polat, 2006) has been shown to be strongly affected by the dietary history and exhibiting strong seasonality, facts that explain the high heterogeneity.

However, some pronounced differences between wild and cultured counterparts concerning individual fatty acids have been discussed previously. The higher levels of linoleic acid (18:2*n*-6) in cultured counterparts and higher levels of arachidonic acid in wild counterparts, reported for both gilthead sea bream (Grigorakis et al., 2002; Saglik et al., 2003; Mnari et al., 2007) and sea bass (Krajnovic-Ozretic et al., 1994; Alasalvar et al., 2002), have been justified by the presence of the terrestrial plant-originated 18:2*n*-6 in the feeds but the relative absence in the natural marine food chain and the opposite for the arachidonic acid. The presence of 22:1*n*-11 in much higher quantities in cultured fish in some cases (Grigorakis et al., 2002) has been justified by its presence in the dietary fish oils of Northern

Table 1
Proximate composition of gilthead sea bream, *Sparus aurata*: literature values and weighed averages (AVG) and standard deviations (SD) for intensively cultured (IC), extensively cultured (EC) and wild fish

No. of individuals analyzed	Muscle proximate composition %				Body weight (g)	Diet characteristics			Notes (culture characteristics)	Season/ temperature °C	Reference
	Protein	Fat	Moisture	Ash		Dietary protein %	Dietary fat %	Feeding intensity (% body weight)			
Cultured											
4	21.3	6.81	69.9	1.56	500	49	20	0.6	Commercial feed	September	Amerio et al. (1996)
3	19.7	8.42	69.1	1.28	400				Intensive culture, commercial diet	December	Orban et al. (1996)
3	20.7	3.78	73.2	1.37	400				Extensive culture		
3	21.8	7.69	70.3	1.32	410	45	15		Intensive culture		Kyrana et al. (1997)
3		9.36	72.3		1100	48	8	1.5	Pre-spawn females, commercial diet	Nov./19–22	Almansa et al. (2001)
3		6.56	76.1			46	12	1.5	Post-spawn females, experimental diet (control)	June/19–22	
3		5.63	76.2			46	12	1.5	Post-spawn females, experimental diet (*n*-3 deficient, rich in 18:1*n*-9, 18:3*n*-3)	June/19–22	
6	21.1	3.00	73.5	1.40	515						Huidobro et al. (2001)
6	21.1	6.10	72.2	1.57							Tejada and Huidobro (2002)
6	22.4	4.16	70.8	1.53							
10	22.9	3.94	71.7	1.46	305	50	10		Intensive culture, self feeding	Spring	Flos et al. (2002)
10	21.3	2.53	73.9	1.41	313	48	12		Extensive culture, hand feeding 2/day	24–26	
10	21.1	5.98	71.7	1.26	303	48	12		Extensive culture, self feeding		
5	18.1	9.80	71.2	1.36	318	45	22		Commercial feed	Jan./14	Grigorakis et al. (2002)
5	18.0	6.53	74.7	1.53	320	45	22		According to manufacturers tables	May/19	
5	18.3	10.4	69.9	1.22	285	45	22			Aug./25	
10	21.6	6.02	69.8	1.64	500				Natural light	18.3–22.9	Gines et al. (2004)
10	21.3	5.74	70.9	1.56					Long constant photoperiod (16 h)		
10	21.8	5.37	71.0	1.59					Continuous lighting		
12	20.7	9.36	69.4	1.32	348	38	20	*ad lib*		September	Grigorakis and Alexis (2005)
12	19.2	9.39	69.5	1.33	337	45	15	*ad lib*			
12	20.7	9.64	68.8	1.28	349	51	10	*ad lib*			
14	20.7	7.55	70.0		303				Intensive culture		Vasiliadou et al. (2005)
5	21.0	5.00	73.7		99	47	21		Initial	18	Ibarz et al. (2005)
10	21.6	4.00	74.8		87	47	21		Gradual temperature drop (1 °C/day)	18 → 8	
10	21.2	4.10	74.8		89	47	21		Sharp temperature drop	18 → 8	
5	18.8	11.1	68.6	1.26	273						Testi et al. (2006)[a]
15	19.7	3.4	75.7	1.4	279.2	53	23		Commercial diet	Febr./15	Senso et al. (2007)

Table 1 (*continued*)

No. of individuals analyzed	Muscle proximate composition %				Body weight (g)	Diet characteristics			Notes (culture characteristics)	Season/ temperature °C	Reference
	Protein	Fat	Moisture	Ash		Dietary protein %	Dietary fat %	Feeding intensity (% body weight)			
Cultured											
15	19.4	3.7	74.6	1.4	297.8	53	23			Apr./18	
15	19.2	2.5	76.6	1.4	274.2	53	23			June/21	
15	19.8	3.6	75.0	1.4	261.0	53	23			Aug./24	
15	20.0	2.8	75.2	1.5	313.8	53	23			Oct./20	
15	20.2	3.1	75.8	1.4	266.3	53	23			Dec./16	
Wild											
10	21.2	0.92	76.5	1.39	337					Spring	Flos et al. (2002)
5	20.1	1.16	78.1	1.44	380					Jan./14	Grigorakis et al. (2002)
5	19.5	0.85	79.9	1.47	502					May/19	
3	19.8	1.88	75.9	1.28	113					November	Ozyurt et al. (2005)
3	19.3	1.59	77.3	1.31						February	
3	19.3	2.01	76.4	1.39						April	
3	19.9	3.01	75.4	1.37						July	
AVG IC	20.4	5.34 b	70.7 a	1.43							
SD	1.31	2.67	2.51	0.12							
AVG EC	21.1	4.19 ab	72.9 ab	1.34							
SD	0.31	1.75	1.12	0.08							
AVG wild	20.2	1.4 a	77.2 b	1.39							
SD	0.66	0.76	1.53	0.07							

Different letters denote statistical significant difference between weighed average ($P<0.05$).

[a] Calculated by the dorsal and ventral yields and the respective compositional percentages.

Atlantic origin (Henderson and Tocher, 1987). In general, literature has indicated for both sea bass and gilthead bream a higher *n*-3/*n*-6 ratio for wild fish (Alasalvar et al., 2002; Saglik et al., 2003; Mnari et al., 2007). Such a tendency appears by the present collective data only for gilthead sea bream (although no statistically significant).

Limited data exist on whole body (Kaushik, 1998) and muscle (Nicolosi Asmundo et al., 1993; Amerio et al., 1996; Ozyurt and Polat, 2006) amino acid composition of gilthead sea bream and sea bass. Figs. 1 and 2 present the A/E ratio for each essential amino acid and the E/N ratios respectively in gilthead sea bream and sea bass muscle. Statistical analysis showed no significant differences ($P>0.05$) in either of these parameters between wild and cultured sea bass.

Beyond the previously discussed proximate and fatty acid quality differences, Carpene et al. (1998) found biochemical differences of wild and cultured gilthead bream muscle in aspects of trace elements. Thus, wild fish muscle (either white or red) has been found significantly richer in trace elements. The former scientists have given three possible explanations for higher concentrations of trace elements in wild fish muscle: (i) wild fish receive cations from water and diet and possibly their natural environment is richer in these, (ii) the richer in fat cultured fish muscle has lower affinity for metals, or (iii) the greater exercise of wild fish is coupled with increase of protein expression with high affinity of trace elements.

Contrary to that found in gilthead sea bream, trace minerals comparison between wild and cultured sea bass muscle showed no significant differences in their total contents (Alasalvar et al., 2002). Only some individual differences, such as higher Fe and Al in wild fish and higher Ti and V in cultured fish, were observed (Alasalvar et al., 2002). Nevertheless, since trace minerals contents are influenced by diet, environment, season, and also by sampling procedures and analyzing techniques used (Lall, 1995) further data is required to establish a comprehensible picture.

In gilthead sea bream, differences were evident in myosin subunits proportions between the red muscles of the two counterparts, as electrophoresis of myosin light chains revealed (Carpene et al., 1998). Structural differences have been mentioned for the sea bass as

Table 2
Proximate composition of sea bass *Dicentrarchus labrax*: literature values, weighed averages (AVG) and standard deviations (SD) for cultured (C) and wild (W) fish

No. of individuals analyzed	Muscle proximate composition %				Body weight (g)	Diet characteristics			Notes (culture characteristics)	Season/ temperature °C	Reference
	Protein	Fat	Moisture	Ash		Dietary protein %	Dietary fat %	Feeding intensity (% body weight)			
Cultured											
3	21.8	4.85	71.7	1.56	80			2	1+ age commercial diet		Nicolosi Asmundo et al. (1993)
3	21.4	5.19	72.8	1.39	250			2	2+ age commercial diet		
3	20.9	5.73	71.0	1.89	>300			2	3+ age commercial diet		
4	20.1	7.62	70.9	1.52		48.6	20	0.6	Commercial feed	September	Amerio et al. (1996)
20	21.9	9.20	64.4	1.39		44	27.5	*ad lib*	4/day	–/18.2–26.3	Gatta et al. (2000)
3		4.9	73.4		306	52	11	0.95	Commercial feed	–/21.9	Poli et al. (2001)
3		4.5			296		11	0.95			
3		4.6			292		15	0.95			
3		5.5			331		19	0.95			
4	20.7	5.2	72.2	1.5	224	46	20		Commercial feed	May/18–19	Alasalvar et al. (2002)
6	19.4	4.81	76.7	1.23	302	48	14				Kyrana and Lougovois (2002)
10	18.6	4.54	75.2	1.27	349	45	15		Commercial diet	Dec./14	Grigorakis et al. (2004)
10	20.3	3.90	74.4	1.3	236	45	15			July/25	
11	23.4	6.66	72.6		360	48	14	*ad lib*			Periago et al. (2005)
5	18.8	7.98	72.6	1.27	226						Testi et al. (2006)[a]
Wild											
3	19.2	1.4	75.5	1.5	203					May/18–19	Alasalvar et al. (2002)
3	18.7	1.67	77.9	1.11							Ozogul et al. (2005)
14	17.6	9.19	69.5		365					March	Periago et al. (2005)
3	18.7	2.18	77.3	1.23	354					November	Ozyurt and Polat (2006)
3	19.8	1.22	77.4	1.17	350					February	
3	21.4	6.05	70.8	1.27	352					April	
3	21.8	5.85	71.0	1.05	344					July	
AVG C	20.9	6.37	71.2	1.40 a							
SD	1.38	1.55	2.94	0.26							
AVG W	18.9	5.74	72.6	1.22 b							
SD	1.52	3.10	3.63	0.16							

Different letters denote statistical significant difference between weighed average ($P<0.05$)
[a] Calculated by the dorsal and ventral yields and the respective compositional percentages.

well (Periago et al., 2005). The latter study showed that, white muscle fibre density in farmed sea bass is significantly lower in farmed compared to wild fish, indicating different patterns of muscle growth. The higher white muscle fibre density in wild fish was associated to a higher rate of hyperplasia during growth. (Periago et al., 2005).

2.1. Factors affecting muscle composition and fat deposition

There is serious evidence that proximate composition of muscle and fat deposition is affected by feeding characteristics of the fish, although, in many cases, relations among dietary and quality parameters seem to be rather complicated

Table 3
Perivisceral and peritoneal fat in gilthead sea bream

Perivisceral fat (% body weight)	Peritoneal fat (% body weight)	Fish size (g)	Diet characteristics	Reference
1.31			CP/CF: 47/15%	Santinha et al. (1999)
1.64			CP/CF: 47/21%	
1.51			CP/CF: 51/15%	
1.64			CP/CF: 51/21%	
2.43	0.43	449.5	Ration 0.6%, Nov. 20 °C	Grigorakis et al. (2002)
1.03	0.53	317.9	Ration 0.3%, Jan. 14 °C	
1.97	0.60	361.2	Ration 0.6%, Apr. 16 °C	
0.79	0.34	320.4	Ration 0.7%, May 19 °C	
2.11	1.24	285.0	Ration 0.9%, Aug. 25 °C	
0.00	0.00	373.0	Wild December 14 °C	
0.00	0.00	380.1	Wild January 14 °C	
0.13	0.00	501.8	Wild, May 19 °C	

CP: dietary protein content, CF: dietary fat content.

(Lanari et al., 1999; Santinha et al., 1999; Vergara et al., 1999; Poli et al., 2001; Boujard et al., 2004).

In gilthead sea bream, increase of dietary lipid content from 15% to 28% lead to body lipid content increase when fish fed with good quality fishmeal but not when received standard quality fishmeal (Vergara et al., 1999). Increase of body fat shows that dietary lipid influences the fat deposition, although it is not defined which fat depot (muscle, perivisceral, peritoneal fat) is mostly affected. Santinha et al. (1999) found that muscle lipid has been increased with dietary lipid, while on the contrary visceral lipid remained unaffected in gilthead bream of slightly smaller than commercial weight (140–150 g).

Increase of dietary fat (three levels 11%, 15%, and 19%) in sea bass resulted to increase in mesenteric and peripheric fat irrespective to the level of dietary NFE (*N*-free extract) level received, as well as in muscle fat only at higher dietary NFE level (Lanari et al., 1999). Peripheric, mesenteric and muscle fat increase correspondingly to the dietary fat elevation (from 11% to 19%) has been also mentioned by Poli et al. (2001). Boujard et al. (2004) tested three diets of low, medium and high fat content in commercially sized sea bass and found that higher dietary fat content (30%) resulted into significantly higher body fat than in fish fat with low dietary fat (11.3%). This was not reflected in the muscle lipid where no significant differences were observed among dietary groups. Based on these observations the former scientists suggest that dietary fat result into fat deposition primarily in liver and perivisceral adipose tissue.

Although literature fail to show direct effect of dietary lipid levels to muscle fat, present collective results in sea bass revealed correlation at a significance level of 0.05 between dietary fat and muscle fat contents ($r=0.787$). Based on this finding, and since that none of the published studies were focusing in studying directly the effect of dietary fat in sea bass quality, a further investigation would be of interest.

Lupatsch et al. (2003) in a study of energy and protein efficiency for sea bass and gilthead sea bream indicated that the lower lipid retention efficiency for gilthead bream suggests that in addition to lipid energy, protein energy is involved in lipid deposition of gilthead sea bream, i.e. at high intake levels protein is used not just for protein deposition but also as an energy source. This observation, on one hand introduces one extra complexity-adding factor in studies about the role of dietary lipid in fish quality, but also designates the need to conduct research on the exact impact of dietary protein in lipid deposition.

The diet type (extruded, pelleted) has been reported to influence muscle lipid composition in gilthead bream, extruded diets leading to increased fat content despite lower fat levels (Aksness et al., 1997). Similar observations have been made for sea bass by Poli et al. (2001), i.e. increase of intramuscular lipid in fish received an extruded diet than those fed with pelleted diet (2.92% vs. 4.05%). Other scientists (Guroy et al., 2006), however, failed to show differences between extruded and pellet diet-received sea bass in their muscle and visceral fat.

In a 7-week experiment evaluating dietary fat levels and feeding ration for gilthead sea bream fingerlings, mesenteric fat index increase was observed along with increase of ration and differences were observed between low (7%) and high (17%) dietary fat at the low feeding ratio (1%) but not when fed *ad libitum* (Company et al., 1999). The very high fat deposition in *ad lib* fed commercially sized gilthead sea bream, irrespectively to the dietary fat level (Grigorakis and Alexis, 2005), together with the previously mentioned results (Company et al., 1999) indicate that increase of ration size at *ad libitum* level has a strong effect overwhelming any compositional effects.

Table 4
Perivisceral and peritoneal fat in European sea bass

Perivisceral fat (% body weight)	Peritoneal fat (% body weight)	Fish size (g)	Diet characteristics/notes	Reference
7.6 (perivisc.+periton. fat)		306	19% CF	Poli et al. (2001)
7.0 (perivisc.+periton. fat)			15% CF	
6.3 (perivisc.+periton. fat)			11% CF	
2.40		145.1	Salinity 37‰	Roche et al. (1989)
2.73		180.5	Adapt. to salinity 5‰	
4.65 **		243	Initial	Boujard et al. (2004)
4.31 **		441	10% CF	
5.47 **		453	20% CF	
6.16 **		482	30% CF	
3.03	0	349.6	45/15 *, Dec. 14 °C	Grigorakis et al. (2004)
6.16	0.61	236	45/15 *, July 25 °C	
6.3 (perivisc.+periton. fat)			21.5% NFE, 11% CF	Lanari et al. (1999)
7.2 (perivisc.+periton. fat)			21.5% NFE, 15%CF	
7.6 (perivisc.+periton. fat)			21.5% NFE, 19% CF	
6.3 (perivisc.+periton. fat)			28.5% NFE, 11% CF	
6.8 (perivisc.+periton. fat)			28.5% NFE, 15% CF	
7.5 (perivisc.+periton. fat)			28.5% NFE, 19% CF	
4.46 ***		174	46/12 * Seawater raised	Eroldogan and Kumlu (2002)
3.62 ***		181	46/12 * Freshwater raised	
1.14 ***		360.0	Cultured	Periago et al. (2005)
1.10 ***		365.5	Wild	
0.7		171	Initial	Guroy et al. (2006)
4.7		294	47/17 * extruded, 2/day	
4.2		301	47/17 * extruded, 3/day	
4.2		288	47/17 * pelleted, 2/day	
4.4		289	47/17 * pelleted, 3/day	

*CP %/CF %, where CP: dietary protein content, CF: dietary fat content.
**Values calculated from visceral weight, total body weight, and visceral fat contents (expressed as % of visceral weight), ***values calculated from total body weights and visceral fat weights in g.

In sea bass, very few existing literature data (Guroy et al., 2006) fail to establish relationship between ration size and resulted quality.

Based on the published information for gilthead bream (Table 1, Amerio et al., 1996; Almansa et al., 2001; Grigorakis and Alexis, 2005), muscle fat was found to correlate (two tail Pearson correlation) at a significance level of 0.012 with feeding intensity ($r=0.823$), but the same statistical testing in the sea bass data (Table 2; Nicolosi Asmundo et al., 1993; Amerio et al., 1996; Gatta et al., 2000; Poli et al., 2001; Periago et al., 2005) revealed no similar trend.

Fasting has been mentioned to cause alterations in muscle quality and fat deposition of gilthead sea bream (Company et al., 1999; Grigorakis and Alexis, 2005; Ibarz et al., 2005). Cold-induced fasting (temperature <13 °C), in 100 g weighed fish, lead in significant decrease of body weight and loss of perivisceral fat and muscle non-polar lipids (Ibarz et al., 2005). In overfed fish, a 3-week fasting resulted in muscle fat reduction and a more delayed and lower deposit fat reduction, but without weight loss (Grigorakis and Alexis, 2005). Fat mobilization has been also mentioned in fingerling gilthead sea bream during 18 days fasting (Company et al., 1999), which was also accompanied by weight decrease. Both scientists have mentioned slight differentiations relating to the diet that the fish have received prior to the fasting period. The fat mobilization pattern for gilthead sea bream seems to be an initial mobilization of liver and subsequently of muscle fat (Grigorakis and Alexis, 2005).

In sea bass starved for periods of 60 days, a visceral and hepatic fat mobilization was observed (Stirling, 1976). In prolonged food deprivation for sea bass Echevarria et al. (1997) mentioned two phases, the first one (up to 50 days starvation) in which energy reserves, mainly hepatic and intestinal, occurs, and the second one (up to 150 days when experiment terminated) where global structural reserves were mobilized accompanied with muscle protein reduction. In the later references no significant muscle fat reduction was observed. This could be interpreted as muscle fat preservation. Given the fact, however, that in both these studies the initial muscle fat was very low (1.2% and 1% respectively) when compared to the general literature (Table 2: Nicolosi Asmundo et al., 1993; Amerio et al., 1996; Gatta et al., 2000; Poli et al.,

2001; Alasalvar et al., 2002; Kyrana and Lougovois, 2002; Grigorakis et al., 2004; Periago et al., 2005; Testi et al., 2006), such an interpretation may be proved wrong since the picture may have been different with fish containing higher muscle fat depots.

Factors other than diet and feeding characteristics also seem to influence muscle composition and fat deposition in gilthead sea bream and sea bass. Changes in photoperiod alter muscle composition in gilthead sea bream, with continuous light resulting in reduced fat content, a fact explained by the hypothesis of greater activity metabolism under long days (Gines et al., 2004). Also adjustment to low salinity (5‰) in sea bass has been mentioned to result into elevated perivisceral fat according to Roche et al. (1989). However, this difference could be possibly attributed to the different body weight of the two groups at the end of experiment (145.1 g of control group vs. 180.5 g of adjusted group) rather than salinity effect. Other researchers (Eroldogan and Kumlu, 2002) did not detect differences in fillet proximate composition and perivisceral fat contents of sea raised in seawater and in freshwater, respectively.

There is evidence indicating that, irrespectively to feeding history of the fish, muscle fat as well as perivisceral and peritoneal fat increase with fish weight/size for both sea bass and gilthead bream (Nicolosi Asmundo et al., 1993; Poli et al., 2001; Gines et al., 2004, Grigorakis and Alexis, 2005). Other studies, however, did not detect direct relation between body weight and muscle fat content (Grigorakis et al., 2002; Senso et al., 2007). A possible explanation is that in the latter references there was no statistical correlation test made between the individual values of these parameters, but simple comparisons of average values, unlike in the studies of Gines et al. (2004) and Grigorakis and Alexis (2005) that observed the size–fat depots correlations. Correlation ($P<0.05$) between body weight and muscle fat ($r=0.351$) has been observed for the collective literature results in gilthead bream and confirms the positive effect of fish size to the fat deposition. A significant correlation between body weight and muscle ash ($r=0.618$, $P<0.01$) obtained from the collective data in the gilthead sea bream, indicates muscle ash increase with fish size.

Seasonal impact in muscle and deposit fat content, that showed increased fat depots at the end of the summer and beginning of autumn and low fat depots after winter, can be actually attributed to the feeding intensity and in the cases of wild fish also to the gonadal maturation and spawning (Grigorakis et al., 2002; Gialamas et al., 2003; Ozyurt et al., 2005). A monitoring study in gilthead sea bream and sea bass originated from various Greek fish farms failed to show a seasonal effect in muscle fat in the first species which was found to be mainly affected by feeding strategy (Foundoulaki et al., 2003), but any potential seasonal effect may have been masked through heterogeneity of studied groups.

Also there are some indications that commercialized sea bass and gilthead bream occasionally carry pathologies that may affect their quality (Manera et al., 2003). In specific, fish obtained from wholesalers from Greece and Italy exhibited pathologies that caused changes in muscle composition, i.e. muscle moisture increase due to winter syndrome in gilthead bream, or fat and protein reduced levels due to parasitosis in sea bass (Manera et al., 2003). However, former results refer to a very limited number of individuals (four unaffected and four from each pathological group), and taking into account that the studied fish could also reflect very deviate dietary histories, further research is needed in relation to compositional alterations due to pathologies.

In general, fatty acid composition of fish muscle greatly reflects the dietary fatty acid composition and this is well documented for both gilthead sea bream and sea bass (Nicolosi Asmundo et al., 1993; Krajnovic-Ozretic et al., 1994; Grigorakis et al., 2002; Izquierdo et al., 2003, 2005; Montero et al., 2005; Mnari et al., 2007). Given the fact that fish oil is a limited source and moreover there is a turn towards alternative fat sources of plant origin (Hardy et al., 2001; Tacon, 1997; Izquierdo et al., 2003), it is of interest to know how fish muscle fatty acids change during these substitutions, and what is the ability of our fish species for recovering their initial muscle fatty acid profiles.

Fish oil substitution experiments showed fatty acid alterations in fish muscle of gilthead sea bream (Izquierdo et al., 2003, 2005) and sea bass (Izquierdo et al., 2003; Montero et al., 2005; Mourente et al., 2005). Feeding with soybean oil, linseed oil, rapeseed oil (at inclusion levels 60 and 80%) and olive oil (60%) containing diets has been tested in the above-mentioned literature for periods of 81 up to 238 days (34 weeks). The common and most profound alterations derived from the use of various plant oil containing diets consist of EPA/DHA ratio reduction and of EPA and DHA total quantity reduction, and respectively of *n*-3/*n*-6 ratio reduction (Izquierdo et al., 2003, 2005; Montero et al., 2005; Mourente et al., 2005). Arachidonic acid significantly decreased in all the cases of soybean, linseed and rapeseed oil substitutions but not in the case of olive oil inclusion (Mourente et al., 2005). On the other side, in all studies and for all oil sources and substitutions levels, monounsaturated fatty acids of plant origin were increased in fish muscle, especially linoleic acid in the

Table 5
Fatty acid composition of gilthead sea bream, *Sparus aurata*: literature values and weighed averages (AVG) and standard deviations (SD) for cultured (C) and wild (W) fish

No. of individuals analyzed	Fatty acid composition						Atherogenic Index	Thrombogenic index	Body weight (g)	Diet characteristics/notes (CP/CF, feed. intensity % body weight)	Season/ temperature °C	Reference
	Saturated %	Monounsat. %	*n*-3 Polyun-sat %	EPA/ DHA	*n*-3/ *n*-6	EPA + DHA %						
Cultured												
	23.5	34.7	24.2	0.61	1.40	20.7	0.543	0.278	550	Com. feed, CP 48.6%/CF 20%, 0.6%	September	Amerio et al. (1996)
3	25.3	27.3		0.50		18.2	0.653		400	Intensive culture	December	Orban et al. (1996)
3	26.0	36.7		0.79		19.6	0.322		400	Extensive culture		
3	22.8	24.3	14.0	0.64	2.99	10.4			1100	Pre-spawn females, commercial diet CP 48%/CF 8%	Nov./19–22	Almansa et al. (2001) [a]
3	14.0	16.9	12.6	0.31	3.68	9.84				Post-spawn females, experimental diet CP 46%/CF 12% (control)	June/19–22	
3	11.2	16.8	10.0	0.18	3.05	7.14				Post-spawn females, experimental diet CP 46%/CF 12% (*n*-3 deficient, rich in 18:1*n*-9, 18:3*n*-3)	June/19–22	
3	28.2	37.2	22.8	0.45	1.92	18.4	0.507	0.289	450	Commercial diet, CP 45%, CF 22%	Nov./20	Grigorakis et al. (2002)
3	26.9	32.1	24.4	0.28	3.17	23.1	0.419	0.280	248	Commercial feed	May	Saglik et al. (2003) [a]
18	29.8	36.0	23.41	1.24	3.07	16.4	0.635	0.305	464	Fish oil		Izquierdo et al. (2005)
18	25.3	33.1	14.7	0.82	0.58	9.06	0.421	0.334	460	60% soybean oil		
18	22.9	46.3	15.0	0.74	1.04	8.49	0.386	0.293	446	60% rapeseed oil		
18	24.8	33.1	29.3	0.76	2.51	8.08	0.398	0.214	459	60% linseed oil		
18	23.7	32.5	12.9	0.63	0.43	6.32	0.343	0.327	441	80% soybean oil		
18	22.6	31.8	31.5	0.58	2.47	6.31	0.337	0.185	440	80% linseed oil		
14	26.6	31.8	21.8	0.60	1.70	16.2						Vasiliadou et al. (2005)
5	27.6	32.0	21.0	0.49	1.47	16.0	0.272	0.259	99	Initial (comm. feed, CP 47%, CF 21%)	18	Ibarz et al. (2005) [b]
10	27.4	32.5	21.4	0.46	1.56	16.7	0.277	0.263	87	Gradual temperature drop (1 °C/day)	18 → 8	
10	29.7	32.0	22.6	0.47	1.57	17.9	0.272	0.339	89	Sharp temperature drop	18 → 8	

5	27.0	37.2	22.5	0.46	2.70	17.1			273			Testi et al. (2006)[c]
7	31.4	29.6	31.2	0.35	4.09	29.4	0.481	0.205	53	Commercial feed, CP 50%, CF 21%	Autumn/22	Mnari et al. (2007)
24	20.5	19.4	29.5	0.01	2.0	24.2	0.221	0.178	279	Commercial feed, CP 53%, CF 23%	Febr./15	Senso et al. (2007)
24	20.3	30.7	26.2	0.07	1.6	19.4	0.210	0.188	298		Apr./18	
24	22.7	23.0	35.3	0.01	2.6	30.2	0.268	0.170	274		June/21	
24	18.0	27.6	28.3	0.25	2.0	20.6	0.255	0.162	261		Aug./24	
24	19.4	27.1	26.6	0.42	3.2	22.1	0.285	0.190	314		Oct./20	
24	18.4	21.9	37.4	0.17	3.6	31.3	0.225	0.137	266		Dec./16	
Wild												
	34.5	27.5	28.7	0.40	3.09	24.6	0.603	0.313	373		December	Grigorakis et al. (2002)
3	28.3	23.9	32.6	0.15	3.75	32.6	0.411	0.250	233		May	Saglik et al. (2003)[a]
3	27.4	28.5	22.2	0.35	2.63	20.8	0.729	0283	113		November	Ozyurt et al. (2005)
3	22.3	28.4	19.8	0.33	2.26	18.9	0.326	0.249			February	
3	32.7	28.5	15.3	0.55	3.75	14.7	0.566	0.452			April	
3	32.2	26.1	12.1	0.60	1.91	11.3	0.662	0.489			July	
15	34.4	27.2	19.1	0.80	1.02	16.4	0.415	0.355	42		Autumn/25	Mnari et al. (2007)
AVG[d] C	23.3	27.9	26.6	0.38	2.39	21.2	0.323 a	0.212a				
SD	4.34	5.04	5.83	0.29	0.86	6.21	0.156	0.081				
AVG W	24.9	27.8	19.6	0.45	2.73	18.1	0.577 b	0.357 b				
SD	4.48	1.68	7.20	0.21	1.00	7.05	0.149	0.096				

CP: dietary protein content, CF: dietary fat content.

Different letters denote statistical significant difference between weighed average ($P<0.05$).

[a] Calculated by the data provided in the respective reference (neutral and polar lipid percentages and the respective fatty acid profiles for Almansa et al., 2001; total lipid content and individual f.a. contents in g/100 g tissue in Saglik et al., 2003).

[b] Calculated from the polar, neutral lipid percentages.

[c] Calculated by the dorsal and ventral yields and the respective fatty acid percentages.

[d] The values from the fish oil replaced dietary groups are not included in the weighed average calculation.

Table 6
Fatty acid composition of sea bass, *Dicentrarchus labrax*: literature values and weighed averages (AVG) and standard deviations (SD) for cultured (C) and wild (W) fish

No. of individuals analyzed	Fatty acid composition						Atherogenic Index	Thrombogenic index	Body weight (g)	Diet characteristics/ notes (protein/fat, feed. intensity % body weight)	Season/ temperature °C	Reference
	Saturated %	Monounsat. %	*n*-3 Polyunsat %	EPA/ DHA	*n*-3/*n*-6	EPA+DHA %						
Cultured												
3	28.4	36.5	26.06	0.55	2.77	21.7	0.467	0.260	80	1+ age commercial diet		Nicolosi Asmundo et al. (1993)
3	29.4	31.1	30.68	0.46	3.25	26.8	0.446	0.244	250	2+ twice a day		
3	32.7	30.9	28.49	0.46	3.29	24.9	0.562	0.290	>300	3+ 2% of body weight		
5	72.7	11.5	10.9	0.43					171	Com. CP/CF 49/8%, *ad lib*., twice a day	Sept–Nov	Krajnovic-Ozretic et al. (1994)
5	48.2	24.9	7.69	2.00					144	Com. CP/CF 50/10%, *ad lib*., twice a day		
5	50.8	28.8	7.17	4.04					153	Com. CP/CF 48/9%, *ad lib*., twice a day		
3	34.5	25.9	29.2	0.41	2.78	28.4	0.328	0.264	150–	Non-fasted		Delgado et al. (1994)
3	28.5	30.9	25.7	0.47	1.78	22.6	0.289	0.271	250	2 month fasting		
4	24.2	34.7	24.6	0.80	1.5	23.0	0.478	0.240		Com. feed CP 48.6%/ CF 20%, 0.6% body weight	September	Amerio et al. (1996)
14	29.0	39.9	19.0	0.80	1.7	14.8	0.500	0.326	310	21.5% NFE, 11% CF	22	Lanari et al. (1999)
14	28.8	40.6	19.8	0.77	2.0	15.4	0.515	0.319	299	21.5% NFE, 15% CF	22	
14	27.5	38.9	22.2	0.84	2.1	17.1	0.490	0.281	342	21.5% NFE, 19% CF	22	
14	30.7	42.6	16.4	0.77	1.7	13.1	0.525	0.382	303	28.5% NFE, 11% CF	22	
14	28.8	41.3	19.3	0.79	2.0	15.0	0.502	0.322	306	28.5% NFE, 15% CF	22	
14	26.8	38.6	24.1	0.88	2.6	18.4	0.477	0.258	338	28.5% NFE, 19% CF	22	
8	28.0	26.2	38.7	0.78	6.56	32.1				27.5% CF	–/18.2–26.3	Pirini et al. (2000)
3	29.2	34.6	26.8	0.33	2.88	24.1	0.465	0.267	224		May/18–19	Alasalvar et al. (2002)
3	28.4	34.6	16.8	0.64	1.14	22.9	0.455	0.364	286	Commercial diet	May	Saglik et al. (2003)
3	25.3	26.5	35.0	0.47	5.83	29.8	0.631	0.205	442	Fish oil	20	Mourente et al. (2005)
3	19.8	43.0	20.0	0.53	1.94	14.4	0.348	0.186	430	60% rapeseed oil	20	
3	21.5	31.9	31.9	0.40	4.09	20.1	0.314	0.139	434	60% linseed oil	20	

3	24.1	38.7	23.7	0.49	2.89	19.2	0.441	0.208	405	60% olive oil	20	
3	31.3	31.9	28.4	0.65	4.2	23.3	0.623	0.279	378	Fish oil, 3 times a day, 6 days/week	17.8–22.8	Montero et al. (2005)
3	27.8	31.2	19.4	0.52	0.9	14.3	0.432	0.315	372	60% soybean oil, 3 times a day, 6 days/wk		
3	26.6	43.3	18.6	0.55	1.8	13.6	0.439	0.306	356	60% rapeseed oil, 3 times a day, 6 days/wk		
3	32.1	30.9	27.2	0.55	3.1	11.9	0.526	0.301	358	60% linseed oil, 3 times a day, 6 days/wk		
3	24.1	28.9	35.1	0.49	3.2	12.1	0.353	0.184	366	80% linseed oil, 3 times a day, 6 days/wk		
11	27.4	41.6	29.0		3.49		0.561	0.235		CP 48%, CF 14%, *ad libitum*		Periago et al. (2005)
5	27.5	35.8	24.8	0.53	3.51	20.6	0.524	0.264	226			Testi et al. (2006)[a]
Wild												
5	31.1	23.2	44.0	0.57		31.2	0.353		239			Krajnovic-Ozretic et al. (1994)
3	33.4	19.4	35.6	0.54	3.02	30.1	0.434	0.259	203		May/18.5	Alasalvar et al. (2002)
3	43.3	30.0	18.3	0.57	3.67	18.3	0.785	0.570	243		May	Saglik et al. (2003)
15	28.3	24.9	39.8	0.51	5.79	34.4			388	2 years old Tyrrhenian sea		Passi et al. (2004)[b]
15	27.9	25.9	39.1	0.45	5.54	36.7			1217	5 years old		
14	25.7	37.6	28.3		2.11		0.475	0.229	365		March	Periago et al. (2005)
2	34.0	23.9	9.4	0.79	0.92	8.70	0.785	0.705	354	NE Mediterranean	November	Ozyurt and Polat (2006)
2	27.1	30.7	14.8	0.72	2.01	13.0	0.547	0.372	350		February	
2	29.7	31.5	21.9	0.50	2.20	20.7	0.550	0.307	352		April	
2	27.3	31.7	20.7	0.52	2.48	19.3	0.552	0.313	344		July	
AVG[c] C	31.3	36.0	22.2	0.87	2.87	20.7	0.483	0.284 a				
SD	10.29	7.03	7.67	0.70	1.32	5.68	0.090	0.060				
AVG W	29.8	31.1	27.6	0.56	2.32	20.8	0.513	0.325 [c]				
SD	5.65	5.87	11.33	0.11	0.86	7.65	0.15	0.18				

CP: dietary protein content, CF: dietary fat content.

[a] Calculated by the dorsal and ventral yields and the respective fatty acid percentages.

[b] Calculated by the data provided in the respective reference (neutral and polar lipid percentages and the respective fatty acid profiles).

[c] The values from the fish oil replaced dietary groups are not included in the weighed average calculation.

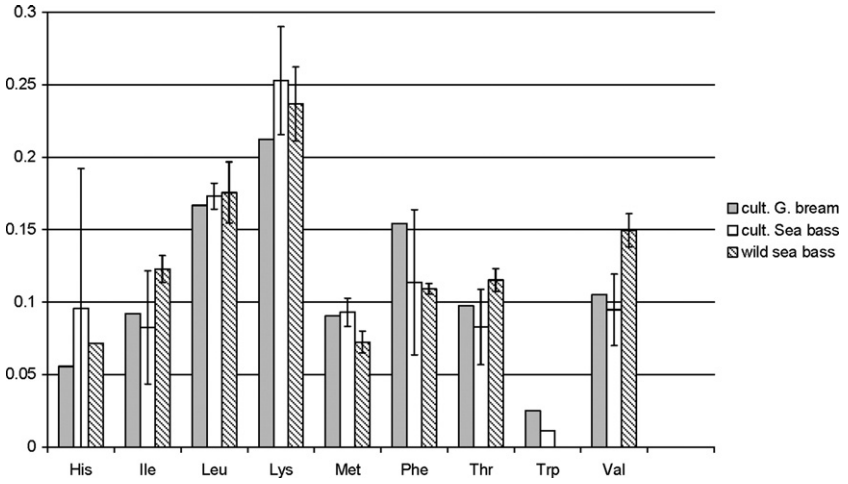

Fig. 1. A/E ratios for cultured gilthead sea bream and wild and cultured sea bass. Means are weighed averages of values calculated from amino acid contents provided by the literature. Sources: Nicolosi Asmundo et al. (1993): cultured sea bass, $n=6$; Amerio et al. (1996): cultured sea bass, $n=4$, and cultured gilthead sea bream, $n=4$; Beklevik et al. (2005): wild sea bass, $n=4$; Ozyurt and Polat (2006): wild sea bass, $n=12$. Bars represent standard deviations of the literature means.

SO and linolenic acid in LO inclusions (Izquierdo et al., 2003, 2005; Montero et al., 2005). Also reduction of muscle saturated fatty acids in both sea bass and gilthead sea bream have been observed due to dietary saturated fatty acids reduction by the inclusion of vegetable oils (Izquierdo et al., 2003).

The knowledge of the impacts of various finishing diets on the quality of gilthead bream and sea bass is limited into the studies of re-feeding with fish oil containing diets, for periods of 60–150 d, fish that previously received plant oil containing diets. Recovery was effective after 90 days for all flesh fatty acids, except in the case of eicosapentaenoic acid (EPA) which seems to be the limiting factor. (Izquierdo et al., 2005; Montero et al., 2005; Mourente et al., 2005).

Muscle fatty acid mobilization during long fasting (2 months) has been studied only in sea bass (Delgado et al., 1994) and a reduction in saturated fatty acids (particularly 17:0) maintenance of total unsaturated fatty acids but reduction of EPA, and appearance of 20:2 as a product of elongation of 18:2 is showed.

Two tail Pearson correlation when conducted for the available fatty acid data (listed in Tables 5 and 6) provided by the literature, showed significant correlations between dietary fat and *n*-3 fatty acids for so gilthead sea bream ($r=0.711$, $P<0.05$) as for sea bass ($r=0.884$, $P<0.01$). Dietary fat also correlated with the sum of EPA and DHA in gilthead bream ($r=0.696$, $P<0.05$) and sea bass ($r=0.911$, $P<0.01$), but also negatively correlated with total saturates in sea bass ($r=-0.643$, $P<0.05$). The former results potentially indicate a preferential deposition for certain fatty acids, but it would be of interest, this speculation to be experimentally confirmed.

Factors other than dietary may influence the muscle fatty acid profile. Gonadal maturation/spawning for gilthead bream has a significant impact in muscle fatty acids (Almansa et al., 2001). On the other hand differentiations in muscle fatty acid pattern was observed in some cases but not in other with age in sea bass. In specifically, Nicolosi Asmundo et al. (1993) mentioned gradual increase of saturated fatty acids with age, and increase of EPA and DHA in the age of 2 years (total weight 250 g) when compared with 1 year old fish (80 g). Some contradicting results (Poli et al., 2001) showed, increase of indexes of atherogeneity from 0.40 and thrombogeneity from 0.16 in 350 g fish to 0.57 and 0.27

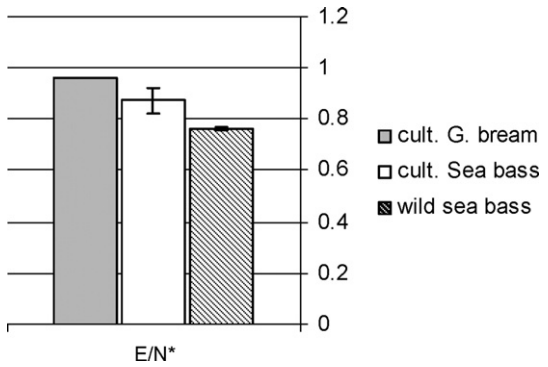

Fig. 2. The E/N ratios in cultured gilthead sea bream and in cultured and wild sea bass, calculated from the literature. The sources are the same with those mentioned in Fig. 1. Bars represent standard deviations.

respectively in 930 g fish, thus indicating increasing trends for saturated fatty acids and/or decreasing of polyunsaturated ones. Passi et al. (2004) observed no differences in fatty acid pattern among 1 year old (64 g), 3 years old (388 g) and 5 years old (1217 g) sea bass. Statistical analysis of present literature data in sea bass showed also positive correlation of weight with total EPA and DHA levels ($r=0.441$, $P<0.05$) and *n*-3/*n*-6 ratio ($r=0.501$, $P<0.05$). Age or size impacts may be a complex effect, since factors associated with growth, and therefore with age, interfere that may modify fatty acid pattern are the feed utilization, hormone production and general metabolism changes (Passi et al., 2004).

Moreover, environmental factors including salinity and water temperature have been shown to influence the fatty acid composition (Cordier et al., 2002; Ibarz et al., 2005). In gilthead sea bream increase of unsaturation in muscle polar lipids (EPA and DHA in particular) has been related to cold acclimation from 18 to 8 °C irrespectively to the temperature drop rate (Ibarz et al., 2005). In cultured sea bass, increase of salinity was negatively correlated with 22:6*n*-3 concentration in muscle polar lipids, while annual changes of 20:5*n*-3/20:4*n*-6 ratio were observed linked to water temperature. (Cordier et al., 2002).

Concerning the factors influencing the muscle amino acids in the Mediterranean fish species, very little data are available. In sea bass, muscle amino acid profile seemed to change with fish size (Nicolosi Asmundo et al., 1993), while seasonal alterations have been observed in their wild counterparts (Ozyurt and Polat, 2006). Dietary impacts on muscle amino acids, as well as on muscle free amino acids, which are major taste and flavour contributors, have been mentioned for salmonids (Mente et al., 2003; Sunde et al., 2004; Yamamoto et al., 2004, 2005). The only respective research in gilthead sea bream, referred to juvenile fish and indicated muscle free amino acid pool increase by more dietary plant protein supply (Gomez-Requeni et al., 2004). From the general lack of data regarding the muscle amino acids of commercially sized bream and bass and the factors affecting them, it becomes obvious that further research is required on this direction.

It must be additionally said, that compositional traits (i.e. muscle proximate and fatty acid composition) vary significantly within the parts of same fillet, as it was shown by the differences found in dorsal and ventral fillet parts for both gilthead sea bream and sea bass (Testi et al., 2006; Mnari et al., 2007). The most pronounced among these differences was the fat content that is almost two and three times higher in ventral part of gilthead bream (Testi et al., 2006; Mnari et al., 2007) and sea bass (Testi et al., 2006), respectively. Furthermore, different muscle cellularity was found within sea bass fillet, with cranial musculature (measured at cross-section in the fourth radius of dorsal fin) exhibiting higher white muscle total cross-sectional area than the caudal one (anal opening) (Abdel et al., 2005). These fat and musculature differences within the same fillet are important since they may impact the results in the various studies, depending on whether muscle analyzes took place in the whole homogenized fillet or at a certain fillet point). Due to these compositional and structural differences, organoleptic properties may be variable within the fillet.

3. Nutritional quality

The protective role of fish consumption against coronary heart diseases has been widely demonstrated and has been mainly attributed to the effects of *n*-3 fatty acids and their cardioprotective action (Kris-Etherton et al., 2003; Psota et al., 2006).

The atherogenic index (AI), calculated as weighed average from the literature data, was 0.324 for cultured gilthead sea bream and 0.577 for wild counterparts (Amerio et al., 1996; Orban et al., 1996; Grigorakis et al., 2002; Saglik et al., 2003; Ibarz et al., 2005; Izquierdo et al., 2005; Ozyurt et al., 2005; Mnari et al., 2007; Senso et al., 2007). The respective values for thrombogenic index (TI) were 0.212 for cultured and 0.357 for wild gilthead bream (Amerio et al., 1996; Grigorakis et al., 2002; Saglik et al., 2003; Ibarz et al., 2005; Izquierdo et al., 2005; Ozyurt et al., 2005; Mnari et al., 2007; Senso et al., 2007). AI and TI in wild counterparts were significantly higher (Table 5).

In cultured and wild sea bass, AI was calculated to be 0.501 and 0.513 and TI 0.333 and 0.324, respectively (Nicolosi Asmundo et al., 1993; Delgado et al., 1994; Amerio et al., 1996; Lanari et al., 1999; Alasalvar et al., 2002; Saglik et al., 2003; Passi et al., 2004; Mourente et al., 2005; Montero et al., 2005; Ozyurt and Polat, 2006; Periago et al., 2005; Testi et al., 2006). No significant differences occurred between the two counterparts.

Factors that affect AI and TI are those that affect the fatty acid profile and have been discussed in detail above.

The *n*-3 polyunsaturated fatty acid contents and the atherogenic and thrombogenic indexes of fish muscle give a picture of its nutritional quality, but are not adequate by themselves. Additional knowledge of other parameters may be needed to describe the nutritional value of fish lipids, since the mechanism of atherosclerosis seems to be complicated, and some theories exist for its explanation (Nasopoulou et al., 2007).

Low density lipoprotein (LDL) and platelet activating factor (PAF), an LDL oxidation product, induce inflammatory response leading to atherogenesis (Steinberg, 1997; Nasopoulou et al., 2007). The presence of PAF antagonists may explain the beneficial effects of certain food. In various fish, both PAF like and anti-PAF activities in have been demonstrated and differ between fish species. Additionally, farmed species exhibited strong aggregatory biological activities, whereas the open sea species showed mainly inhibitory (anti-PAF) activities. (Nomikos et al., 2006).

In a study comparing the biological activities of wild and cultured gilthead sea bream and sea bass, Nasopoulou et al. (2007) found that the total lipids of wild sea bass had a bimodal effect on platelets, inhibiting aggregation at low concentrations and inducing it at higher concentrations. Wild sea bass also showed similar biological activities. Former scientists demonstrated strong anti-PAF activities for neutral lipid fraction of wild gilthead sea bream and cultured sea bass and for polar lipids of cultured sea bass. They however, concluded that the presence of compounds with PAF-like activities in polar lipids from wild bream and bass may also be beneficial, on the basis of their action as weak PAF agonists that compete with PAF for common binding sites during the formation of atheromatic plaque in blood arteries and thus actually acting as PAF inhibitors.

Elucidation of structure of wild and cultured fish active compounds and their further examination *in vivo* is required in order to have a more clear view of how bream and bass lipids actually act for human health. Furthermore, a correlation of activity differences between wild and cultured fish with nutrition differences would be useful.

4. External appearance and organoleptic characteristics

External appearance reflects in some degree the life history of the fish in gilthead sea bream. Wild gilthead sea bream showed significantly different somatometry than farmed individuals exhibiting lower body height, sharper snout and being more spindle-shaped with smaller belly and sharper dorsal fins (Alasalvar et al., 2002; Grigorakis et al., 2002). Also, wild counterparts showed different coloration, having a more bleached appearance and species characteristic colors, and also appears to have thinner skin with scales and bigger sharper teeth (Grigorakis et al., 2002). Significant differences have also been observed in external smell with wild fish having a softer smell (Grigorakis et al., 2002). Flos et al. (2002) showed that gilthead sea bream cultured under semi-intensive conditions, showed significant external similarities with wild fish rather than intensively cultured fish that showed a more compact shape i.e. being shorter, wider and higher. In sea bass, external differences among wild and cultured fish are not so pronounced, and identification can not be relied on shape, color or general appearance (Eaton, 1996).

The shape differences in various gilthead sea bream groups bring forward the importance of condition index, as a measurement of body shape and as a good indicator of dietary condition and history. A condition index increase with intensification of culture has been observed for gilthead bream (Francescon et al., 1988; Sañudo et al., 1993; Flos et al., 2002), while condition index reduces during food deprivation for both gilthead bream (Grigorakis and Alexis, 2005) and sea bass (Stirling, 1976; Echevarria et al., 1997). Furthermore, strong correlation ($P<0.01$) of condition index with deposit fat has been shown in gilthead bream (Grigorakis and Alexis, 2005).

However, body shape and existence of scales seem to be strongly affected by culturing conditions, in particular by stocking density and therefore they are related to the movement ability of fish, further to the feeding strategy (Hurtado et al., 2006; Anastasiou, personal communication; Kyriakakos, personal communication). Body shape also was found significantly differentiated for cultured gilthead sea bream purchased from different hatcheries and raised under the same conditions up to commercial sizes (Loy et al., 1999), thus indicating significant genetic influence as well as a significant effect of larval and post-larval rearing conditions.

Skin and muscle coloration of sea bream have also received some attention. Skin pigmentation in gilthead sea bream has been related to various sources of carotenoid (Gomes et al., 2002; Gouveia et al., 2002). Flos et al. (2002) found that semi-intensive produced fish showed a coloration similar to that found in wild fish and related that to the access of fish to natural food rather than to the commercial feed received (Flos et al., 2002). Coloration change, and in particular bleaching of skin has been observed in gilthead bream when going through fasting (Gines et al., 2002; Grigorakis and Alexis, 2005).

Muscle coloration on the other hand does not seem to be affected by dietary carotenoids, since there is no evidence of their incorporation in the muscle (Gouveia et al., 2002). Color of the muscle seem to be strongly related to its fat content, with increased muscle fat resulting to whiter muscle color (Grigorakis et al., 2003). Colorimetric measurements for both sea bass and gilthead bream muscle have revealed color differentiation for fish

fed with linseed oil substituted diet comparing to fish oil containing diet, although organoleptic evaluation failed to detect these differences (Montero et al., 2005; Izquierdo et al., 2005).

Wild gilthead sea bream were found to have significant organoleptic differences compared to their cultured counterparts with results indicating a superiority of the wild fish (Grigorakis et al., 2004). Assessors distinguished between wild and cultured fish in a forced choice triangle test. They described wild fish as having more pleasant taste and firmer texture and cultured fish of poorer taste. Although no organoleptic comparison has been mentioned between wild and cultured sea bass, instrumental texture measurement has similarly shown a firmer texture in wild fish (Periago et al., 2005).

Furthermore, organoleptic differences have been described between the muscle of extensively and intensively cultured gilthead sea bream (Orban et al., 1996). These differences consist of higher fatness, juiciness and fresh fish flavour, and lower fibrousness in intensively cultured fish.

Fatness and juiciness have both positively correlated with fat content in tissue (Dunajki, 1979; Venugopal and Shahidi, 1996; Einen and Thomassen, 1998; Izquierdo et al., 2003; Grigorakis et al., 2004), while concerning taste and flavour, fishy descriptors have also been attributed to higher fat content. Fatty fish give a smooth and succulent ("juicy") mouth sensation, while less fatty fish give a more dry/fibrous mouth sensation (Love, 1992). Thus, the muscle juiciness depends on the muscle fat content rather than moisture content.

A better, more delicate taste found in wild gilthead bream can be possibly related to the higher number of volatile flavour-contributing compounds observed (Grigorakis et al., 2004; Alasalvar et al., 2005). Also flesh lipid contribution in taste/flavour is important, because lipids themselves have a slight taste, and unsaturated fatty acids are important precursors of volatile flavour compounds.

Organoleptic quality of gilthead sea bream and sea bass has been found to be influenced by their dietary history (Izquierdo et al., 2003, 2005; Lopparelli et al., 2004; Montero et al., 2005). Two sea bass groups having fed different fat levels showed differences in muscle fat (7.7% in low fat group vs. 8.9% in high fat group) and subsequently in organoleptic properties, with high fat group exhibiting significantly higher juiciness and tenderness (Lopparelli et al., 2004).

Partial inclusion of vegetable lipid sources showed slight influences in organoleptic properties like stronger smell and taste in soybean oil fed gilthead sea bream and increase of juiciness and reduction of hardness in vegetable oil received fish groups (Izquierdo et al., 2003, 2005). Substitution of fish oil with soybean oil in sea bass indicated some differentiation in odour and flavour, although this effect was not statistically significant (Montero et al., 2005). Although these organoleptic changes due to dietary oil substitution are of small intensity, they indicate that a special attention should be given to them, as under circumstances they can become important.

5. Concluding remarks

The review of the published data showed that differences occur between wild and cultured fish in the two studied species. Furthermore, differences between individuals obtained from different culture systems, reveal the general impact of the life history of the fish in its final quality attributes.

A better understanding of the impacts of different factors (water temperature, feeding ratio, feed composition, fish size), would have been achieved if there was a possibility of using Principle Component Analysis (PCA) in the statistical process. This would enable to outline the most significant parameters for each of the studied fish quality parameter. Nevertheless, this was not possible due to sporadic existence of the required data that does not create adequate cases to conduct PCA.

From the fact that differences between wild and cultured fish are more pronounced in gilthead sea bream than in sea bass, including fat, moisture, nutritional quality (AI, TI) and sensory differences, it can possibly concluded that sea bass is better adopted to the commercial feeding than the gilthead sea bream. This is probably due to the fact that artificial diets are closer to the sea bass nutritional needs. The latter can be supported considering that basic constituents of diets are fish oil and fishmeal, and in nature sea bass of commercial sizes exhibits carnivorous, fish consuming habits (Kelley, 1987; Costa, 1988; Kara and Derbal, 1996; Pusineri et al., 2004), while gilthead bream exhibits more omnivorous trends and consumes primarily mollusks (gastropods and bivalves) and carcinoids (Pita et al., 2002; Gamito et al., 2003; Tancioni et al., 2003).

The substitution of dietary fish oil, being a future necessity in aquaculture, showed alterations of muscle fatty acid profile depending on the plant oil fed to the fish. The administration of fish oil finishing diets showed adequate muscle fatty acid recovery in the, but not in the case of eicosapentaenoic, which levels remained low, and this seem to be the major problem in substitutions based on the nutritional importance of this

fatty acid. Therefore, future research in substitutions should focus on preventing initial decrease of EPA or overcoming its recovery problem.

Beyond the atherogenic and thrombogenic indexes and the contents of *n*-3 unsaturated fatty acids that consist valuable indicators of nutritional quality, initial results showed the significance of the nature of biological activities of fish lipids, i.e. whether they induce or inhibit aggregation of platelets. Nevertheless, further investigation is required for both the exact mechanisms, as well as the dietary effects on the lipid activities.

External differences are pronounced only between wild and cultured gilthead sea bream, mainly in color, shape scales existence and teeth morphology. Regarding the organoleptic quality of gilthead bream and sea bass, the total lipid contents of the muscle as well as the volatile taste and flavor-contributing compounds seem to be the most important mouth impression contributors. There is serious evidence that life history and dietary characteristics have important significance through their impact on these factors. More systematic knowledge is required on understanding the chemical basis of taste and flavour of gilthead sea bream and sea bass in order to illustrate the exact dietary impacts.

In some cases, divergences occur in the results of comparable experiments, but this can be justified through the very complex series of factors interfering and affecting quality of sea bass and gilthead bream. Beyond dietary factors, water temperature and fish weight have a great impact on quality parameters, as already discussed, while genetic factors seem to have a significant interference (as it can be assumed by high inter-individual variations observed by the majority of the literature). At present selection and strains development in sea bass and gilthead sea bream occurs only recently and focused on growth and survival performance (Knibb et al., 1998; Gorshkov et al., 2002), but genetic selection for quality parameters would help to examine the exact impact of genetic factor and the heritability of quality attributes.

Generally, manipulation of quality through feeding can be achieved, as shown by the fact that general improvement of feeding strategy has lead to improvement of gilthead bream and sea bass quality at least in aspects of muscle fat deposition (Foundoulaki et al., 2003).

Appendix A

All average values derived from the existing literature and were calculated as weighted means from the values obtained from the various references, taking into account the number of individuals analyzed in each study.

Some important indexes that describe the nutritional value of fish have been determined by using the collective data from the existing literature. These included the atherogenic index (AI), which is a measure of the ability to reduce blood lipid content, and thrombogenic index (TI), which is a measure of the ability to reduce platelet activity. Atherogenic and Thrombogenic indexes were calculated according to Ulbricht and Southgate (1991) as following: $AI = (12:0 + 4 \times 14:0 + 16:0)/(\text{Sum MUFAs} + \text{Sum PUFAs})$ and $TI = (14:0 + 16:0 + 18:0)/[0.5 \times \text{Sum MUFAs} + 0.5 \times \text{Sum } (n\text{-}6) \text{ PUFAs} + 3 \times \text{Sum } (n\text{-}3) \text{ PUFAs} + (n\text{-}3/n\text{-}6)]$, where MUFAs the monounsaturated fatty acids and PUFAs the polyunsaturated fatty acids.

For the evaluation of the fish protein quality the following indexes have been calculated: A/E ratio (the ratios of the contents of individual essential amino acids to the total essential amino acids content) and E/N ratio (molar ratio of essential to non essential amino acids).

Independent *t*-test was used for comparisons of quality parameters between wild and cultured counterparts, while in cases comparisons included intensively cultured, extensively cultured and wild fish one way ANOVA was used. Confidence levels in all cases were set at 95%. Parameters were correlated with each other by two tailed significance correlation.

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