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Nutritional Value of Gilthead Sea Bream and Sea Bass

Constantina Nasopoulou[1] • Haralabos C. Karantonis[2] • Ioannis Zabetakis[1*]

[1] Laboratory of Food Chemistry, Department of Chemistry, National and Kapodistrian University of Athens, Panepistimioupolis, 157-71 Athens, Greece
[2] Department of Science of Food and Nutrition, School of the Environment, University of the Aegean, 2 Metropoliti Ioakim Str., 814-00, Myrina, Lemnos, Greece

***Corresponding author*: * izabet@chem.uoa.gr**

ABSTRACT

Fish and fish oil have a high nutritional value and protect against cardiovascular diseases. Given the intrinsic difficulties in sustaining the availability of wild fish, the industry has moved, over the past three decades, towards establishing aquaculture units where fish are produced under controlled conditions. Sea bass (*Dicentrarchus labrax*) and gilthead sea bream (*Sparus aurata*) are the two most commercial aqua cultured species in Europe. In this mini review, the studies of the nutritional value of these two species are evaluated in terms of contents of ω-3 fatty acids and micro constituents of fish lipids with a particular focus on their ability to inhibit or not the initiation of atherogenesis. Platelet Activating Factor (PAF), a key trigger molecule in atherogenesis, and PAF antagonists, that are present in fish, play a crucial role in inhibiting the formation of atheromatic lesions. The diet of aqua cultured fish is also evaluated for its contents of ω-3 fatty acids and its capacity to inhibit PAF activity. New trends are presented towards modifying this diet to produce fish with a higher nutritional value.

Keywords: Farmed fish, ω-3 fatty acids, micro constituents, antiatherogenic properties

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INTRODUCTION

Consumers consider organoleptic properties (e.g. flavour and texture), freshness and nutritional value as the main signs of quality when selecting fish. The nutritional value of fish is directly related to its chemical composition that is dependant upon many factors such as species, age, size (Iverson *et al.* 2002; Grigorakis 2007), sex, spawning (Grigorakis 2007), environmental factors such as season (Grun *et al.* 1999; Iverson *et al.* 2002), water temperature (Grigorakis 2007), salinity (Roche *et al.* 1989), changes in photoperiod (Gines *et al.* 2004), geographical origin (Nettleton 1985; Ackman 1989; Saito *et al.* 1999) and feeding history especially concerning farmed fish (diet composition and feeding ratio) (Huss 1988). Fish flesh flavour depends on fish tissue composition and also on harvesting and handling methods. For instance fatness and juiciness of fish flesh have both positively correlated with fat content in tissue (Izquierdo *et al.* 2003; Grigorakis *et al.* 2004). Furthermore, organoleptic differences have been described between the muscle textures of extensively and intensively farmed gilthead sea bream (Orban *et al.* 1996). These differences consist of higher fatness, juiciness and fresh fish flavour, and lower fibrousness in intensively farmed fish.

The main source of ω-3 polyunsaturated fatty acids (PUFAs) within our diet is from fish and fish oils, this is especially true for eicosapentaenoic acid (EPA) (20:5 ω-3) and docosahexaenoic acid (DHA) (22:6 ω-3) whose presence is 10-100 greater in marine oil than in fruits, vegetables, flaxy seeds, walnuts, and other vegetables (Simopoulos *et al.* 2000; Chen *et al.* 2003; Solfrizzi *et al.* 2005). Several studies demonstrated that fish oils actively benefit the symptoms of certain diseases such as cardiovascular diseases (Dyerberg *et al.* 1978, 1979; Simopoulos *et al.* 1997), cancer (Terry *et al.* 2001), arthritis rheumatoid (James *et al.* 1997), diabetes II (Salmeron *et al.* 2001), neuropsychiatric diseases such as depression (Adams *et al.* 1996), maniodepression (Stoll *et al.* 1999) and schizophrenia (Richardson *et al.* 2000). The nutritional value and the ω-3 fatty acids contents of several fish species, such as Atlantic salmon (*Salmo salar* L.), Atlantic cod (*Gadus morhua* L.), Atlantic herring (*Clupea harengus*) (Shearer 1994; Krogdahl *et al.* 2004), gilthead sea bream (*Sparus aurata*), sea bass (*Dicentrarchus labrax*) (Grigorakis 2007) and fresh water fish (Pickova *et al.* 2009) have been reviewed in other publications. Fish lipids also contain some micro constituents such as selenium and α-tocopherol, whose beneficial effect has been attributed to their ability to act as antioxidants in humans (de Lorgeril *et al.* 2001), and platelet activity factor (PAF, 1-*O*-alkyl-2-acetyl-sn-glyceryl-3-phosphocholine) antagonists, that possess antiatherogenic properties. In other words, these PAF antagonists inhibit the

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Invited Review

formation of atheromatic plaque, i.e. the narrowing of human's arteries.

Studies have shown that ω-3 fatty acids of marine origin inhibit platelet reactivity and thrombosis but only when in very high doses (Mori *et al.* 1997; Kristensen *et al.* 2001). Apart from marine ω-3 fatty acids, the beneficial effects of fish consumption on thrombosis and cardiovascular disease may also be attributed to other lipid micro constituents that antagonize PAF which is a strong lipid mediator of thrombosis and inflammation (Nasopoulou *et al.* 2007). Synergistic activity of lipid micro constituents that antagonize PAF (including ω-3 fatty acids) is an issue that has to be studied in the near future. PAF is a crucial inflammatory phospholipids mediator (Demopoulos *et al.* 1979), that is implicated in many pathological conditions such as atherogenesis (Demopoulos *et al.* 2003), cancer (Tsoupras *et al.* 2009), and allergies (Kajiwara *et al.* 2008). The presence of PAF antagonists in fish lipids reinforces their cardioprotective effect, and the mechanistic activity of PAF and PAF antagonists was described in detail by Demopoulos *et al.* (2003).

Aquaculture farms are located all across Europe: from the Mediterranean in the south, to the Arctic Circle in the north. Three species of fish have dominated the aquaculture industry in Europe: Atlantic salmon (540,000 tonnes in 1999), sea bass and gilthead sea bream (87,000 tonnes combined in 1999) (Shields *et al.* 2001). Atlantic salmon is cultured mainly in northern Europe, meanwhile sea bass and gilthead sea bream in southern Europe (Shields *et al.* 2001; Alasalvar *et al.* 2002; Holmer *et al.* 2003). Market demand (and, as result, the price) for fresh sea bass has increased over the past decade due to the desirable flavour and quality attributes of this fish (Holmer *et al.* 2003).

The aim of the present study is to review and discuss the existing knowledge regarding the nutritional value of farmed gilthead sea bream and sea bass in regard to the contents of ω-3 fatty acids and micro constituents of fish lipids. The manuscript will also focus on the ability of these compounds to inhibit the initiation of atherogenesis and on how to influence the quality of the fish meat.

COMPOSITION OF MUSCLE, FAT CONTENT, FATTY ACID PROFILE

Skeletal muscle is the largest edible tissue in fish. In marketable gilthead sea bream, the skeletal muscle represents the 34–48% of total body weight (Grigorakis *et al.* 2005; Testi *et al.* 2006) while in sea bass it ranges from 44% (Boujard *et al.* 2004) to 58% (Nicolosi Asmundo *et al.* 1993). Muscle is composed of fat (Liaset *et al.* 2003), proteins, water (Alasalvar *et al.* 2002), inorganic elements (Alasalvar *et al.* 2002), volatile bases such as ammonia, trimethylamin (TMA) and dymethyamin (DMA) (Kyrana *et al.* 2002), trimethylamin oxide (Kyrana *et al.* 2002), free amino acids (Kyrana *et al.* 2002), urea (Lapa-Guimarães *et al.* 2005), vitamins (Espe *et al.* 2001; Brustad *et al.* 2004), carbohydrates (Krogdahl *et al.* 2004) and volatile compounds such as alcohols, aldehydes, ketones and terpenes (Grigorakis *et al.* 2003). Volatile compounds contribute to the fish aroma. The muscle proximate composition of gilthead sea bream and sea bass focusing on the major com-

Table 1 Proximate composition of gilthead sea bream, *Sparus aurata*: Literature values and weighed averages (AVG) and standard deviations for farmed and wild fish.

No. of individuals analyzed	Body weight (g)	Muscle proximate composition %				Diet characteristics		Season/ temperature (°C)	Reference
		Protein	Fat*	Moisture*	Ash	Dietary Protein %	Dietary fat %		
Farmed fish									
4	500	21.3	6.81	69.9	1.56	49	20	September	Amerio *et al*. 1996
3	410	21.8	7.69	70.3	1.32	45	15		Kyrana *et al*. 1997
6	515	21.1	3.00	73.5	1.40				Huidobro *et al*. 2001
5	318	18.1	9.80	71.2	1.36	45	22	Jan./14	Grigorakis *et al*. 2002
5	320	18.0	6.53	74.7	1.53	45	22	May/19	Grigorakis *et al*. 2002
5	285	18.3	10.4	69.9	1.22	45	22	Aug./25	Grigorakis *et al*. 2002
12	348	20.7	9.36	69.4	1.32	38	20	September	Grigorakis and Alexis 2005
12	337	19.2	9.39	69.5	1.33	45	15		Grigorakis and Alexis 2005
12	349	20.7	9.64	68.8	1.28	51	10		Grigorakis and Alexis 2005
14	303	20.7	7.55	70.0					Vasiliadou *et al*. 2005
5	273	18.8	11.1	68.6	1.26				Testi *et al*. 2006
15	279	19.7	3.40	75.7	1.40	53	23	Feb./15	Senso *et al*. 2007
15	298	19.4	3.70	74.6	1.40	53	23	Apr./18	Senso *et al*. 2007
15	274	19.2	2.50	76.6	1.40	53	23	June/21	Senso *et al*. 2007
15	261	19.8	3.60	75.0	1.40	53	23	Aug./24	Senso *et al*. 2007
15	314	20.0	2.80	75.2	1.50	53	23	Oct./20	Senso *et al*. 2007
15	266	20.2	3.10	75.8	1.40	53	23	Dec./16	Senso *et al*. 2007
3	300-400	17.7	13.3	62.0	4.36	47	18	June-Oct./27	Wassef *et al*. 2009
3	300-400	16.7	12.9	63.6	4.91	46	18	June-Oct./27	Wassef *et al*. 2009
3	300-400	17.3	13.4	62.5	4.12	46	18	June-Oct./27	Wassef *et al*. 2009
9	260	20.3	4.37	73.2	1.58	47	19	Aug./26	Fountoulaki *et al.* 2009
9	259	20.6	4.90	73.0	1.59	47	19	Aug./26	Fountoulaki *et al.* 2009
9	229	20.3	4.15	73.3	1.55	46	19	Aug./26	Fountoulaki *et al.* 2009
9	252	20.5	4.89	72.8	1.54	47	20	Aug./26	Fountoulaki *et al.* 2009
Wild fish									
10	337	21.2	0.92	76.5	1.39			Spring	Flos *et al*. 2002
5	380	20.1	1.16	78.1	1.44			Jan./14	Grigorakis *et al*. 2002
5	502	19.5	0.85	79.9	1.47			May/ 19	Grigorakis *et al*. 2002
3	113	19.8	1.88	75.9	1.28			November	Ozyurt *et al*. 2005
3		19.3	1.59	77.3	1.31			February	Ozyurt *et al*. 2005
3		19.3	2.01	76.4	1.39			April	Ozyurt *et al*. 2005
3		19.9	3.01	75.4	1.37			July	Ozyurt *et al*. 2005
AVG farmed		19.2 ± 1.08	8.05 ± 2.42 a	69.1 ± 2.60 a	2.63 ± 0.94				
AVG wild		19.9 ± 0.66	1.63 ± 0.76 b	77.1 ± 1.53 b	1.38 ± 0.27				

AVG: weighed averages
* Different letters within a column indicate significant differences according to Mann–Whitney U-test ($p < 0.05$).

Table 2 Proximate composition of sea bass, *Dicentrarchus labrax*: Literature values and weighed averages (AVG) and standard deviations for farmed and wild fish.

No. of individuals analyzed	Body weight (g)	Fatty acid composition				Diet characteristics		Season/ temperature (°C)	Reference
		Protein	Fat	Moisture	Ash	Dietary Protein %	Dietary fat %		
Farmed fish									
3	80	21.8	4.85	71.7	1.56				Nicolosi Asmundo *et al*. 1993
3	250	21.4	5.19	72.8	1.39				Nicolosi Asmundo *et al*. 1993
3	>300	20.9	5.73	71.0	1.89				Nicolosi Asmundo *et al*. 1993
4		20.1	7.62	70.9	1.52	49	20	September	Amerio *et al*. 1996
20		21.9	9.20	64.4	1.39	44	28		Gatta *et al*. 2000
3	306		4.90	73.4		52	11		Poli *et al*. 2001
3	296		4.50				11		Poli *et al*. 2001
3	292		4.60				15		Poli *et al*. 2001
3	331		5.50				19		Poli *et al*. 2001
4	224	20.7	5.20	72.2	1.5	46	20	May/18-19	Alasalvar *et al*. 2002
6	302	19.4	4.81	76.7	1.23	48	14		Kyrana and Lougovois 2002
10	349	18.6	4.54	75.2	1.27	45	15	Dec./14	Grigorakis *et al*. 2004
10	236	20.3	3.90	74.4	1.3	45	15	July/25	Grigorakis *et al*. 2004
11	360	23.4	6.66	72.6		48	14		Periago *et al*. 2005
5	226	18.8	7.98	72.6	1.27				Testi *et al*. 2006
9	396	19.10	4.38	74.56	1.21	46	18	June	Fuentes *et al*. 2010
9	401	17.39	4.57	76.70	1.20	48	14	June	Fuentes *et al*. 2010
Wild fish									
3	203	19.2	1.40	75.5	1.5			May/18-19	Alasalvar *et al*. 2002
3		18.7	1.67	77.9	1.11				Ozogult *et al*. 2005
14	365	17.6	9.19	69.5				March	Periago *et al*. 2005
3	354	18.7	2.18	77.3	1.23			November	Ozyurt and Polat 2006
3	350	19.8	1.22	77.4	1.17			February	Ozyurt and Polat 2006
3	352	21.4	6.05	70.8	1.27			April	Ozyurt and Polat 2006
3	344	21.8	5.85	71.0	1.05			July	Ozyurt and Polat 2006
9	439	21.61	1.04	77.49	1.26			June	Fuentes *et al*. 2010
AVG farmed		18.9 ± 1.12	4.88 ± 1.20	75.1 ± 3.10	1.28 ± 0.12				
AVG wild		20.6 ± 1.64	2.49 ± 1.53	75.8 ± 3.78	1.24 ± 0.19				

AVG: weighed averages

ponents, as found in literature, are presented in **Tables 1** and **2**.

In both fish species, gilthead sea bream and sea bass, whether farmed or wild, water was found to be the main component of muscle followed by protein and fat. Farmed gilthead sea bream was found to have significantly higher muscle fat and significantly lower muscle moisture compared to wild counterparts (**Table 1**). In sea bass, unlike gilthead bream, no compositional differences were observed in their muscle fat and moisture (**Table 2**). Deposit fat 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). Protein content in both fish species both farmed and wild do not exhibit significant differences.

Fat

Muscle composition of fresh fish has a major effect on how the fish is orally perceived by the consumer. The lipids of the edible part of the fish are important since they affect the organoleptic characteristics of the fish such as 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). Fish lipids are composed from major and micro lipid constituents. In particular, they contain triacyloglycerols, free fatty acids, cholesterol and traces of phospholipids such as phosphatidylcholine (PC), phosphatidylethanolamine (PE), phosphatidylinositol (PI), phosphatidylserine (PS), sphingomyelin (SM) and cardiolipin (Liaset *et al*. 2003).

Fish fat is located in the liver, muscles, perivisceral and subcutaneous tissues. Fish are classified according to their fat content as lean with less than 1% muscle fat (e.g. sole, gilthead sea bream, cod, perch), intermediate with 5-10% muscle fat (e.g. mackerel, mullet and herring) and fatty with more than 10% muscle fat (e.g. tuna, salmon, sardine and eel) (Corraze *et al.* 1999). Furthermore, flesh lipids are important precursors of flavour compounds since fatty acid autoxidation produces volatile compounds characteristic of the fish flavour (German 1990; Kawai 1996).

Fatty acids

Regarding fatty acid content of gilthead sea bream, the various fatty acid groups such as saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA) did not exhibit significant alternations among wild and farmed counterparts (**Table 3**) (Amerio *et al*. 1996; Grigorakis *et al*. 2002; Ibarz *et al*. 2005; Izquierdo *et al*. 2005; Ozyurt *et al*. 2005; Vasiliadou *et al.* 2005; Testi *et al*. 2006; Mnari *et al*. 2007; Senso *et al.* 2007; Fountoulaki *et al*. 2009; Wassef *et al.* 2009). Although the weighed mean for ω-3/ω-6 ratio and the ω-3 polyunsaturated fatty acids, as weighed mean value, for farmed fish was lower than the one for wild fish and the weighed mean for EPA/DHA ratio higher than those of wild counterparts, significant differences between wild and farmed fish regarding ω-3 fatty acid content and EPA/DHA and ω-3/ω-6 ratios were not observed. In sea bass, both ω-3/ω-6 ratio and the weighed average for ω-3 total amounts exhibited a lower average value for farmed fish (**Table 4**). Both differences were not found statistically significant, although average values differ remarkably (Nicolosi Asmundo *et al*. 1993; Krajnovic-Ozretic *et al*. 1994; Amerio *et al*. 1996; Lanari *et al*. 1999; Alasalvar *et al*. 2002; Saglik *et al*. 2003; Montero *et al*. 2005; Mourente *et al*. 2005; Periago *et al*. 2005; Ozyurt *et al.* 2006; Testi *et al*. 2006; Fuentes *et al*. 2010).

Table 3 Fatty acid composition of gilthead sea bream, *Sparus aurata*: literature values and weighed averages (AVG) and standard deviations for farmed and wild fish.

No. of individuals analyzed	Body weight (g)	Fatty acid composition						Diet characteristics/ culture characteristics	Season/ temp. (°C)	Reference
		Saturated (%)	Monounsaturated (%)	ω-3 Polyunsaturated (%)	EPA/ DHA	ω-3 / ω-6	EPA+ DHA (%)			
Farmed fish										
	550	23.5	34.7	24.2	0.61	1.40	20.7	Commercial diet (49 % protein, 20% fat)	Sept.	Amerio *et al*. 1996
3	450	28.2	37.2	22.8	0.45	1.92	18.4	Commercial diet (45% protein, 22% fat)	Nov. /20	Grigorakis *et al*. 2002
18	464	29.8	36.0	23.4	1.24	3.07	16.4	Fish oil		Izquierdo *et al*. 2005
18	460	25.3	33.1	14.7	0.82	0.58	9.06	60% soybean oil		Izquierdo *et al*. 2005
18	446	22.9	46.3	15.0	0.74	1.04	8.49	60% rapeseed oil		Izquierdo *et al*. 2005
18	459	24.8	33.1	29.3	0.76	2.51	8.08	60% linseed oil		Izquierdo *et al*. 2005
18	441	23.7	32.5	12.9	0.63	0.43	6.32	80% soybean oil		Izquierdo *et al*. 2005
18	440	22.6	31.8	31.5	0.58	2.47	6.31	80% linseed oil		Izquierdo *et al*. 2005
14		26.6	31.8	21.8	0.60	1.70	16.2			Vasiliadou *et al*. 2005
5	99	27.6	32.0	21.0	0.49	1.47	16.0	Commercial diet (47% protein, 21% fat)	18	Ibarz *et al*. 2005
10	87	27.4	32.5	21.4	0.46	1.56	16.7	Gradual temperature reduction (1°C/day)	18→ 8	Ibarz *et al*. 2005
10	89	29.7	32.0	22.6	0.47	1.57	17.9	Sharp temperature reduction	18→ 8	Ibarz *et al*. 2005
5	273	27.0	37.2	22.5	0.46	2.70	17.1			Testi *et al*. 2006
7	53	31.4	29.6	31.2	0.35	4.09	29.4	Commercial diet (50% protein, 21% fat)	Autumn/22	Mnari *et al*. 2007
24	279	20.5	19.4	29.5	0.01	2.00	24.2	Commercial diet (53% protein, 23% fat)	Febr./15	Senso *et al*. 2007
24	298	20.3	30.7	26.2	0.07	1.60	19.4		April/18	Senso *et al*. 2007
24	274	22.7	23.0	35.3	0.01	2.62	30.2		June/21	Senso *et al*. 2007
24	261	18.0	27.6	28.3	0.25	2.04	20.6		Aug./24	Senso *et al*. 2007
24	314	19.4	27.1	26.6	0.4	3.21	22.1		Oct./20	Senso *et al*. 2007
24	266	18.4	21.9	37.4	0.17	3.60	31.3		Dec./16	Senso *et al*. 2007
3	300-400	23.1	51.1	12.8	1.16	4.11	12.3	100% cod liver oil	June-Oct./27	Wassef *et al.* 2009
3	300-400	24.6	16.0	8.94	1.05	3.16	8.43	40% cod liver oil, 60% SO, CO, LO (1:1:1, w/w/w)	June-Oct./27	Wassef *et al.* 2009
3	300-400	26.8	13.9	11.2	1.26	2.90	10.7	40% cod liver oil, 60% SO, CO, SO (1:1:1, w/w/w)	June-Oct./27	Wassef *et al.* 2009
9	260	26.9	30.3	30.8	0.84	2.75	21.7	100% fish oil	Aug./26	Fountoulaki *et al.* 2009
9	259	22.1	27.8	17.6	0.62	0.56	10.5	31% fish oil, 69% SO	Aug./26	Fountoulaki *et al.* 2009
9	229	27.7	39.6	15.7	0.56	0.95	10.9	31% fish oil, 69% PO	Aug./26	Fountoulaki *et al.* 2009
9	252	18.9	45.2	16.3	0.53	0.86	8.93	31% fish oil, 69% RO	Aug./26	Fountoulaki *et al.* 2009
Wild fish										
	373	34.5	27.5	28.7	0.40	3.09	24.6		Dec.	Grigorakis *et al*. 2002
3	113	27.4	28.5	22.2	0.35	2.63	20.8		Nov.	Ozyurt *et al*. 2005
3		22.3	28.4	19.8	0.33	2.26	18.9		February	Ozyurt *et al*. 2005
3		32.7	28.5	15.3	0.55	3.75	14.7		April	Ozyurt *et al*. 2005
3		32.2	26.1	12.1	0.60	1.91	11.3		July	Ozyurt *et al*. 2005
15	42	34.4	27.2	19.1	0.80	1.02	16.4		Autumn/25	Mnari *et al*. 2007
AVG Farmed		24.0 ± 3.83	31.9 ± 6.02	17.3 ± 4.63	0.81 ± 0.73	2.16 ± 1.05	12.6 ± 5.48			
AVG Wild		30.6 ± 4.81	27.7 ± 0.96	19.5 ± 5.74	0.51 ± 0.18	2.44 ± 0.95	17.8 ± 4.70			

AVG: weighed averages; SO: sunflower oil; CO: cottonseed oil; LO: linseed oil; SO: soybean oil; PO: palm oil; RO: rapeseed oil

The main reason explaining the lack of significant differences in the content of fatty acid groups between wild and farmed counterparts for either species is the high standard deviations that reflect the high variability found within the literature. In addition, fatty acid composition in gilthead sea bream (Grigorakis *et al*. 2002; Ozyurt *et al*. 2005; Mnari *et al*. 2007; Senso *et al.* 2007; Fountoulaki *et al.* 2009) and in sea bass (Krajnovic-Ozretic *et al*. 1994; Alasalvar *et al*. 2002; Ozyurt *et al*. 2006; Fuentes *et al.* 2010) was strongly influenced by diet and exhibited seasonal variations, facts that explain and reinforce the high heterogeneity. However, pronounced differences have been observed between wild and farmed counterparts concerning individual fatty acids. The higher levels of linoleic acid (18:2 ω-6) in farmed fish 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; Fuentes *et al.* 2010), have been attributed to the presence of the terrestrial plant-originated 18:2 ω-6 in the feeds but the relative absence in the natural marine food chain. The opposite can be said for the arachidonic acid. Furthermore, the presence of 22:1 ω-11 in much higher quantities in farmed fish in some cases (Grigorakis *et al.* 2002) has been justified by its presence in the dietary fish oils of Northern Atlantic origin (Henderson *et al*. 1987). In

Table 4 Fatty acid composition of sea bass, *Dicentrarchus labrax*: literature values and weighed averages (AVG) and standard deviations for farmed and wild fish.

No. of individuals analyzed	Body weight (g)	Fatty acid composition: Saturated (%)	Monounsaturated (%)	ω-3 Polyunsaturated (%)	EPA/DHA	ω-3 / ω-6	EPA+DHA (%)	Diet characteristics/ culture characteristics	Season/ temp. (°C)	Reference
Farmed fish										
3	80	28.4	36.5	26.1	0.55	2.77	21.7	Commercial diet (1 year old)		Nicolosi Asmundo *et al*. 1993
3	250	29.4	31.1	30.7	0.46	3.25	26.8	Commercial diet twice a day (2 years old)		Nicolosi Asmundo *et al*. 1993
3	>300	32.7	30.9	28.5	0.46	3.29	24.9	Commercial diet 2% of body weight (3 years old)		Nicolosi Asmundo *et al*. 1993
5	171	72.7	11.5	10.9	0.43			Commercial diet (protein/ fat 49/8%) twice a day	Sept.-Nov.	Krajnovic-Ozretic *et al*. 1994
5	144	48.2	24.9	7.69	2.00			Commercial diet (protein/ fat 50/10%) twice a day		Krajnovic-Ozretic *et al*. 1994
5	153	50.8	28.8	7.17	4.04			Commercial diet (protein/ fat 48/9%) twice a day		Krajnovic-Ozretic *et al*. 1994
4		24.2	34.7	24.6	0.80	1.50	23.0	Commercial diet (protein/ fat 49/20%) 0.6% body weight	Sept.	Amerio *et al*. 1996
14	310	29.0	39.9	19.0	0.80	1.70	14.8		22	Lanari *et al*. 1999
14	299	28.8	40.6	19.8	0.77	2.00	15.4		22	Lanari *et al*. 1999
14	342	27.5	38.9	22.2	0.84	2.10	17.1		22	Lanari *et al*. 1999
14	303	30.7	42.6	16.4	0.77	1.70	13.1		22	Lanari *et al*. 1999
14	306	28.8	41.3	19.3	0.79	2.00	15.0		22	Lanari *et al*. 1999
14	338	26.8	38.6	24.1	0.88	2.60	18.4		22	Lanari *et al*. 1999
3	224	29.2	34.6	26.8	0.33	2.88	24.1		May/18-19	Alasalvar *et al*. 2002
3	286	28.4	34.6	16.8	0.64	1.14	22.9	Commercial diet	May	Saglik *et al*. 2003
3	442	25.3	26.5	35.0	0.47	5.83	29.8	Fish oil	20	Mourente *et al*. 2005
3	430	19.8	43.0	20.0	0.53	1.94	14.4	60% rapeseed	20	Mourente *et al*. 2005
3	434	21.5	31.9	31.9	0.40	4.09	20.1	60% linseed	20	Mourente *et al*. 2005
3	405	24.1	38.7	23.7	0.49	2.89	19.2	60% live oil	20	Mourente *et al*. 2005
3	378	31.3	31.9	28.4	0.65	4.20	23.3	Fish oil, 3 times a day, 6 days/week	18	Montero *et al*. 2005
3	372	27.8	31.2	19.4	0.52	0.90	14.3	60% soybean oil, 3 times a day, 6 days/week	23	Montero *et al*. 2005
3	356	26.6	43.3	18.6	0.55	1.80	13.6	60% rapeseed oil, 3 times a day, 6 days/week		Montero *et al*. 2005
3	358	32.1	30.9	27.2	0.55	3.10	11.9	60% linseed oil, 3 times a day, 6 days/week		Montero *et al*. 2005
3	366	24.1	28.9	35.1	0.49	3.20	12.1	80% linseed oil, 3 times a day, 6 days/week		Montero *et al*. 2005
5	226	27.5	35.8	24.8	0.53	3.51	20.6			Testi *et al*. 2006
9	396	30.38	36.47	17.29	0.94	1.09	16.1		June	Fuentes *et al*. 2010
9	401	30.57	36.32	17.81	1.26	1.43	16.6		June	Fuentes *et al*. 2010
Wild fish										
5	239	31.1	23.2	44.0	0.57		31.2			Krajnovic-Ozretic *et al*. 1994
3	203	33.4	19.4	35.6	0.54	3.02	30.1		May/19	Alasalvar *et al*. 2002
3	243	43.3	30.0	18.3	0.57	3.67	18.3		May	Saglik *et al*. 2003
14	365	25.7	37.6	28.3		2.11			March	Periago *et al*. 2005
2	354	34.0	23.9	9.40	0.79	0.92	8.70		November	Ozyurt and Polat 2006
2	350	27.1	30.7	14.8	0.72	2.01	13.0		February	Ozyurt and Polat 2006
2	352	29.7	31.5	21.9	0.50	2.20	20.7		April	Ozyurt and Polat 2006
2	344	27.3	31.7	20.7	0.52	2.48	19.3		July	Ozyurt and Polat 2006
9	439	37.38	23.54	29.92	0.73	3.27	28.8		June	Fuentes *et al*. 2010
AVG Farmed		30.8 ± 10.2	35.6 ± 7.22	19.2 ± 6.95	0.99 ± 0.82	1.72 ± 0.85	17.2 ± 4.69			
AVG Wild		34.4 ± 5.85	26.0 ± 5.87	27.0 ± 10.8	0.67 ± 0.25	2.81 ± 1.08	24.5 ± 8.97			

AVG: weighed averages

general, literature has indicated for both sea bass and gilthead sea bream a higher ω-3/ω-6 ratio for wild fish (Alasalvar *et al*. 2002; Saglik *et al*. 2003; Mnari *et al*. 2007; Fuentes *et al*. 2010). Such a tendency appears by the present collective data for both gilthead sea bream and sea bass (although not statistically significant).

Factors affecting muscle composition and fat deposition

As mentioned before, the chemical composition of the fish muscle depends on many factors affecting quality and the harvesting and handling methods. More specifically, fat deposition in muscles increases with fish weight/size (Shearer 1994; Grigorakis 2007) whilst it decreases during spawning. This reduction is due to the fact that fish feeding frequency is reduced during this period and the muscle fat that has already been deposited is metabolized or stored in gonads (Shearer 1994; Bell *et al.* 1998; Grigorakis *et al.* 2002).

Fat deposition increases at the end of the summer and reduces after winter probably due to the feeding intensity and in the cases of wild fish due to the gonadal maturation and spawning (Grigorakis *et al.* 2002). In addition, warm sea waters result in higher fat deposition in fish muscle in comparison with colder waters (Shearer 1994), while continuous day light results in reduction of fat content probably due to more intense metabolic activity during daylight hours (Gines *et al.* 2004). Some researchers found that low salinity (5‰) result in elevated fat content however this fact could be probably attributed to body weight of the two groups at the end of experiment (145 g of control group vs. 181 g of adjusted group) rather than the effect of salinity (Roche *et al.* 1989). On the other hand, other researchers (Eroldogan *et al.* 2002) did not detect differences in fish muscle fat contents of fish grown in seawater as opposed to freshwater.

Many studies have demonstrated that muscle fat content varies according to whether fish are wild or farmed thus it is strongly influenced by the diet and especially by the lipid content of the diet. More particularly fat content is elevated by a high lipid content diet (Lanari *et al.* 1999; Santinha *et al.* 1999; Vergara *et al.* 1999; Poli *et al.* 2001).

Muscle fatty acid composition is also influenced by the diet. Many studies have demonstrated that the fish muscle fatty acid content reflects the dietary fatty acid composition (Nicolosi Asmundo *et al*. 1993; Krajnovic-Ozretic *et al.* 1994; Grigorakis *et al.* 2002; Izquierdo *et al*. 2003; Izquierdo *et al*. 2005; Montero *et al*. 2005; Mnari *et al*. 2007). Moreover, the final lipid content is influenced by the fact that the aqua cultured fish tend to be fattier than the wild ones. In particular the percentage of EPA and DHA levels in total fatty acids is usually lower in farmed fish compared to wild ones despite the total levels of EPA and DHA in farmed fish being usually higher than that of wild fish. This is due to higher total lipid content (Higgs *et al.* 1989; Nettleton 1992). The fatty acid composition of the formulated food used for farmed fish, results in farmed fish having higher total lipid content in comparison to the wild counterparts.

Some studies found differentiations in muscle fatty acids with age while others did not. In particular it was mentioned that saturated fatty acids and PUFAs EPA and DHA increased within a year (Nicolosi Asmundo *et al.* 1993), while Passi *et al*. (2004) observed no differences in fatty acid patterns among 1 year (64 g), 3 year (388 g) and 5 year old (1217 g) sea bass. The impact of growth factors on fatty acid profiles depend on feed utilization, hormone production as well as general metabolic changes and therefore the relationship of age and size to the muscle fatty acids is a complex one. Hence, significant variance in results has been reported (Passi *et al*. 2004). Yet another factor that influences the muscle fatty acid content is the gonadal maturation/spawning (Almansa *et al*. 2001).

Regarding environmental factors, colder waters result in the elevation of PUFAs especially EPA and DHA (Cordier *et al*. 2002; Ibarz *et al.* 2005), whilst the increase in salinity was negatively correlated with 22:6 ω-3 concentration in muscle polar lipids (Cordier *et al*. 2002).

FISH LIPID MICRO CONSTITUENTS

Fish lipids consist of major and micro constituents. The content and composition of lipid micro constituents depend on the species, the catching season and whether the fish is wild or farmed. For instance, in farmed fish there are higher amounts of PAF antagonists than in wild fish (Nasopoulou *et al.* 2007). In addition, farmed fish usually have increased levels of α-tocopherol compared to those of wild fish. This comes as a result from the usage of α-tocopherol as an antioxidant in the preparation of the food for the farmed fish (Guillaume *et al.* 2001).

The differences in the levels of lipid micro constituents between wild and farmed fish could be attributed to different diet history (i.e. wild fish eat plankton, benthos and other fish, whereas farmed fish's food is formulated) and growth conditions (i.e. aeration and temperature are controlled and regulated in the case of farmed fish). On the other hand constituents such as cholesterol, proteins and vitamins such as thiamine, riboflavin, niacin, pantothenic acid, pyridoxine and folic acid levels are at the same levels both in wild and farmed fish (Nettleton *et al.* 1992).

Mercury in its methylated form has been positively associated with coronary heart disease, implying that high mercury content may diminish the cardioprotective effect of fish consumption (Guallar *et al.* 2002). One mechanism for this detrimental harmful action of mercury is the mercury-induced ω-3 fatty acid peroxidation (Salonen *et al.* 1995). The fact that the growth of farmed fish is controlled in comparison to that of wild ones makes farmed fish safer in concern to the content of harmful heavy metals such as mercury. Moreover micro constituents that either prevent or promote cardiovascular diseases such as trace elements are also more easily controlled in farmed fish (Cahu *et al.* 2004).

Many studies have shown that selenium acts as an antidote to the toxicity of mercury (Goyer 1997; Combs 2001). This is because selenium, as a cofactor of redox enzyme systems such as glutathione peroxidase and thioredoxin reductase, acts as an antioxidant defender in humans (de Lorgeril *et al.* 2001). Thus, lower levels of mercury lead to lower levels of selenium so not surprisingly, farmed fish have been reported to have less selenium than wild fish (50-100 μg/100 g wild fish versus 20-30 μg/100 g farmed fish) (Cahu *et al.* 2004).

PAF antagonists

PAF antagonists are lipid micro constituents that have been detected in lipid fractions obtained from various fish such as rainbow trout (*Oncorhynchus mykiss*), golden trout (*Oncorhynchus mykiss aguabonita*), Atlantic, herring, coley (*Clupea harengus harengus*), plaice (*Pleutonectes platessa*) (Nomikos *et al.* 2006), Atlantic mackerel (*Scombrus Scombrus*) (Rementzis *et al.* 1997), gilthead sea bream (Nasopoulou *et al.* 2008) and cod (*Gadus morhua*) (Panayiotou *et al.* 2000). PAF antagonists acquire their name from their ability to antagonize a lipid mediator of thrombosis and inflammation known as PAF. PAF plays a critical role in the initiation and propagation of atherosclerosis and other inflammation-based diseases (Feliste *et al.* 1989; Demopoulos *et al.* 2003; Ninio *et al.* 2005). Lipid micro constituents that act as PAF antagonists are mainly polar lipids and to a lesser extent neutral lipids (Nomikos *et al.* 2006; Nasopoulou *et al.* 2008) including specific phenolic compounds and phospho- or glycol-lipids (Rementzis *et al.* 1996; Opstvedt 1997).

The comparison of the PAF antagonistic activity of wild to farmed sea bass and gilthead sea bream shows that wild fish exert higher biological activities than the farmed ones (Nasopoulou *et al.* 2007). Recent experimental data show that polar lipids extracted from farmed gilthead sea bream exhibited *in vivo* antiatherogenic properties in hypercholesterolemic rabbits (Nasopoulou *et al.* 2009) In particular the fish polar lipids that were used for this *in vivo* experiment contained PAF inhibitors and the main result was the significant reduction of the intimal thickening of atheromatous lesions in aortas of animals that were fed with atherogenic diet (1% cholesterol) enriched with fish polar lipids (0.06% w/w) compared to animals that were fed with atherogenic diet (1% cholesterol). Structural elucidation of PAF antagonists in fish should help to understand the mechanisms of preventing the development of atherosclerosis.

ANTIATHEROGENIC PROPERTIES OF FISH LIPIDS

It is well known that dietary factors play a functional role in protecting or promoting various diseases. Some dietary factors are related to thrombosis and atherogenesis and may be linked with the incidence of cardiovascular diseases. For example PUFA and MUFA prevent the development of cardiovascular diseases whereas saturated fatty acids (SFA) promote it. Despite the complexity of the relationships amongst dietary factors and the development of cardiovascular diseases the [SFA/(PUFA +MUFA)] ratio has been used to express their functional role in terms of atherogenic index (AI) and thrombogenic index (TI) (Ulbricht *et al.* 1991). These dietary factors influence blood lipids, such as total cholesterol and HDL-cholesterol that in turn are factors of the expression of the biochemical atherogenic indexes of a living organism, such as the ratio of [total cholesterol-HDLcholesterol]/[HDLcholesterol]. Micro constituents are another issue of dietary factors that affect the human health by inhibiting or promoting various complex pathophysiological mechanisms. These micro constituents exert beneficial activities and their structures vary from phenolic compounds to phospho- or glycol-lipids (Rementzis *et al.* 1996; Opstvedt 1997).

Fish oil, composed of various fish lipids, is known for its antiatherogenic effect. One mechanism of this beneficial effect involves the modulation of blood lipid levels such as those of total cholesterol, HDL-cholesterol and lipoprotein (a) (Kris-Etherton *et al.* 2003; Din *et al.* 2004). Another mechanism concerns the control of immune functions and the modulation of normal inflammatory processes where platelet and leucocyte function (Thomas *et al.* 1990; Osterud 1995; Lombardi *et al.* 2001) as well as PAF activity (Mayer *et al.* 2002) is also implicated. The administration of semi purified fish oil exert more positive effects compared to highly purified fish oil in terms of blood lipids (Haglund *et al.* 1992). This result shows that bioactive micro constituents in fish oil, such as PAF antagonists, may have a critical role in the prevention of atherosclerosis through fish consumption that is complementary to that of PUFA and MUFA (Mayer *et al.* 2002).

CONCLUSIONS

The study of the published data exhibited that differences exist between farmed and wild gilthead sea bream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) such as muscle composition and the content of micro constituents. Moreover alterations in muscle composition occur between farmed fish from different aquacultures that follow different culture systems e.g. different finishing diets, reinforcing the aspect that the growing conditions of the farmed fish has a potent impact in the quality of the final product. Fish muscle composition is significantly influenced by various factors such as the dietary history e.g. feeding composition, feeding ratio, as mentioned above, environmental parameters e.g. catching season and water temperature, fish age and size.

In particular gilthead sea bream exhibited more potent alterations between the farmed and the wild fish in reference to fat and moisture content as well as to the levels of PAF-antagonists in comparison to sea bass. Fat content is higher in farmed gilthead sea bream than in wild ones and similarly the levels of PAF-antagonists are higher in the farmed counterparts, while such differences do not occur in sea bass.

The likely reason for this occurrence is the composition of fish feed used in aquacultures being closer to the natural diet of sea bass as opposed to gilthead sea bream. Aquaculture diets are rich in fish and fish oil and are thereby in keeping with the carnivorous nature of wild sea bass (Kelley 1987; Costa 1988; Kara *et al.* 1996; Pusineri *et al.* 2004). Adversely, wild gilthead sea bream are omnivorous by nature primarily consuming molluscs (gastropods and bivalves) and carcinoids (Pita *et al*. 2002; Gamito *et al*. 2003; Tancioni *et al*. 2003).

With regard to the fatty acid composition, significant differences were not observed between farmed and wild fish of both species and this may be due to high standard deviations that reflect the high variability found within the literature.

According to the literature it has been well documented that fish oil exerts beneficial roles against cardiovascular diseases. These roles are attributed not only to the ω-3 fatty acid (EPA and DHA) content of fish muscle but also to some micro constituents. Some of these micro constituents are α-tocopherol, selenium and PAF antagonists. The levels of α-tocopherol and PAF-antagonists were higher in farmed fish than in wild ones, a fact that in the case of α-tocopherol was attributed to the usage of α-tocopherol as antioxidant in the preparation of the food for the farmed fish.

PAF-antagonists have the ability to inhibit PAF action, which is related to the initiation and development of atherosclerosis and to other inflammatory diseases. Such micro constituents have been detected in a large number of fish. Taking into account that atherogenesis is linked to the control of immune system and to the modulation of normal inflammatory processes where platelet and leucocyte function, implicating PAF activity, the presence of PAF-antagonists in fish muscles reinforces the beneficial effect of fish against atherogenesis. The differences of lipid content and the levels of lipid micro constituents between wild and farmed fish could be attributed to different diet history. Thus it is of major importance to study and alter the chemical composition of the farmed fish diet in order to improve their nutritional value in terms of preventing atherosclerosis development.

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