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Dietary macroalgae is a natural and effective tool to fortify gilthead seabream fillets with iodine: Effects on growth, sensory quality and nutritional value

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ABSTRACT

Marine fish are a rich source of iodine in the human diet. Exogenous feeding under captivity opens the possibility of tailoring fish composition with health valuable nutrients, such as iodine, and establishing it as a functional food. A study was undertaken to test the efficacy of various dietary iodine supplemental forms on the growth performance of gilthead seabream and assess the effects on sensory attributes and nutritional value of fillets. Duplicate groups of 35 seabream (IBW: 252 g) were fed over 118 days: a) control diet (CTRL) with 3 mg I kg^{-1}, supplied as potassium iodide; b) this same control diet supplemented with potassium iodide (diet KI: 26 mg I$\cdot$$kg^{-1}$) or with ethylenediamine dihydroiodide (diet EDDI; 22 mg I$\cdot$$kg^{-1}$); c) a fourth diet with 10% of *Laminaria digitata*, an iodine-rich macroalgae (diet LAM). At the end of the trial, fish doubled their initial weight, but irrespective of the iodine form used, the elevation of dietary iodine level had no effect ($P > 0.05$) on feed intake, growth rate, feed conversion, nutrient utilization or whole-body composition. Dietary iodine supplementation led to a significant increase ($P < 0.05$) of the iodine content in seabream fillets. In comparison to the CTRL treatment (0.13 mg$\cdot$$kg^{-1}$), seabream fed KI and EDDI supplemented diets showed a significant enhancement ($P < 0.05$) of their fillet iodine content (0.17 mg$\cdot$$kg^{-1}$). Feeding seabream with the iodine-rich brown algae *L. digitata* resulted in a significant ($P < 0.05$) 6.5-fold increase (0.84 mg$\cdot$$kg^{-1}$ fillet) of fillet iodine content over the levels found in the CTRL treatment. Overall sensory difference between CTRL and fish fed supplemented diets was significant ($P < 0.05$) only for fish fed the EDDI diet. Steam-cooking elicited 13–20% losses of the iodine content of seabream fillets. Iodine supplementation had no effect ($P > 0.05$) on the fatty acid profile of seabream muscle. Dietary iodine-rich macroalgae was an effective and natural strategy to fortify muscle with iodine, showing that a 160 g portion of steam-cooked seabream fillets could cover approximately 80% of the Daily Recommended Intake for iodine and 370% of the Daily Adequate Intake of EPA + DHA for enhanced cardiovascular health in adults.

1. Introduction

Food and nutritional sciences have moved from identifying and correcting nutritional deficiencies to designing foods that promote optimal health and reduce the risk of disease. The Concerted Action on Diplock et al. (1999) defined as functional, a food that beneficially affects one or more target functions in the body beyond adequate nutritional effects in a way that is relevant to either an improved state of health and well-being and/or reduction of disease; also it should be consumed as part of a normal food pattern (Diplock et al., 1999). Being a rich source of important nutrients, including highly digestible proteins, vitamins (A, D, niacin and B12), trace minerals (iodine, selenium) and n − 3 PUFAs, fish is generally regarded as healthy food. In particular, marine fish lipids have been unequivocally associated to a protective role against a number of human diseases (FAO/WHO, 2011; Levitan et al., 2009; Raatz et al., 2013; Saravanan et al., 2010). Moreover the American Heart Association recommends an intake of at least two portions of fish per week with cardio-protective effects (Gidding et al., 2009; Lichtenstein et al., 2006). Globally, in 2009 fish represented about 16.6% of animal protein supply for human consumption. In 2011 the annual per capita fish consumption was 18.8 kg (FAO, 2012) and by 2022 it is estimated to rise up to 20.6 kg per capita. With the stagnation of capture fisheries aquaculture is expected to respond to this increasing demand (OECD-FAO, 2013).

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Recent studies estimate that almost 44% of school-age children in Europe have inadequate iodine intake and extrapolations to the general population reveal 1.88 billion individuals worldwide with insufficient iodine intake (Andersson et al., 2012). Additionally, studies performed in pregnant women found critical levels of iodine status in several European countries (Aguayo et al., 2013; Bath et al., 2013; Hiéronimus et al., 2009; Limbert et al., 2010). Iodine deficiency disorders (IDD) result in several metabolic changes including goitre and hypothyroidism which can occur at any stage of life, but the most devastating consequences take place during foetal development and childhood, with stillbirth, miscarriages, poor growth, and cognitive impairment (Andersson et al., 2012). Although cretinism is the most extreme manifestation, of considerably greater significance are the more subtle degrees of mental impairment that lead to poor school performance, reduced intellectual ability, and impaired work capacity (Bath et al., 2013). Iodine deficiency is the world's greatest single cause of preventable brain damage, and this fact is the primary motivation behind the current worldwide drive to eliminate iodine deficiency (WHO, 2007).

The primary strategy for iodine supplementation relies on salt iodization, however with the implementation of salt intake reduction programmes, prevention of iodine deficiency may be less effective and alternatives are required (Land et al., 2013). Several foods, including fish, have been suggested as suitable vehicles for iodine fortification as one of the alternatives to salt (WHO, 2014). A previous WHO/FAO (2006) report defined a suitable food to serve as vehicle for extra nutrients as being consumed in constant quantities, affordable and available all year long. Fish and seafood are the richest natural sources of iodine in food (Haldimann et al., 2005; Institute of Medicine and Food and Nutrition Board, 2001). Since fish also meets the defined criteria for a food vehicle, fish fortification with iodine could be an excellent tool in the strategy of diminishing iodine deficiency in the world population.

Exogenous feeding in aquaculture unlocks the possibility to tailor fish composition in terms of its content of health valuable nutrients. Under farming conditions, fish quality traits such as fatty acid composition and concentration of several trace nutrients are known to be influenced by diet composition. Several studies have demonstrated that feed supplements can effectively tailor the composition of fish fillets in terms of bioactive fatty acids (Kennedy et al., 2007; Ramos et al., 2008; Rosa et al., 2010) or selenium (Lorentzen et al., 1994; Schram et al., 2010). Iodine has also been successfully used in fish fortification either as an organic form with macroalgae (Schmid et al., 2003) or an inorganic salt, potassium iodide (Julshamn et al., 2006).

The objectives of this study were to test the effect of various dietary iodine supplemental forms on the growth performance of gilthead seabream, assess iodine deposition efficacy in fish muscle and evaluate its effects on the nutritional value and sensory quality of fish fillets.

2. Material and methods

2.1. Experimental diets

Four experimental diets were formulated to be isonitrogenous (48% crude protein), isolipidic (19% crude fat) and isoenergetic (23 $MJ \cdot kg^{-1}$ gross energy). A control diet (CTRL), similar to a commercial seabream feed, was formulated to contain 3 mg $iodine \cdot kg^{-1}$, supplied as potassium iodide through the mineral premix and the endogenous content of

Table 1
Ingredient and proximate composition of experimental diets.

Ingredients, $g \cdot kg^{-1}$	CTRL	KI	EDDI	LAM
Fishmeal LT 70[a]	100	100	100	100
Fishmeal FAQ[b]	200	200	200	200
Wheat gluten[c]	40	40	40	55
Corn gluten[d]	116	116	116	120
Soybean meal[e]	140	140	140	140
Whole wheat	139	139	139	80
Dehulled pea grits[f]	90	90	90	30
Fish oil[g]	140	140	140	140
Vitamin and mineral premix[h]	10	10	10	10
Guar gum	5	5	5	5
Dicalcium phosphate[i]	10	10	10	10
L-Lysine	5	5	5	5
DL-Methionine	5	5	5	5
KI ($mg \cdot kg^{-1}$)[j]		29.1		
EDDI ($mg \cdot kg^{-1}$)[j]			25.2	
Macroalgae meal[k]				100
Dry matter (DM), %	94.8 ± 0.1	94.3 ± 0.1	93.7 ± 0.1	91.7 ± 0.0
Crude protein, %DM	42.4 ± 0.0	42.1 ± 0.3	42.8 ± 0.1	42.3 ± 0.5
Crude fat, % DM	17.0 ± 0.2	16.7 ± 0.0	17.0 ± 0.1	16.8 ± 0.5
Ash, %DM	9.6 ± 0.0	9.5 ± 0.0	9.6 ± 0.0	11.5 ± 0.1
Total phosphorus, % DM	1.4 ± 0.0	1.5 ± 0.1	1.4 ± 0.0	1.4 ± 0.0
Gross energy, $kJ \cdot g^{-1}$ DM	21.7 ± 0.1	21.7 ± 0.0	21.8 ± 0.2	21.5 ± 0.1
Iodine, $mg \cdot kg^{-1}$ DM	2.4 ± 0.4	26.1 ± 1.7	22.9 ± 1.7	426.2 ± 24

[a] Peruvian fishmeal LT: 71% crude protein (CP), 11% crude fat (CF), EXALMAR, Peru.
[b] Fair Average Quality (FAQ) fishmeal: 62% CP, 12%CF, COFACO, Portugal.
[c] VITEN: 85.7% CP, 1.3% CF, ROQUETTE, France.
[d] Corn gluten feed: 61% CP, 6% CF, COPAM, Portugal.
[e] Solvent extracted dehulled soybean meal: 47% CP, 2.6% CF, SORGAL SA, Portugal.
[f] Aquatex G2000: 24% CP, 0.4% CF, SOTEXPRO, France.
[g] COPPENS International, The Netherlands.
[h] Premix for marine fish, PREMIX Lda, Portugal. Vitamins (IU or mg/kg diet): DL-alpha tocopherol acetate, 100 mg; sodium menadione bisulphate, 25 mg; retinyl acetate, 20,000 IU; DL-cholecalciferol, 2000 IU; thiamin, 30 mg; riboflavin, 30 mg; pyridoxine, 20 mg; cyanocobalamin, 0.1 mg; nicotinic acid, 200 mg; folic acid, 15 mg; ascorbic acid, 1000 mg; inositol, 500 mg; biotin, 3 mg; calcium panthotenate, 100 mg; choline chloride, 1000 mg, betaine, 500 mg. Minerals (g or mg/kg diet): cobalt carbonate, 0.65 mg; copper sulphate, 9 mg; ferric sulphate, 6 mg; potassium iodide, 0.5 mg; manganese oxide, 9.6 mg; sodium selenite, 0.01 mg; zinc sulphate, 7.5 mg; sodium chloride, 400 mg; calcium carbonate, 1.86 g; excipient wheat middlings.
[i] Dicalcium phosphate: 18% phosphorus, 23% calcium, Fosfitalia, Italy.
[j] Sigma-Aldrich: KI — potassium iodide ref. 30315; EDDI — ethylenediamine dihydroiodide, ref. S573019.
[k] Dry *Laminaria digitata*: 5.4% CP, 0.5% CF, 3700 mg iodine/kg, Agrimer, France.