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A general review on the use of alternative protein sources in diets for Mediterranean fish

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SUMMARY – The most important raw materials used in the fish feed industry are fishmeal and fish oil. Fishmeal is the preferred as a protein source due to its high protein content, good amino acid balance, lack of antinutrients and high palatability. However, because of its cost and limited resources, its substitution is a basic prerequisite for the sustainability of aquaculture. The number of feedstuffs with high protein content that can currently be used to replace fishmeals is very limited. They include plant feedstuffs, like soybean meal and corn gluten meal, and animal by-products, like poultry by-products. All these materials have deficiencies in essential amino acids. The use of plant materials is furthermore limited since they contain growth inhibitors. The optimization of technological treatments to remove anti-nutrients in plant materials could increase their use in fish feeds and may reduce reliance on fish products.

Keywords: Fish feeds, fish meal, plant materials.

RESUME – *"Révision générale sur l'utilisation des sources alternatives de protéine dans l'alimentation des poissons méditeranéens". Dans l'industrie productrice d'aliment poisson, les matières premières de base les plus importantes qui sont utilisées sont la farine de poisson et l'huile de poisson. La farine de poisson est la source de protéines préférée en raison de sa forte teneur en protéines, son bon équilibre en acides aminés, l'absence de facteurs antinutritionnels et la bonne palatabilité. Cependant leur coût et le fait que ces ressources sont limitées font qu'il soit nécessaire de les substituer comme pré-requis pour la durabilité de l'aquaculture. Il existe un nombre très réduit de matières à forte teneur en protéines qui puissent être actuellement utilisées en remplacement de la farine de poisson. Parmi celles-ci des aliments d'origine végétale tels que la farine de soja et la farine de gluten de maïs, et des sous-produits animaux provenant de l'élevage de volailles. Toutes ces matières présentent un ou plusieurs déficits en acides aminés indispensables. L'utilisation de produits végétaux est en outre limitée en raison des inhibiteurs de croissance qu'ils contiennent. L'optimisation des traitements technologiques pour éliminer les facteurs antinutritionnels existant dans les produits végétaux pourrait permettre de les incorporer davantage dans les aliments pour poissons et de réduire la dépendance par rapport aux produits à base de poisson.*

Mots-clés : *Aliment poisson, farine de poisson, matières d'origine végétale.*

In the industry of fish feed production, the raw materials which determine the effectiveness of fish diet composition at a financial and quality level, are those derived from the marine environment, the most vital being fish meal and fish oil, while the complementary role is played by products and by-products of crustaceans and seaweed meals.

Fish meal and fish oil production from fishing activities has stabilized at present, whereas the significant increase in demand is the result of the tremendous growth of aquaculture worldwide. This fact combined with: (i) the application of quotas to fisheries for the protection of natural marine resources; (ii) the adverse climatological changes affecting fishing grounds caused by alterations in the ocean thermocline; and (iii) the banning on the utilization of alternative raw materials as a source of protein from land animals, have lead to a very uncertain environment, as far as availability and cost of fish meal and fish oil are concerned. The cost of these two components represents more than 50% of the annual expenses of the Mediterranean Fish Feed Industry and any changes affect significantly the cost of fish diet and thus, the production cost of farmed fish.

In Greece, more than 90% of the mariculture industry produces fish species with high protein and ω-3 fatty acid requirements. Under these circumstances, the industry is obliged to maintain the production cost at a competitive level, regardless of the increased cost of raw materials. This obligation is the result of restrictive profit limits in aquaculture due to the relation between demand and supply, as well as, to the pressure from the European Union to maintain the prices of food products.

From the nutritional point of view, the extensive use and reliance on fishmeals in aquafeeds is mainly in response to the attributes listed below:

(i) The high protein level (65-72%) and good source of essential amino acids, especially lysine and methionine.

(ii) Balanced and "available" amino acid profile for fish (high EAAI score).

(iii) Good source of essential fatty acids (EFA's) within the residual oil, 1-2% of the total triglycerides.

(iv) Provision of calcium and phosphorous together with a range of trace elements and vitamins.

(v) Minimum or zero anti-nutritional properties, except for the high ash, low-grade fishmeals.

(vi) Normally very palatable to most fish species and suitable for stimulating appetite and feeding response in salmon and marine fish.

(vii) Generally of a consistent quality and defined source, and manufactured under standard conditions.

Table 1 shows growth parameters of seabream fed on diets containing different fish meals.

Table 1. Effect of fish meal (Norwegian origin) quality on growth, feed utilization, and digestibility of seabream

Fish meal	Protein content	Lipid content	Fish weight (g/fish)		SGR†	FE††	Protein digestibility	Reference
			Initial	Final				
LT	73	10	67	165	1.0	0.66	91.6	Aksnes *et al.*, 1997
Standard	70	11	70	158	0.9	0.58	91.4	Aksnes *et al.*, 1997

†SGR: specific growth rate.
††FE: feed efficiency.

Animal protein supplements are a good and low price source of protein, which could substitute successfully part of the fishmeal protein, plant materials of high protein content being also another alternative. However, given the directives that exclude the use of any meal produced from land animals in aquafeeds, the use of plant ingredients as the only alternative nutrient sources is the only choice.

Table 2 shows the adequacy of different feedstuffs to satisfy the amino acid requirements of seabass and seabream.

Fish meal, corn gluten meal and poultry byproduct meal are also deficient in methionine + cystine for seabass whereas for seabream methionine + cystine are deficient only for poultry byproduct meal.

Table 3 summarizes digestibility coefficients of various raw materials for seabream and seabass.

The results demonstrate the high digestibilities exhibited for soybean meals and corn gluten.

Table 2. Amino acid profile of raw materials and adequacy for meeting the essential amino acid requirements of Mediterranean marine fish

	Fish meal			Soybean meal			Corn gluten meal			Poultry by-products		
	% of protein	% of requirement		% of protein	% of requirement		% of protein	% of requirement		% of protein	% of requirement	
		Bass	Bream		Bass	Bream		Bass	Bream		Bass	Bream
Arginine	6.4	156	107	7.75	189	129	3.1	76	52	5.9	144	98
Lysine	7.5	156	150	6.35	132	127	1.5	31	30	4.6	96	92
Histidine	2.4			2.65			2.1			1.6		
Isoleucine	4.5			5.1			3.8			3.8		
Leucine	7.4			7.45			15.2			6.3		
Valine	5.1			4.9			4.6			4.5		
Methionine+ Cystine	4.0	90	100	2.6	59	65	4.1	93	103	3.2	72	80
Phenylalanine	4.2			5.1			5.9			2.9		
Threonine	4.0	160		4.05	162		3.3	132		3.1	124	
Tyrosine	3.2			3.35			4.7			1.5		
Tryptophan	1.1		183	1.2		200	0.4		67	0.7		117

Based on the reported EAA requirements of seabass (Thebault *et al*., 1985; Tibaldi and Lanari, 1991; Tibaldi *et al*., 1994; Tibaldi and Tulli, 1999) soybean protein is deficient in methionine + cystine. Soybean meal is also deficient in these two EAA'S for seabream (Luquet and Sabaut, 1974; Amerio *et al*., 1998).

Table 3. Digestibility values of protein sources for seabream and seabass

	Protein	Lipids	Energy	Reference
Bream				
Fish meal	95.8		94.1	Nengas *et al*., 1995
Soybean meal	88.0 - 90 .9		45.0 – 62.0	Nengas *et al*., 1995; Lupatsch *et al*., 1997
Full fat soy	75.7	84.6	61.9	Nengas *et al*., 1995
Corn gluten	90.0	82.9	79.7	Nengas *et al*., 1995
Sunflower meal	86.2	59.6		Nengas *et al*., 1995
Flaked maize	60.3	45.4	33.7	Nengas *et al*., 1995
Bass				
Soybean meal	85.0 – 88.9		69.3 – 82.2	Tibaldi and Tulli, 1998; Gomes da Silva and Oliva-Teles, 1998

The most commonly used protein sources of plant origin are the soybean meal and the corn gluten. These materials, due to special market conditions in the European Union, have to be from genetically modified free products. Furthermore, as far as the corn gluten is concerned there is also a limitation in the availability due to its extended use in the animal production in general.

Soybean meal is by far the most commonly available feed ingredient with a global production of 80 million metric tones in 1994. However, these feed ingredients vary considerably in terms of their nutritional value for farmed fish. Many researchers have reported partial success rates in replacing the fish meal component of the ration with one or more combinations in turn (Akiyama 1991) (Tables 4 and 5).

According to the results of growth studies published, it seems that soybean products are well tolerated by seabass up to a 40% substitution of the dietary protein (Table 4). It has to be noted that in all cases that good results were obtained, supplementation with soy lecithin and methionine was also used. Furthermore, similar growth to that of the control was attained through an increase in feed consumption by fish, which had a slight (and no significant) negative effect on feed conversion.

Soya protein concentrate appears to be a promising source of protein for even higher substitution rates of fish meal since a 60% substitution rate of fish meal protein resulted in similar performances to that of the control (Tibaldi and Tulli, 1998).

Table 4. Experimental conditions of trials performed for evaluating maximum incorporation levels of soy products in seabass diets and main results obtained

Soy product†	Protein source substituted	Level of substitution (%)	Feeding	General result	Reference
SBM	Fish meal	Diet: 19.4, 38.8	To satiation	Acceptable up to the highest level used	Alliot *et al*., 1979
SBM	Animal protein sources	Diet: 30	Constant restricted rate	Acceptable at TIA levels of 12.8mg/g	Amerio *et al*., 1991
SBM FFS	Animal protein &sources	Diet: 25 Diet: 28	Constant restricted rate	Lower performance of SBM diet	Amerio *et al*., 1991
SPC	Fish meal	Protein: 67	To satiation	Acceptable with the addition of attractant	Dias *et al*., 1997
SBM	Fish + yeast + blood meal	Protein: 25, 50		Acceptable up to 25%	Lanari *et al*., 1998
SBM	Fish meal LT	Diet: 19.6, 39, 56 Protein: 20, 40, 60	To satiation	Acceptable up to 40% protein substitution	Tibaldi and Tulli, 1998
SPC	Fish meal LT	Diet: 43 Protein: 60	To satiation	Acceptable at 60% protein substitution	Tibaldi and Tulli, 1998

†SBM: soybean meal; FFS: full fat soy; SPC: soy protein concetrate.

Table 5. Experimental conditions of trials performed for evaluating maximum incorporation levels of soy products in seabream diets and main results obtained

Soya product†	Protein source substituted	Level of substitution (%)	Feeding	General result	Reference
SBM	Fish meal	Diet: 10, 20, 30	To satiation	Acceptable up to the highest level used	Robaina *et al*., 1995
SBM FFS	Fish meal Fish meal	Protein: 10, 20, 30,40 Protein: 35	Constant restricted rate	Acceptable up to 30% Acceptable when properly heated.	Nengas *et al*., 1996
SPC	Fish meal	Protein: 35		Not acceptable.	
SBM SBM extruded	Fish meal Fish meal	Diet: 21,33,44 Diet: 21,33,44	Satiation Satiation	Similar growths, reduced feed efficiency from 21% inclusion	Venou *et al*., 1997
SPC	Fish meal	Protein : 30,60,100	Satiation	acceptable at 30%	Kissil *et al*., 2000

† SBM: soybean meal; FFS: full fat soy; SPC: soy protein concetrate.

Experimentation with seabream showed negative effects on growth or feed utilization from a 30% protein substitution rate when white fishmeal was replaced and from a 22% protein substitution rate when low temperature fish meal was replaced. Since the studies for seabass showing the feasibility of a 40% protein substitution rate (Tibaldi and Tulli, 1998) may show that seabream is more sensitive to dietary inclusion of SBM than seabass. However, there were certain differences regarding the composition of the diets used that could have affected the results.

The better performance of both seabass and seabream when full fat soya was used compared to SBM (Nengas *et al.*, 1996) is difficult to understand since both materials contain the same antinutrients, the only difference being that FFS contains soy lecithin. Robaina *et al.* (1998) reported that soy lecithin may improve histological appearance of gilthead liver.

Corn gluten is also a good source of protein (60%) but mainly due to imbalances of its amino acid profile, the maximum inclusion in fish diets is reported to vary among species. In seabream digestibility studies corn gluten exhibited high protein and energy coefficients (Nengas *et al.*, 1995).

Since the banning on the utilization of alternative raw materials as a source of protein from land animals, feed ingredients of plant origin are at present the only potential substitutes of fishmeal and other marine origin ingredients.

Optimization of technological treatments to remove the antinutrients found in plant raw materials is the last step that would allow higher inclusion rates of these products in fish feeds.

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