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Insect Meal in the Fish Diet and Feeding Cost: First Economic Simulations on European Sea bass Farming by a Case Study in Italy

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Abstract:

This proposal aims to estimate the incidence of fish meal basis diet into the total farm cost structure and how the weight can change considering different hypotheses related to introduction of insect meal into the diet. Hypotheses were proposed on the basis of increasing levels of insect meal into the diet and different prices for purchasing this meal. Economic effects were simulated according to some empirical trials carried out into the scientific literature and were applied to the European sea bass farming. A case study approach on a specialized off-shore sea bass farm in Italy was proposed. It is a small-scale farm that solely produce for local and domestic market. Findings suggest that feeding cost amounts to about 63% of the total farm cost. Possible introduction of insect meal – specifically composed by Tenebrio molitor basis – would force farmers to increase feeding cost. As it stands today, higher environmental sustainability expected by inclusion of insect meal would not be gone with more economic convenience. However technological development, higher competition into the insect meal industry, increase of production scale, and adoption of strategies aimed to weaken bargaining power between fish farmers and meal suppliers could generate a price decrease.

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This proposal aims to estimate the incidence of fish meal basis diet into the total farm cost structure and how the weight can change considering different hypothesis related to introduction of insect meal into the diet. Hypotheses were proposed on the basis of increasing levels of insect meal into the diet and different prices for purchasing this meal. Economic effects were simulated according to some empirical trials carried out into the scientific literature and were applied to the European sea bass farming. A case study approach on a specialized off-shore sea bass farm in Italy was proposed. It is a small-scale farm that solely produce for local and domestic market. Findings suggest that feeding cost amounts to about 63% of the total farm cost. Possible introduction of insect meal – specifically composed by *Tenebrio molitor* basis – would force farmers to increase feeding cost. As it stands today, therefore, higher environmental sustainability expected by inclusion of insect meal in the diet would not be gone with more economic convenience. However technological development in this field, higher competition into the insect meal industry – today characterized by concentration of firms – increase of farm plants and production scale, and adoption of strategies aimed to weaken bargaining power between fish farmers and meal suppliers could generate a price decrease. This is a hoped perspective, but today we can only verify that introduction of insect meal in the fed basis of a small-scale aquaculture farm would worsen costs.

Keywords: Tenebrio molitor meal; Economic sustainability; **S**mall-scale fish farming.

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1. Introduction

Aquaculture - that is the practice of rearing, growing or producing sea or freshwater organisms as a renewable food source - is a potential solution to the over-exploitation and misuse of the seas (Tunde et al., 2015). Fisheries has caused the decline in the availability of wild aquatic organisms (fish and crustaceans) and the growing increase in the demand for fish that cannot be met by wild catch (Barroso et al., 2014; Riddick, 2014). In recent years, this activity has been given a primary role in nutrition - as fish is the primary source of proteins, essential fats, minerals and vitamins - (FAO, 2016) and in the fight against hunger and malnutrition (FAO, 2017), in food security (Devic et al., 2017), in the provision of livelihoods (Adwan, 2017), and in sustainable production through the intelligent use of natural resources (Bossier and Ekasari, 2017).

At present, aquaculture represents the fastest growing food industry in the world (FAO, 2017). It contributes to the production of more than half of world fish production (FAO, 2016; Shaalan et al., 2017) which amounted to 66.6 million tonnes in 2012 for a value of US $ 137.7 billion; a value destined to grow by 62% in 2030 (FAO, 2014).

Based on the estimates of the expected increase in population, the world production of aquatic food will have to make an additional amount of 23 million tonnes in order to keep per capita consumption unchanged (Magalhães et al., 2017). These quantities must necessarily come from aquaculture as fishing catching has stabilized in recent decades (FAO, 2016).

In connection with the growth of these values, studies aimed at ensuring the sustainability of this industry are increasing (Taufek et al., 2017).

At the macro-level, the focus is on the conceptualization of systems intended to reduce both the resources' consumption and the environmental impact of aquaculture with simultaneous increases in productivity and profitability (Asche et al., 2008; Bossier and Ekasari, 2017; FAO, 2017). The research focus is on the study of sustainable food resources in order to (a) allow the long-term sustainability of aquaculture production at economic and environmental level (Barroso et al., 2014), (b) allow the optimal development, growth and reproduction of fish (Ayoola, 2010), (c) replace the fish meal (FM) and soy (Van Huis et al., 2013). This is because the FM is being environmentally unsustainable and it is one of the source of the high price of feed formulations (Hardy, 2010). The soy, for its part, stands accused of having generated both the deforestation of areas with high biological value and significant environmental deterioration caused by the high consumption of water, pesticides, fertilizers and transgenic varieties (Sánchez-Muros et al., 2014). Furthermore, the soy contains anti-nutritional factors that generate inflammations of the digestive tract of the fish, has low palatability of food, and its contribution of amino acids containing sulfur (methionine and cysteine) is limited (Barroso et al., 2014; Henry et al., 2015; Magalhães et al., 2017).

At micro-level, the few studies conducted are aimed at investigating the ability of individual companies to be economically sustainable, *i.e.* guaranteeing a competitive business position with stable returns over time (Tunde et al., 2015). The European Union is heavily dependent on the importation of fish products, requiring a thorough analysis of the cost and benefit of farming fish relating the introduction of innovations in feeding practices (Mancuso et al., 2016). In fact, previous studies have identified the main problems as being the feeding cost - that is greater in carnivorous fish, as they require huge quantities of FM (Manzano-Agugliaro et al., 2012) - estimating it at 40-70% of the cost of production (Henry et al., 2015; Rana et al., 2009; Wilson, 2002) and at 75-85% of variable costs (Dickson et al., 2016; Kleih et al., 2013; Shaalan et al., 2017). Furthermore, the price of the feed is the principal cause for slowing down sustainable development of this industry, given that the rise in fish feed prices is not reflected in the final product sales price (Adwan, 2017), significantly affecting the economic feasibility of the individual businesses (Shaalan et al., 2017).

Therefore, research needs to find alternative solutions able to limit environmental burden and to contain farming costs. At the same time, feed alternatives can allow a better quality of commercial products with probable evidence on prices. Especially, the fish feed industry urges valid substitutes for FM as a protein source. This goal must be achieved by ensuring fish performances and robustness, and a control of the food quality as well as a minimization of the environmental impact.

The European Commission has responded to the problems of environmental and economic sustainability of the aquaculture industry with the Regulation 893/2017. It has allowed the use of insect meal in the diet of farmed fish with limitations on their production and amount of use in the fish diet. The permitted species are three: the black soldier fly (*Hermetia Illucens*) and the common fly (*Musca domestica*); the yellow mealworm beetle (*Tenebrio Molitor*) and the alphitobium (*Alphitobius Diaperinus*); the domestic cricket (*Acheta domesticus*), the tropical cricket (*Gryllodes sigillatus*), and the silent cricket (*Gryllus Assimilis*).

The openness of the EU to this new FM derives from the result of numerous studies, that demonstrated that insects represent a valid substitute for FM, fish oil and soy (Barroso et al., 2014; Henry et al., 2015; Magalhães et al., 2017), in particular, with respect to proteins and amino acids, lipids and fatty acids, vitamins and minerals (Henry et al., 2015). Insects are salt or freshwater fish natural food (Howe et al., 2014; Whitley and Bollens, 2014) especially in the juvenile stage (Riddick, 2014).

The peculiarities relating to insects are: low environmental impact and in the limited need of arable land (Henry et al., 2015; Oonincx and de Boer, 2012), rapid breeding cycles (Gasco et al., 2016a) and high-value protein (Henry et al., 2015). The average protein content of insects (dry matter, DM) varies between 50% and 82% (Rumpold and Schlüter, 2013) on the basis of the insect species or the method of processing them (Banjo et al., 2006; Fasakin et al., 2003), while the different fish species have protein requirements ranging between 28% and 55% of the dry matter (Henry et al., 2015). This percentage decreases with the growth of fish (Lovell, 1989) and is higher in marine species (usually carnivorous,) which require more dietary proteins (40-55%) than most freshwater fish (25-40%) (25-40%) (Boonyaratpalin, 1997; Hasan, 2000; Sales and Janssens, 2003).

These characteristics are fundamental for the intensification of aquaculture production, which requires the use of food with a high protein value (Shaalan et al., 2017). For this reason, the feeding of fish with insects could represent a driving force for the growth of individual companies, also in the light of the forecasts of BOM (2016) about the price competitiveness of insect proteins with fishmeal after 2023.

This article is into the more recent stream of search about a sustainable alternative to FM (Barroso et al., 2014; Gasco et al., 2016; Henry et al., 2015; Su et al., 2017). In particular, this proposal aims to estimate how feed weights into the total farm cost structure and the possible effects on costs related to the introduction of innovative diet. Applied on the Italian context, more specifically this work focus on the cost effects derived from the introduction of insect meal into the diet of European sea bass, "*a major species culture in Mediterranean region*" (Gasco et al., 2016, p. 35) whose production in the EU in 2015 amounted to 158,479 tonnes (FEAP, 2016). In our knowledge, this study is one of the first attempt aimed to evaluate economic consequence of inclusion of insect meal into the fish diet, especially relatively to the European farming.

The evaluation was carried out by a case study approach on a specialized off-shore farm located in the Sardinia region of Italy. Preliminarily, we applied a balance sheet analysis as to describe the baseline scenario; afterwards, we assessed the possible main effects by a cost perspective derived from the introduction of *Tenebrio Molitor* (TM) meal into the European sea bass diet on the basis of different percentage of insect meal inclusion in the diet and market hypotheses.

The paper is articulated as follows: section two provides a review of the previous study on both the use of the TM as insect meal for fish, and the fish farm cost structure. The research methodology and the case study description are illustrated in Section three. Section four firstly illustrates the results of research. Section five concludes our paper and outlines the implications for practice, policy-makers, and academia as well as the recommendations for future research.

2. Literature Review

The ever-growing world population will cause a global protein shortage in the next years (Iaconisi et al., 2018). The quality and quantity of fish protein requirements are quite high, which is why FM (with optimal protein and amino acid level) has been used as the best protein source in the feed formulation (Gasco et al., 2016), together with the soy flour. However, this use clashes with the need of protein sources to meet certain criteria that go beyond the nutritional perspective, "*such as regular availability in quantity, economic value, non competition with resources for humans* *(water, land, or even the same source, as occurs with soy) and environmental sustainability*" (Sánchez-Muros et al., 2016, p. 1). Indeed, FM supply product is limited (Oliva-Teles et al., 2015) and the rapid rise of aquaculture and the consequent increase in FM demand, is generating important problems of sustainability of the sector (Hardy, 2010). Moreover, the plant proteins present problems relating to the anti-nutritional factors, high level of fibre and non-starch polysaccharides, inadequate fatty acid (FA) and amino acid profile (Gai et al., 2012), low palatability (Gatlin et al., 2007), impairment of fish intestinal enterocyte integrity (Ferrara et al., 2015).

Therefore, research on alternative protein sources for fish feeds receiving more and more attention. Edible insects meal are able to respond to this problems.

On the side of nutritional value, there are many reasons to use insect meal in the fish diet, first of all, they're being a source of protein and other components of unquestionable quality (Su et al., 2017, p. 56). It is a high protein content (between 60% and 80%), a well-balanced essential amino acid profile (Alegbeleye et al., 2012; Barroso et al., 2014; Henry et al., 2015) and right hint of mineral (such as potassium, calcium, iron, magnesium, and selenium) and several vitamins (Henry et al., 2015). Their nutrient composition may vary on the basis of the taxonomic group, the rearing substrates and the technological process, *i.e.* different rearing conditions and technological treatments can produce different lipid content and fatty acid composition (Barroso et al., 2014). Finally, insect meal is part of the natural diet of freshwater and marine fish (Howe et al., 2014; Whitley and Bollens, 2014).

Among different candidate species to produce insect meal for aquaculture, the yellow mealworm (*Tenebrio Molitor*) is especially interesting (Henry et al., 2018), because: (a) it is a worldwide distributed coleopter belonging to the Tenebrionidae family (Makkar et al., 2014); (b) its larvae in addition to being rich in crude protein (53.2%), fat (34.5%) (Ghosh et al., 2017) and having an adequate amino acid profile, it is easy to breed and feed (De Marco et al., 2015); (c) it is rich in zinc, selenium, riboflavin, biotin, pantothenic acid, folic acid, chitin and antimicrobial peptide (AMP) (LIU et al., 2005; Rumpold and Schlüter, 2013); (d) it has high values of isoleucine, leucine, lysine, and unsaturated fatty acids (De Marco et al., 2015; Rumpold and Schlüter, 2013; Siemianowska et al., 2013).

From the other side, insect meal is considered a highly sustainable source of nutrients (Van Huis, 2013), and their rearing and process environmental-friendly (Makkar et al., 2014). It allows production with low water input and emission of greenhouse gases and ammonia, high feed conversion efficiency, use of 'waste nutrients' for insect growth sources (Sánchez-Muros et al., 2016), and low risk of transmitting zoonotic infections (Van Huis, 2013). Furthermore, insect meal does not compete with human nutrition (Van Huis, 2013). For all these reasons, and given that the European Union (EU) suffer from important protein deficiency and imports over 70% of consumed proteins (EU report 2010/2111(INI)), recently, the EU Commission has regulated about insects introduction in animal diet.

The production of these insects aimed at their transformation into feed is subject to the same prohibition imposed on breeding animals (category including insects at Article 3, paragraph 6, EC Regulation No. 1069/2009) concerning the use of protein derived from ruminants, kitchen and catering waste, meat and bone meal and manure (Article 7 and Annex IV, EC Regulation No 999/2001, EC Regulation No 1069/2009), and stool (Annex III, Regulation (EC) No 767/2009 of the European Parliament and of the Council) for their feeding. This prohibition contrasts with some of the main reasons that led to insect research as an alternative source of food that could favour the circular economy, including: (a) the transformation by larvae of low quality organic waste into fertilizers good quality (Van Huis et al., 2013), reducing the final mass of manure by 50%, the waste of nitrogen 30-50% and phosphorus waste of 61-70% (Diener et al., 2009; Newton et al., 2005; Van Huis et al., 2013); (b) the reduction of the pathogenic bacterial load in the microflora of manure (Erickson et al., 2004; Liu et al., 2008); (c) the output of the manure bioconversion process, *i.e.* a high quantity of insect larvae or pre-pupae rich in proteins (40%) and lipids (30%) (Newton et al., 2005; Sheppard et al., 1994). It is precisely for these reasons that most of these studies have been carried out in Asian, African and South American countries (Veldkamp et al., 2012).

Although it is believed that the mass rearing of insects meals can be the key to have a production with constant quantity, high quality, and stability of supply and price (Sánchez-Muros et al., 2016) and price reduction (Mancuso et al., 2016), their present cost price of insect meals is still not competitive in respect of other protein sources (Koeleman, 2014). This is added to a cost structure of aquaculture enterprises that show, as reported above, that the cost of fish and fish oil is the most urgent problem. Moreover, the price of the feed slows down the sustainable development of the practice of aquaculture also due to its increase that is not reflected in the sale of the final product, significantly affecting the economic feasibility of the company itself, which moreover, it requires ever-increasing investments in fixed capital (Adwan, 2017; Shaalan et al., 2017).

3. The case study and methodology

The case study method is based on a multidimensional approach to the phenomenon investigated and allows a deep analysis of a contemporary phenomenon within its real-life context (Yin, 2013). This method, often employed in business studies for theoretical objectives and for suggesting concrete routes of action, gives voice to the experiences of successful business managers. Furthermore, notwithstanding the nature of qualitative research, that gives priority to the particulars of the cases rather than their representativeness (Flick, 2009; Glasser and Strauss, 1967) and does not readily allow the generalization of its results, it provides significant theoretical propositions that can be tested through larger quantitative research projects.

The use of the qualitative case study method (Eisenhardt, 1989; Yin, 2013) in this work is justified because it is a preliminary study, aimed to fill the literature gap about the cost structure of the fish farm and the possible use of insect meal to overcome the constraint to the sustainable development of aquaculture industry related to the high production cost.

The observed sea bass farm

The empirical analysis is based on the case study of an small size off-shore farm located in Sardinia (Italy). The farm is specialized in the production of sea bass and has started activity in the early ‘00s.

The farm as well as the other aquaculture farms in the territory exclusively use FM as fed basis. This does not allow us to have available real data able to precisely assess economic effects derived from use of other meals (insect meal in the matter of question). However this farm was chosen due to inclination of the farmer (manager) to introduce innovative feed as to potentially reduce costs and improve product quality.

For information gathering purposes, we used two connected investigation tools. Firstly, a semi-structured interview with the farm director was conducted in 2017. Secondly, the budget and internal documentation relating both to the variable and fix costs were analyzed.

This information allowed us to describe the *status quo* concerning the sea bass farm, especially in terms of feeding cost and its incidence in the complexive costs. Starting from this *status quo* condition, we simulated the main economic effects related to introduction of insects in the diet on the basis of different technical solutions and economic scenarios.

Sea bass production and feeding cost

Table 1 shows the main information on sea bass process and plant dimension of the considered farm.

Production seabass cycle amounts to 18 months and specimens are growed in 2 cages. During the 18 months-cycle, the farm produces about 260K specimens, therefore annual production amounts to about 175K specimens. The commercial size of a specimen corresponds, on average, to 0.40 Kg, meaning that annual production is about 66 tons.

Production is mostly destined to the domestic market, especially to big retailers. Price at the gate farm is from 5.5 to 6.5 €/Kg.

Table 1 – Main technical characteristics of sea bass production process in the considered farm

N. cages	2
N. specimen (by cage)	130,000
N. specimen (total)	260,000
Biological cycle	18 months
Size of marketable sea-bass	0.40 Kg
Weight gain (WG)	0.38 Kg
Feed for specimen	0.76 Kg
Feed Conversion Ratio	2.00 (2:1)
Feed distributed (total)	197,600 Kg

Concerning diet, the farm esclusively use FM as protein source. The meal formulation given to sea basses is composed by about 70% of fish meal – percentage depends on type of formulation on the basis of the age of each specimen – and this data is close to what reported by Gasco et al. (2016) about experimental trials on European sea bass in case of fish meal as unique protein source.

The Feed Convertion Ratio - *i.e.*, the total feed supplied in terms of g. of dry basis / weight gain of single specimen) amounts to 2:1. This measure takes into account both the mortality index and the waste of feed in the sea. Since sea bass juveniles weight about 0.02 g., the weight gain corresponds, on average, to 0.38 Kg and, as a consequence, feed for specimen is equal to 0.76 Kg.

The average price of formulation is 1.85 €/Kg, implying that cost for feed considering the longness of biological cycle is about 366K €. It means that annual feeding cost is close to 244K €.

Balance sheet analysis

Analysis was effected in order to calculate the cost structure of the sea bass farm, the incidence of feeding cost into the cost on the whole, and the profit achieved. Balance items are reported in the Table 2.

Table 2 – Balance items considered and their description

Item	Description
Revenues	
Value of production	Value of sea basses produced (€)
Variable costs	
Cost for energy and water	Cost for use of energy and water (€)
Cost for fuel	Cost for use of fuel (€)
Rent of boat	Cost for use of boat (€)
Cost for raw materials: livestock cost	Cost for purchaising juveniles and other raw materials for livestock (€)
Cost for raw materials: feeding cost	Cost for feed (€)
Salaries	Cost for salaries of seasonal workers (€)
Other variable cost	Other variable cost (€)
Fix cost	
Wage and salaries	Cost for wage and salary for permanent employers (€)
Depreciation of capital	Annual quoteof depreciation of capital (€)
Taxes	Cost for taxes (€)

Revenues are solely constituted by the value of marketable sea basses produced.

Capital is basically represented by the two cages for livestock, by the machineries for feeding, and by the headquarter whereas the boat useful for movement is annually rented. Manual and directive labour is mainly given by permanent employers, included the farmer that also operates as worker. However, the farm takes advantages of seasonal workers, especially in the phase of harvesting the specimen.

Simulations on use of insect meal.

Cost effects related to introduction of insect meal, were simulated on the basis of probable outcomes derived from the inclusion of insect meal in the diet. Information useful for simulating these outcomes were obtained by some works recently appeared in the scientific literature. Basically, we used data from empirical evidences by Gasco et al. (2016) that conducted a study on implications of introducting different quotas of insect meal into the diet of the European sea bass.

The experimental trials were realized employing *Tenebrio molitor* (TM) meal according to two increasing levels of this meal as fed basis (fed basis weights 70% of the forrmulation): 25% and at 50%, respectively.

Furthermore, we hypothised three scenarios about price of TM meal. As it stand today troughout Europe, TM meal price is sensitively higher than fish meal. For each level of inclusion of TM meal, we estimated cost effects considering 2.5 €/Kg, 5.00 €/Kg, and 10.00 €/Kg. These values were selected on the basis of prices found in literature or by interviewing opinion leaders relatively to different market conditions: (a) price close to the price generally applied for research institutes; (b) average market price reported in the Brabant Development Company (2016); (c) price applied in an extreme market scenario (close to the price for feeding pets).

Finally, we estimeted the indifference price for each described scenario.

4. Results

Balance sheet analysis findings are reported in Table 3. Results are showed considering both an annual and the biological cycle longness perspective.

Table 3 – Balance sheet analysis results

Item	**Cycle (18 months)**	**Year (12 months)**	**% on total cost**
Revenues	**613,600**	**411,430**	
Quantity (Kg)	*104,000*	*69,700*	
Average price (€/Kg)	*5.90*	*5.90*	
Variable costs	**476,009**	**318,926**	***82.2***
Raw materials: feeding cost	365,560	244,925	*63.1*
Raw materials: livestock cost	70,070	46,947	*12.1*
Salaries	15,035	10,073	*2.6*
Fuel	5,346	3,582	*0.9*
Energy and water	3,505	2,348	*0.6*
Rent of boat	11,880	7,960	*2.1*
Other variable costs	4,613	3,091	*0.8*
Fix cost	**103,218**	**69,156**	***17.8***
Wages and salaries	60,618	40,614	*10.5*
Depreciation of capital	6,300	4,221	*1.1*
Taxes	36,300	24,321	*6.2*
Total Cost	**579,227**	**388,082**	***100.0***
Profit	**34,373**	**23,230**	

Table 4 – Results from simulations on the basis of different technical and market scenarios

Item	**TM 0%**	**TM 25%**	**TM 50%**
Diet composition (%)			
Fish meal	70.0%	45.0%	20.0%
TM meal	0.0%	25.0%	50.0%
Others (e.g., oils)	30.0%	30.0%	30.0%
Feed used (Kg)			
Weight gain (WG)	0.38 Kg	0.38 Kg	0.38 Kg
Feed Conversion Ratio	2.00	2.02	2.20
Feed / specimen	0.76 Kg	0.75 Kg	0.69 Kg
Total feed - 18 months cycle	197,600 Kg	195,429 Kg	179,636 Kg
Total feed - annual	131,730 Kg	130,286 Kg	119,757 Kg
Feed Price (€/Kg)			
TM price 1 = 2.50 €/Kg	1.85 €/Kg	2.08 €/Kg	2.31 €/Kg
TM price 1 = 5.00 €/Kg	1.85 €/Kg	2.97 €/Kg	4.10 €/Kg
TM price 1 = 10.00 €/Kg	1.85 €/Kg	4.76 €/Kg	7.67 €/Kg
Feeding cost – 18 months cycle (€)			
TM price 1 = 2.50 €/Kg	365,560 €/Kg	406,491 €/Kg	414,960 €/Kg
TM price 1 = 5.00 €/Kg	365,560 €/Kg	580,423 €/Kg	736,509 €/Kg
TM price 1 = 10.00 €/Kg	365,560 €/Kg	930.240 €/Kg	1,377,811 €/Kg
Feeding cost – annual (€)			
TM price 1 = 2.50 €/Kg	244,925 €/Kg	272,349 €/Kg	278,023 €/Kg
TM price 1 = 5.00 €/Kg	244,925 €/Kg	388,883 €/Kg	493,461 €/Kg
TM price 1 = 10.00 €/Kg	244,925 €/Kg	623,261 €/Kg	923,133 €/Kg
Feeding cost Δ – with reference to status quo			
TM price 1 = 2.50 €/Kg	-	11.2%	13.5%
TM price 1 = 5.00 €/Kg	-	58.8%	101.5%
TM price 1 = 10.00 €/Kg	-	154.4%	276.9%
Incidence on total cost			
TM price 1 = 2.50 €/Kg	63.1%	65.5%	66.0%
TM price 1 = 5.00 €/Kg	63.1%	73.1%	77.5%
TM price 1 = 10.00 €/Kg	63.1%	81.3%	86.9%
Indifference Price	**1.85 €/Kg**	**1.87 €/Kg**	**2.04/Kg**

TM 0%: *status quo*

TM 25%: inclusion of 25% of TM meal into the fed basis

TM 50%: inclusion of 50% of TM meal into the fed basis

Findings suggest that sea bass production is profitable. The quota of the value created in favour of fish farmer is greater than the profit "*in stricto sensu*", *i.e.* as farm ability to generate earnings. This is because he is also a worker, than part of the wages and salaries is entitled to him.

However the high feeding cost suggests that more efforts would be done in order to limit magnitude and incidence of this item. Indeed, feeding cost corresponds to more than 63% of the total cost.

Starting from these results and as reported above, we estimated how the feeding cost would change on the basis of increasing levels of TM meal into the diet and different prices for purchasing this meal. Findings derived from simulations are shown in Table 4. This was estimated considering the same level of production of the *status quo* scenario.

In the alternative scenarios, the Feed Conversion Ratio was estimated on the basis of values reported by Gasco et al. (2016), *i.e.* it increases by 1% and 10% in case of introduction of TM meal at 25% and 50%, respectively. Hence quantity of meal tends to reduce increasing percentage of TM meal in the diet.

Estimations suggest that saving quantity of feed derived from increasing quota of TM meal would not compensate higher prices that today characterizes the European market of insect meal. This means that incidence of feeding cost into the total cost might tend to increase (until to about 87% in the case of TM50% and TM price equal to 10.00 €/Kg).

We also calculated the price that allows farmers to be indifferent about buying fish or TM meal. In other terms, we obtained the price that permits to bear the same feeding cost employing different quantity of FM and to ensure the given level of production. Estimated values are reported in the last row of Table 4. A sensitive difference between the *status quo* and the TM50% scenario arises from this estimation.

5. Discussions and conclusions

The present work has confirmed results from previous studies about the cost structure of aquaculture enterprises (Dickson et al., 2016; Henry et al., 2015; Kleih et al., 2013; Rana et al., 2009; Shaalan et al., 2017; Wilson, 2002). It is a fact that feeding represents the main item in the fish farm cost, especially concerning the small-scale farms. Vice versa, lack of empirical results related to cost effects derived from introduction of insect meal into the fish diet does not allows us to compare our findings. However, in our opinion, estimation of economic consequences of such new diet is pivotal to respond to the urgencies that affect the fish industry today and that might be more relevant in the next future.

The population is constantly growing so much that in 2030, in order to maintain the per capita aquatic food consumption, the world production will have to increase by 23 million tons (Magalhães et al., 2017). Aquaculture plays an essential role in the production of this key source of human food (Barroso et al., 2014). However, the ability of this industry to respond to the ever-increasing amount of fish is held back by two main problems linked to each other.

The first concerns the environmental sustainability of fishmeal and fish oil as the major component of the feed used in aquaculture (Barroso et al., 2014; Magalhães et al., 2017). Although the supplies of these commodities are finite, the expansion of aquaculture production has increased their consume (Hardy, 2010), which, in turn, led to the rapid rise in their prices (Magalhães et al., 2017).

The second refers to the economic sustainability, that is the ability of an aquaculture farm to be profitable in the long-run. Nevertheless, the profit maximization has to be pursued using resources efficiently and minimizing environmental impact. This because the aquaculture bears for the purpose of offering a more environmentally friendly fish production process rather than sea fishing. Therefore, economic sustainability is linked to environmental sustainability. But the reverse is also true: the environmental sustainability depends on the economic sustainability, inasmuch as if the fish farm doesn't make a right profit, it will not be able to bear the burden of new production techniques or new foods that are eco-friendly that often cost more rather than the present state of affairs.

Given the awareness that "there's no alternative to sustainable development" (Nidumolu et al., 2009, p. 57) and that aquaculture has the potential to be environmentally sustainable, it is crucial to understanding how to increase the economic performance of this type of production.

The economic performance of an aquaculture farm is dependent on a number of factors.

First, this industry, often classed as capital intensive, requires large initial investments and financial resources.

Second, revenue streams are directly linked to the market price of European sea bass. The price of the final product doesn't reflect the rising price of feeding costs (Adwan, 2017; Shaalan et al., 2017). However, more and more consumers are demanding higher standards of quality and assurance on the sustainability process of fish production (FAO, 2016), and they are willing to pay a sustainability market price (Muñoz, 2016). Indeed, their are less sensitive to price, hence are more willing to pay a price premium for a product that incorporates social and environmental attributes (Mónica and Pilar, 2016). The use of insect meal into the fish diet responds to such requirement, and recent researches have shown a satisfactory level of its acceptance (Makkar et al., 2014; Mancuso et al., 2016; Popoff et al., 2017; Verbeke et al., 2015). Therefore, consumers sensitive to the problem of environmental sustainability of fishing could be willing to pay more for this type of fish. In addition, since consumers give great prominence to the country of origin of fish (Claret et al., 2012), considering domestic fish of higher quality than imported (Mauracher et al., 2013; Stefani et al., 2012), a local aquaculture farm will benefit from a greater advantage and therefore propose a higher sales price as well.

Finally, aquaculture industry can introduce an eco-labels, given that previous research suggested that its adoption can justify a premium price for food products (Zhou et al., 2016). The quality, the attention to the environment, along with certification standards, can generate greater confidence in consumers about environmental responsibility and food safety of aquaculture products (Washington and Ababouch, 2011), further increasing the demand of these products.

Third, the production costs are related to factors such as the price of production inputs and the economic loss in case of negative externalities (*e.g.* the attack of the dolphins to the cages).

Insect meal is seen by many as a solution to the problems of aquaculture companies in terms of stability and reduction of feeding cost (Mancuso et al., 2016; Sánchez-Muros et al., 2016). However, at present, insect meal is not yet a competitive protein source for aquaculture (Koeleman, 2014).

A recent report drawn up by the Arcluster (2017) estimates that the animal insect production market is worth half a billion dollars, with a growth forecast of over $1bn by 2022. This means that insect feed could account for up to 3% of the entire production of feed market within the next four years (Arcluster, 2017). According to the Brabant Development Company (2016), insect proteins can compete, in terms of price, with those of fishmeal starting from 2023. However, this isn't enough to ensure see an improvement in aquaculture farm cost structure. Given that flour and fish oils will keep or will increase their price, until the insect flour will not have a price significantly lower than the price of flour currently used in aquaculture, the fish farm should find alternative solutions.

One of these may be the change in the production scale, that can allow to reduce waste, by an economic point of view, due to possible presence of increasing return to scale, and to increase its bargaining power with both suppliers and organized large-scale distribution system. To increase the production scale is pivotal the role of institutions and authorities. From the entrepreneur's side, they can actively promote training paths able to fill the lack of experience and knowledge, the lack of technologies used in fish production and extension services and poor management. The increase in the professionalism of the entrepreneur can be the spark for its decision to extend the production scale and risk making new investments in the farm.

From the consumers side, among the attributes that determine the consumption of fish there is also the attribution of positive effects on health and nutritional beliefs (Carlucci et al., 2015), while it is hindered by the warning of problems related to the risk for health, the lack of knowledge in the selection and preparation of fish (Mancuso et al., 2016). Even in this case, institutions and authorities can contribute to increase the knowledge of consumers who will be pushed to search for high quality products and pay a premium price to have them. Consumers are those who will decree the success or failure of the use of insect flours, and only their awareness about the benefits of eating fish products in fish farms and the absence of risk in eating fish fed with insects, it is the key to bringing together economic and environmental sustainability.

Finally, more research in this field is required to improve knowledge of this issue and to support decision makers – farmers, policy-makers, trade unions, etc. – in order to better respond to the future challenges. This is a first attempt – among the other limits, based on simulations, only on sea bass production, and by a case study approach – that has put attention on inclusion of insect meal in fish farming by an economic perspective, showing that the economic dimension of sustainability would be far to drive together with the environmental one, that is a basic condition according to the Goal 14 of the Sustainable Development 2030.

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