Probiotics can have a significant impact on digestion efficiency and the environmental impact of fresh water fish farms.

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Abstract: The health status and feed conversion efficiency of farmed fish may vary according to management and production methods. Successful aquaculture requires safeguarding the health of the growing fish and optimizing the feed conversion and therefore achieving better FCE thus reducing the amount of feed required to produce farmed fish, reducing the environmental impact generated by fish feed production and reducing aquaculture wastes generated by feed wasted or poorly digested. The present review presents illustrative examples from freshwater aquaculture that suggests the potential dual benefits of focusing on the link between feed conversion and the environmental impact of fresh water fish farms. Apart from the need to support future research on new diets for farmed fish (which is mainly driven by limits in the supply of fish protein and the results price fluctuation of all ingredients used by the aquaculture, feed industry), major improvements can be expected by optimizing feeding regimes and the application of probiotics. Aside from the economic benefits and increased production of fish farms, improved feeding regimes and probiotics are expected to have a significant impact on the welfare of farmed fish as well as on digestion efficiency and the environmental impact of fresh water fish farms.

Keywords: Aquaculture; Probiotics, Fish welfare.

1. Introduction

As the world continues to deal with sustainability problems, aquaculture produced seafood has been found to have the potential of playing a major role in achieving global food security since it has a longstanding measure of efficiency in food production. Today, farmed seafoods contribute more to the human food needs by weight than wild-caught to become the fastest-growing source of animal foods [1]. Aquaculture is viewed as having a significant contribution to food security since aquatic animals, especially fish, have an efficient feed conversion ratio that results in a high and reliable supply of animal foods. Feed Conversion Ratio (FCR) is the common measure that measures the efficiency with which animal bodies convert feeds into desired outputs [2]. However, several factors affect FCR efficiency in aquatic life. The environment is a major factor that affects the efficiency of FCR in aquaculture. According to De Vedral et al. [3] the environment strongly influences FCR at the production unit level for farmed seafood. For example, compared to sea based aquaculture, land based fish farms exhibit better FCR and this is partially explained by the unpredictable variability of several environmental parameters at the sea. For example, at sea farmed salmonids can be exposed to a wide range of thermal condtions which requires adjusting feeding regimes while several other parameters such as diurnal oxygen fluctuation and parasitic infestation also affecting the potential growth and FCR [4,5]

Farmed fish are fed with aquaculture feeds which are converted to fish biomass. The amount of feed supplied to each aquaculture pond is adjusted according to feeding regimes and the ratio of dry feed weight to wet weight gain is calculated as the feed conversion ration. An increase in the FCR indicates that feed is converted less efficiently in body mass and thus the amount of feed required to produce one kg of fish will increase. A low feed conversion efficiency (FCE) can be partially attributed to small errors in calculating the biomass and adjusting the amount of feed required in each pond. Small aquaculture units may fail to control feeding. For example there are reports that fish farms may frequently overfeed with additional feeding offered according to the perceptions of farm operators who could decide on the basis of their subjective experience if and how much additional feeding was required [6]. As a result, FCE may vary between fish farms due to unintentional differences in feeding rate. As in several other fish species, overfeeding farmed rainbow trout can compromise food digestibility and function of the intestine, resulting in less efficient feed conversion [7]. This is a crucial parameter for controlling and reducing fish wastes with significant economic and environmental consequences. Further field research in the fish farms in the region is required to confirm and evaluate the magnitude of this problem. There are economic and environmental benefits for the sector if feed waste is reduced. Feed is a significant parameter for the cost of production, usually over 50% and also a significant parameter for the environmental impact of aquaculture.

The organic load generated by fish farms is offering nutrients to support bacteria. If fish are overfed, this will result in suboptimal feed utilisation and this will have an impact on the amount of unconsumed or poorly digested feed. Moreover, excessive feed may increase the possibility of pathological problems in fish, with over feeding resulting in pathological problems in the digestive organs of farmed fish [8, 9].

Aquaculture of intensively cultivated fish is mainly based on fish ponds with recirculating or open flow water using intensive fish farming methods. Environmental conditions, including water quality, stocking density and temperature can affect fish growth and feed conversion efficiency of farmed fish [10]. Furthermore, dietary regimes or pathological problems can compromise digestion and affect FCE [11,12] .

Open flow rainbow trout fish farms generate a considerable amount of nutrients released in the aquatic ecosystems. The organic load generated by fish farms may vary according to unconsumed or poorly digested fish feed, fish metabolism and excretions which can result in the accumulation of suspended nutrients in the water bodies were effluents are released [13,14]. Even within the ponds, waste solids can form sediments were N or P will be deposited and support bacterial growth, affecting levels of NH_4–N , oxygen and P in the water column of fish ponds. All the above may have an impact on the water quality and growth of farmed fish and a negative environmental impact [15]

The organic load and the impact of freshwater fish farms in the aquatic ecosystem can be reduced by manipulation of the dietary regimes, for example by adjusting the quantity of feed according to feed manufacturer feeding tables and reduced phosphorus content in the feeds. In practice, fish farmers may fail to follow the recommended feeding rations, due to inadequate monitoring of size dispersion and total fish biomass which creates uncertainty in the estimation of fish weight [6].

A reduction or increase in FCE may reflect an increase or decrease respectively, of uneaten or poorly digested fish feeds. Uneaten feed and fish excretions will support bacterial growth in the water column and the sediments of the ponds [16].

Nutrient in the water column and the sediment of the ponds can increase according to the organic load released by fish farms, directly increasing the environmental impact of fish farms in the aquatic ecosystem [16, 17].

There are several changes driven by research and global market forces in the composition of aquaculture feeds. There is an obvious trend to reduce the dependence of fish feeds on fisheries and to replace fish protein and fish oils with alternative sources of proteins and fat. This trend reflects a response of the global rising aquaculture industry and the need to increase the production of aquaculture feeds which require wild caught fish as a major raw material, a basic ingredient which is characterised by limited supply of overfished and regulated fish stocks. As a result, research on the formulation of new diets and the replacement of fish proteins with insect and plant proteins is intensified [8,11,18-20]. In any event, any new diet is expected to exhibit good performance in palatability, digestibility and feed conversion efficiency which will also be reflected in improved growth. The environmental issues are also relevant and this can be seen in the composition of aquaculture feeds which changed significantly over the course of the last few decades, resulting in improved feed conversion and reduction of nutrients released in the aquatic environmental by fresh water aquaculture [21].

Sustainable development of fresh water (FW) aquaculture requires minimal environmental impact, monitoring the organic load released in the aquatic ecosystem, while safeguarding fish welfare and the productivity of the sector.

The data reviewed in the present work, illustrate the significant role of probiotics and feeding regimes, on digestion efficiency and the environmental impact of fresh water fish farms.

How feeding regimes and probiotics can help reduce the environmental impact of fresh water fish farms.

Sustainable development of fresh water (FW) aquaculture requires minimal environmental impact, monitoring the organic load released in the aquatic ecosystem, while safeguarding fish welfare and the productivity of the sector. Feed conversion efficiency the organic load generated by land based fish farms is governed by a combination of nutritional, biological and external factors. For example growth may be influenced by biological and genetic elements, by the stocking density of farmed fish, by the quality and quantity of feed, by the digestibility of particular ingredients used for feeding a particular species, as well as by the temperature and other environmental parameters such as oxygen availability and water quality [22-25). Upon reaching maturation, fish divert the majority of energy intake to the growth of gonads. As a result, sexual maturation of farmed fish is also an important parameter with consequences to growth rate and allocation of feed energy to gonad or muscle growth, affecting the FCR which in turn can significantly affect feed conversion and fish wastes generated by aquaculture [26,27].

Figure 1 illustrates a representative situation of how changes in FCR can affect the release of Phosphorus by fish farms. In this particular example, temperature affected FCR of farmed rainbow trout fish farms.

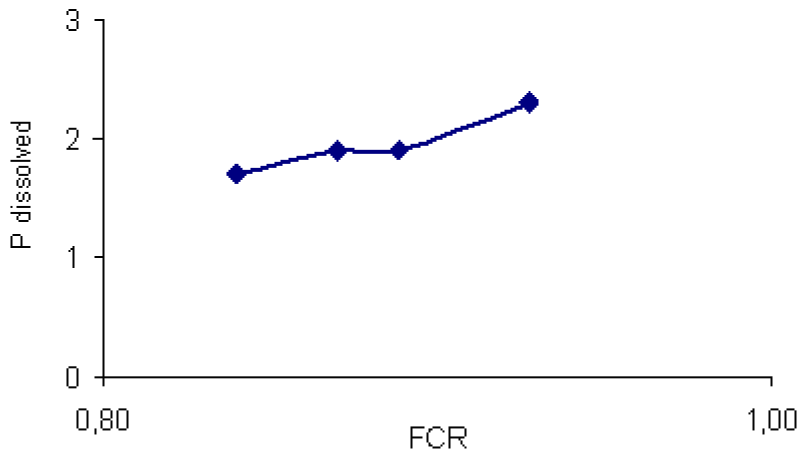

Figure 1. An example of how changes in FCR can affect the Phosphorus ;oad released by farmed rainbow trout. This is due to the fact that increased FCR (i.e. when more feed is required to produce one Kg of weight gain) will result in a proportional higher amount of P released in the aquatic environment. (Data calculated from Azevedo et al. [28].

Temperature is a controlling environmental factor which affects the rate of biochemical reactions in fish [29]. In temperate climates, photoperiod and temperature are important environmental cues that fish use to anticipate seasonal cycles. These cues help fish to adjust their swimming, foraging and metabolic activities in the best possible manner. For example some fish cease to forage and feed when temperature drops bellow a certain value; it would make no sense to actively seek food when winter productivity of the ecosystem is low and digestive enzymes are not functioning properly at low temperatures [22,30]. As a result, temperature can exert a significant influence on the amount of feed required for producing an increase in the body weight of growing fish. The best combination of FCR and feeding is when when fish are not over or underfed but also when feeding regimes are adjusted according to the needs of each species, stage of development, size and overal aquaculture conditions of a fish farm. As a result, the management of fish feeding in aquaculture can result in significant improvements in the FCR and the wastes generated by fish feed [22,30-34].

The current trend is to increase the use alternative protein sources in order to reduce the reliance of aquaculture feeds on fisheries, but this needs to be accompanied by extensive research on nutrition [33] as well on the reduction of feed wastes [27] while at the same time research avenues for the best feed conversion efficiency must be explored. FCR varies tremendously according to feed composition and management practices. It also affected by thermal conditions and feeding regimes. Suboptimal temperature and overfeeding can result in fish wasted as uneaten or poorly digested resulting in increased FCR. For example, at low winter temperatures, farmed rainbow trout can exhibit decreased feed conversion efficiency, digestibility of dry matter, nitrogen and energy of the diet resulting in increased waste of solid nitrogen waste outputs per kg fish produced [28].

Optimal fish feeding, fish welfare, and reduction of the environmental impact of fish farms are crucial parameters for the economic viability and sustainability of the sector [13,15,27,35]. The health status and the efficiency of feed conversion efficiency of farmed fish may vary according to management and method of production [36]. Successful aquaculture requires safeguarding the health of the growing fish and optimizing the feed conversion and therefore achieving better FCE and reducing the amount of feed required to produce farmed fish, reducing the environmental impact generated by fish feed production and reducing aquaculture wastes generated by feed wasted or poorly digested [27].

Poor digestion can result from intestinal digestion and absorption dysfunction resulting in low feed conversion results in increased requirements of feed [37]. Intestinal pathological problems are frequently reported from experimental fish diets reflecting an obstacle in the replacement of fish proteins with alternative sources [8,11,20,25,37]. Intestinal health is crucial for animal growth and the efficiency of animal feeds [9]. Intestinal pathological problems of farmed fish can be associated with the disruption of intestinal function and reduction in the efficiency of feed conversion [8]. Sub acute intestinal pathological problems such as sub-acute intestinal inflammation [40] can affect digestibility of feed [39]. Intestinal pathological issues may affect normal functions of the intestine, a higher index of intestinal pathological score and inflammation can therefore result in higher exrection of nutrients as a result of impaired digestion [27,38,39].

For example, partial supplementation of fish protein with plant protein [11] can result in sub acute pathological problems of the gut. Likewise, inflammation of the gut may also be triggered by infections; compromising hormonal homeostasis and gut microflora [42] and functional integrity of the intestine and consequently further reduce the growth potential of farmed fish [43,44]. For this reason, it can be assumed that even sub-acute pathological problems of the fish intestine will impair digestion efficiency and consequently feed conversion efficiency. This is graphically illustrated in Figure 2 were dietary induced changes in the density of goblet cells were associated with changes in FCR of common carp (data calculated from Ostaszewska et al [38].

Aquaculture is an increasingly important socio-economic area of development for many areas of the world. Over recent years more intensive farming methods have been used to increase yield, with antibiotics used to ensure that fish stocks are healthy and free of disease. The environmental impact of these processes, and the risk to human health from antibiotic-resistance microbes however has necessitated a revision in how these aquaculture environments are regulated. Probiotics offer a more environmentally sustainable approach to fish feed stocks – facilitating an improvement in disease prevention whilst minimising the impact to the surrounding ecological systems [45-51].

Probiotics are members of the healthy intestinal microbiota and there is some evidence to suggest a positive effect of probiotics in improving the digestion, health and growth of farmed fish. Probiotics' microbial modulation may also help improve host's nutritional status and growth with farmed fish fed with probiotic supplements exhibiting improved feed conversion, a significant parameter for sustainability of aquaculture [51, 52].

For example, improved growth of African catfish [53] and common carp [54] was exhibited when probiotics were added in their feeds. Furthermore, probiotics may be used to reduce the usage of antibiotics in aquaculture as probiotics have the ability to modulate gut microbiota, thereby preventing gut inflammation and reducing the need for treatment of gut pathological problems [55-57]

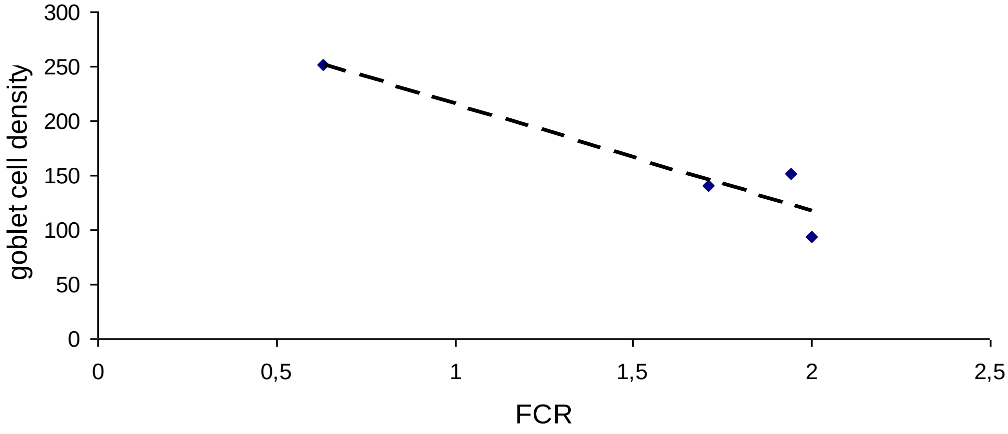

Figure 2. Lower density of goblet cells in common carp (Number of goblet cell/100 μm length intestinal fold) associated with increased FCR. Illustrating how a pathological condition in the intestinal tract can impair feed conversion. Data calculated from Ostaszewska et al [38].

Dietary administrated Lactic acid bacteria for example, are found in the mucosal epithelium of the gut and help to prevent pathogen proliferation [58-60]. Probiotics added in the ponds of farmed Tilapia, resulted in improved growth and increased lactic acid bacterial count in the water and the intestinal tract and improved immune response and resistance against *Aeromonas hydrophila* [61].

The physiological mechanisms of this protection against pathogens include competition of probiotics with pathogens on extracellular binding sites at the mucosal epithelium [58,62] alteration of the extracellular pH [63] and the production of molecules with antibiotic properties [64] which can prevent the proliferation of pathogens. Additionally, improved immune response can be exhibited, for example, *Clostridium butyricum* improved leukocyte phagocytic activity, resulting in increased resistance to vibriosis in farmed rainbow trout [65].

Probiotics can be administrated via differenent methods to improve the physiology, growth performance and immune responses of many fish species [66]. For example, it has been shown that nutrients are absorbed more efficiently when the feed is supplemented with probiotics – providing significant benefits to the digestive processes for a variety of fish species [51,62,67,68]. To ensure that probiotics can be used effectively and improve animal health without impacting the surrounding water quality, the commercial viability of these options is critical. Improvements to feed efficiency is one key area for development, as it can help to reduce production costs and create a more economically sustainable approach for probiotic use [60]. In several studies it has also been demonstrated that probiotics are efficient in the transformation of organic matter to carbon dioxide – helping to minimise the accumulation of dissolved and particulate organic carbon during the growing season and this could ultimately improve local water quality by balancing the production of phytoplankton and eutrophication in these environments [69].

Some issues have been identified with the use of fish feed on probiotic distribution, including the problems associated with early life stages of development and the immaturity of the digestive tract. The supplementation of rearing water is currently the only method which is applicable for fishes of all ages and a higher level of incorporation of probiotic bacteria has been observed (Jahangri and Esteban, 2018). As a result, the most appropriate administration option may be to add probiotics directly to water containing animal larva and combine this with the use of enriched live feed [66,70,71]. In addition to the beneficial effects of probiotics as feed supplements on digestion and health, there is some evidence that adding probiotics to fish pond water can also be beneficial, and these benefits may include improvements in water quality, which is a critical parameter for growth, feed conversion, and farmed fish welfare. Fish excrete NH4-N and nitrogen compounds in fish ponds, which denitrification bacteria can convert to nitrites and nitrates. There is some evidence to suggest that aquaculture in ponds, including recirculated fresh water aquaculture systems, has the potential to reduce toxic levels of ammonia and phosphorus [49,50,51]. Environmental concerns about the amount of organic matter released in aquaculture effluents, combined with global warming and competition from other industries for limited water resources, may limit the availability of water for freshwater fish farms. Under these conditions, technological advances in water treatment, such as partial recirculating aquaculture systems, could pave the way for the future of sustainable fresh water aquaculture. The data reviewed in the present study, indicate that the organic load in the effluents of the fishponds may vary, this can be attributed to feeding control, for example due to subjective or objective minor miscalculation for feeding requirements and fish biomass as well due to intestinal health issues. A reduction in the organic load generated by trout farms could be reduced by a more accurate calculation of the feeding requirements of each pond. Aquatic pollution is a significant environmental issue for freshwater ecosystems, affecting the ecological status of the benthos and the welfare fish in rivers [72]. In addition to the economic and environmental issues, gut health is a significant parameter for the welfare of farmed fish [73, 74]. Gut health status and subacute gut pathological issues are current welfare issues which constitute a major obstacle for sustainable aquaculture development, widely investigated by fish nutritionists working with several farmed fish species [40, 76-78]. Rerearch on improving feding regimes and developing new feeds with optimal digestibility and metabolism [2,79-81] is a prerequisite for sustainable growth of aquaculture.

4. Conclusions

. In conclusion, the data reviewed indicate the potential for improving both the sustainability of fresh water fish farms and the health of farmed fish by investigating the potential benefits of using feeding regimes and probiotics to achieve optimal feed utilisation via improved digestion, feed conversion, and fish health [61,62,82,83].
It can be concluded that there are several reasons to drive research and development of improving FCR, this drive derives from economical, fish welfare and environmental concerns for the Aquaculture industry. There are several parameters which can affect FCR and the environmental impact of fresh water fish farms, which can have direct and indirect effects on the environmental impact of aquaculture, for example via directly affecting the level of phosphorus pollution and indirectly increasing the environmental impact of aquaculture associated with increased feed wasted or poorly digested feeds. Improved feeding regimes and probiotics are expected to have a significant impact on the economics of fish farms, the welfare of farmed fish as well as on digestion efficiency and the environmental impact of fresh water fish farms.

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