Grain 7: Fish nutrition

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Introduction: Importance of feeding in fish farming

The cost of feeding in intensive fish farming systems can reach or even exceed 50% of total costs so that adequate nutritional practices play an increasingly important role in aquaculture, in terms of economic optimization but also to maintain the welfare and health of animals, to obtain adequate growth performance, to ensure the quality of the flesh, in particular its content of omega-3, as well as to reduce the polluting impact of farms by reducing discharges to the environment.

During this topic, you will discover the nutritional characteristics of fish, how they are fed with natural or exogenous feed, and discover new approaches to produce sustainable fish feed.

The nutritional requirements of fish

Unlike other animals, fish have a very wide variety of diets. The main species produced in the southern countries have a low trophic level regime: they are herbivores or omnivores. This is for example the case of carps, tilapia or panga. In contrast, the domestication efforts in developed countries have often focused on high-value species, which are generally carnivores. This is the case of salmon, trout, seabass etc.

The nutritional requirements of many farmed fish are now well known. Fish have significantly higher protein requirements than mammals or birds: 30% for the less demanding like catfish, carps or tilapia, more than 50% for some species like turbot. Lipids are also very important, as they serve both as an energy source but also qualitatively, to provide the (n-3) polyunsaturated fatty acids, the famous omega-3, which give the fish their dietary qualities. However, carbohydrate are not well digested by the majority of fish.

Natural feed

When ponds are stocked at low density, natural aquatic organisms are sufficiently abundant to support the growth of fish without using exogenous food. The fish pond is indeed an ecosystem where many microbial organisms, plants and animals coexist and interact. In order to make the best use of this trophic resource, fish farmers traditionally associate different fish species with complementary natural diets to increase the total biomass produced. This is called polyculture.

The production of these aquatic organisms can be increased by using fertilization and providing nutrients to autotrophs (aquatic plants, including phytoplankton) and heterotrophic organisms (bacteria, ciliates, zooplankton etc.). Fish consume these natural plants and animals that are at the base of the aquatic food web. With a well-managed fertilization, it is possible to increase fish production in a given water body by a factor of 10.

Just like with gardens, it is possible to use inorganic fertilizer or organic fertilizer. Organic fertilizers are very effective because they stimulate both trophic pathways: autotrophic and heterotrophic. But they also have a disadvantage because when brought in excess, they can lead to severe deoxygenation and mortality of all aquatic organisms, including fish. They have another disadvantage, linked to the negative consumer perception. Although this technique has been practiced for centuries in almost all countries of the world, including in France, the use of organic waste, including animal manure is no longer well accepted by consumers. As regard to the sanitary concern, numerous scientific and health monitoring studies have shown that it was not justified, presumably because microalgae naturally produce antibacterial substances and also because their activity creates environmental conditions extremely unfavourable to pathogenic bacteria, such as a very high pH. However, the cultural rejection remains very strong in France and in many developed countries, although this ancient practice of transforming worthless organic waste into high quality protein food is also consistent with modern principles of circular economy.

The limits of the use of fishmeal and fish oils

When the fish biomass increases or when the rearing structures do not allow fish to forage on natural feed, exogenous feed must be supplied. Historically, carnivorous species were fed using "trashfish", ie fish of lesser commercial value, often caught in the wild. This technique, however, has negative impact on wild populations and creates problems of irregularity of supply, as well as a risk of environmental pollution affecting the quality of fed fish.

In the 70s, commercial feed specifically designed to fulfil the nutritional requirements of farmed fish have become available in order to overcome these constraints and improve the quality of fish. They allowed aquaculture production to increase very quickly. Although their formulation improved, they are still manufactured today from a variety of raw materials, among which fishmeal and fish oil, indispensable to meet the high requirements in protein and omega-3 of fish.

With the large-scale development of aquaculture, this started to create an ecological problem of overexploitation of some pelagic fish stocks used to produce fishmeal and fish oils. Alternatives such as animal meals could have been used as replacement, but the mad cow disease crisis highlighted the associated risks. Animal meals have long been banned in Europe and are still banned by the French fish farming industry.

But research progresses and new ways to produce sustainable feed exist: plant feeds, insects etc. The use of macroalgae or insects as ingredients for fishmeal replacement are among the most attractive solution for the future of aquaculture feed.

La valorisation alimentaire des macro-algues en aquaculture

Les promesses des macro-algues

L'exploitation des macro-algues est une thématique prometteuse en termes d'efficacité alimentaire des élevages et de protection de l'environnement. Le CIRAD et l'IFREMER et d'autres partenaires dans la région de Montpellier ont choisi de se pencher sur ces questions afin de contribuer à la durabilité des systèmes aquacoles.

Les macro-algues incluent plusieurs groupes d'algues dont les algues vertes, brunes et rouges. Elles ont toutes en commun de n'avoir pas de racines nourricières, voire pas de racine du tout. Ces algues absorbent donc les sels nutritifs dissous dans l'eau directement par leurs feuilles, ou thalles. Cette caractéristique confère aux macro-algues une forte réactivité en présence d'azote et de phosphore dissous, nitrate (ou ammoniac) et phosphate, respectivement : elles se développent rapidement en réponse à une pollution du milieu. Les blooms de macro-algues sont une nuisance pour le littoral, à l'origine notamment des marées vertes en Bretagne ou des malaïgues dans les étangs côtiers du Languedoc-Roussillon.

Par ailleurs, l'azote et le phosphore absorbés par les macro-algues sont convertis en protéines dont la teneur peut atteindre 45% de la matière sèche dans l'ulve ou salade de mer. La farine d'ulve constituerait une source de protéines alternative dans un contexte de renchérissement des sources de protéines en général et du tourteau de soja en particulier. Le prix de ce dernier a doublé en 10 ans pour atteindre 330 € la tonne ; la France en importe environ 3,9 millions de tonnes (MT) par an pour une valeur d'environ 1,3 milliards d'euros.

Les macro-algues permettraient donc de recycler les protéines des animaux d'élevage dont les poissons. Cette perspective est d'autant plus intéressante que seule une fraction (10-40%) des protéines et donc de l'azote est fixée par les poissons ; la majeure partie est excrétée et perdue. Concrètement, la production d'une tonne de poissons est associée à l'émission d'environ 50 kg d'azote, soit l'équivalent des rejets annuels d'une ville de d'environ 14.000 habitants.

Nos recherches sont focalisées sur les ulves au niveau de la conversion de l'ammoniac en protéines algales et de l'efficacité alimentaire de l'algue pour nourrir des poissons.

Conversion de l'ammoniac en protéines algales

L'azote issu du catabolisme des protéines est excrété par les poissons sous forme d'ammoniac (NH_3 / NH_4^+) au niveau des branchies. L'ammoniac est une molécule toxique pour les poissons qu'il faut donc éliminer du milieu d'élevage. L'ammoniac est éliminé grâce à un changement d'eau ou bien par une transformation en nitrate dans les circuits d'élevage dits ouverts ou fermés, respectivement. La fixation de l'ammoniac par les algues présente les avantages suivants : meilleure absorption que les autres formes azotées, économie d'oxygène et même production d'oxygène et, en plus, fixation du CO_2.

Un essai a montré que l'apport d'ammoniac au milieu de culture des ulves permet de faire passer la teneur en protéines de 10-15% à 35% (% matière sèche) en deux semaines. L'enrichissement le plus fort est obtenu avec un apport en carbone réduit au seul CO_2 atmosphérique. Concrètement, on peut prévoir de faire varier le ratio des apports carbone/azote pour favoriser le gain de biomasse ou l'enrichissement en protéines. En conditions optimales de culture intensive (bassin avec 2 kg/m^2 de biomasse stockée, brassage de l'eau et apport de CO_2), à titre d'ordre de grandeur, une surface de 100 m2 permet en un mois de produire 107 kg de farine d'algue (536 kg d'algue fraîche) dont 38 kg de protéines ; cette production permet de fixer le rejet d'azote (7,5 kg) issu d'une production de 95 kg de poisson.

Un outil pratique a été mis au point afin de suivre en temps réel la composition des ulves, notamment la teneur en protéines (ainsi que la teneur en matière sèche et la teneur en minéraux). Il s'agit de l'analyse par spectrométrie dans le proche infra-rouge (SPIR), couramment employée sur des matières alimentaires terrestres. Cette technique est appliquée de manière non destructrice aux échantillons d'algues fraîches (150 g) et les résultats sont connus en quelques minutes.

L'efficacité alimentaire des algues

S'agissant d'une matière végétale, nous avons choisi de nous intéresser à la valorisation des ulves pour nourrir des poissons marins omnivores. Des travaux sont en cours avec le muge ou mulet (*Liza ramada*) et la saupe (*Sarpa salpa*). *L. ramada* est l'espèce de muge la plus abondante au Nord de la Méditerranée, dans les étangs littoraux et les estuaires en particuliers. La saupe est pratiquement le seul poisson exclusivement herbivore en Méditerranéen qui atteint une taille intéressante (50 cm pour 1 kg). L'intérêt commercial de ces espèces fait débat : dépourvues d'arêtes intramusculaires, elles sont appréciées des consommateurs au Sud de la Méditerranée mais elles ont encore à faire leur preuve en Europe.

A l'échelle mondiale, les poissons omnivores occupent une place importante en pisciculture : la carpe herbivore (*Ctenopharyngodon idella*) est la première espèce produite (> 4 106 tonnes/an), le milkfish (*Chanos chanos*) est le 2ème poisson marin (650.000 T/an) ; le tilapia (*Oreochromis niloticus*) et le panga (*Pangasianodon hypophthalmus*) sont également importants (≈ 2 106 T/an par espèce). Le régime alimentaire omnivore est associé à un coût de production modéré ; en phase de grossissement, les aliments distribués aux poissons ont des teneurs en protéines modérées (20-25%) et les ingrédients sont d'origine végétale pour 90%. Ces poissons sont certes produits principalement en Asie mais, pour le panga et le tilapia, ils sont aussi maintenant massivement importés en Europe. Enfin, l'ormeau (*Haliotis* sp.) un coquillage exclusivement herbivore est produit en aquaculture à un faible tonnage mais sa valeur marchande est très élevée ; il existe une ferme en Bretagne.

Un essai réalisé avec le muge montre qu'il est possible de remplacer la moitié des protéines de soja par des protéines d'ulve dans un granulé complet ; la croissance des poissons est similaire à celle obtenue avec un granulé sans farine d'ulve ; la meilleure croissance a été obtenue avec l'apport de 25% de protéines d'ulve.

Nos travaux en cours portent sur l'optimisation de l'incorporation de la farine d'ulve dans un granulé extrudé. C'est ce type de granulé qui est principalement employé en pisciculture de par sa bonne tenue à l'eau. Or, il semble que la farine d'ulve présente des caractéristiques particulières qui peuvent impacter les propriétés physiques des granulés. En particulier, cette farine à une forte rétention d'eau liée à la résistance des cellules à la dessiccation (qui peuvent donc se réhydrater) et/ou aux propriétés gélifiantes des polysaccharides (ulvanes). Nous essayons de mettre au point un process de production de farine d'ulve qui réduirait ces caractéristiques indésirables. Ce process pourra aussi permettre d'améliorer la digestibilité de cette farine.

Enfin, les ulves – et les autres macro-algues – semblent présenter une variabilité importante au niveau de la composition des protéines, c'est-à-dire de leur profil en acides aminés. Ce profil est un élément essentiel de la qualité des algues, en particulier au niveau de l'abondance des acides aminés essentiels. Nous souhaitons étudier le lien qui pourrait avoir entre les conditions de culture et la composition des protéines.

<u>The benefits of using insect meal to feed fish (Frédéric Maillard)</u>

As already said at the beginning of this video, insect meal is an interesting source of protein to feed fish in aquaculture. Indeed, in the DESIRABLE project we are working at IRSTEA on this topic, as insects are good candidates for a number of reasons:

Insects are a natural component of the diet of many fish

In the wild, insect larvae (caddis flies, mayflies, dragonflies, mosquitoes or midges) are always part of the diet of fish living in river or ponds: trout, salmon, shadow or cyprinids like carp or roach ... Omnivores or carnivores, well known by fly fishermen, these species ingest larvae of aquatic or land insects felt into the water.

There are over 200 species of fish that feed on mosquito larvae, which have been tested to control malaria and improve population nutrition.

The archerfish hunts insects, using a jet of water up to 3 meters above the water surface.

Finally, marine fish that feed on small crustaceans and are capable of digesting their cuticle are also potentially capable of consuming insects.

Insect meal has nutritional benefits quite similar to that of fish meal

<u>Type of insect</u>

According to FAO, the 5 main insects with a major potential for large animal feed production are the Black Soldier Fly (*Hermetia illucens*), the Common Fly (*Musca domestica*), the yellow mealworm (*Tenebrio molitor*) – and two other species of insects, silkworms and crickets. Producers in China, South Africa, Spain and the USA already grow-out huge quantities of flies for aquaculture and poultry feeding, by bioconverting organic wastes.

Nutritional composition of insects

With these 5 main insect species, raw protein content is between 40 and 80% dry weight, with an average around 50%. The variability is more connected to the species than its feeding.
The fat content expressed in % dry weight is between 9 and 45%. Just like the fatty acid profile, it depends on insects' feeding; one should notice a low content in-omega 3 and 6.
The fibber content is between 5.7 and 8.5 % due to the chitin.

Meal production

Fish can be fed with whole-body insects, whether when they are adult, larvae or fingerlings, or by using more or less defatted meals. During experiments, meals are generally obtained after boiling or freezing of insects, and then drying or lyophilisation, chopping or grinding, and sometimes, fat separation. These processes can nevertheless induce changes in the nutritional content. In industrial production or at the pilot scale, the market of insect meal is still relatively new, so that the transformation processes are still being optimized or confidential.

The first lessons of test results conducted with meals of insects such as *Tenebrio molitor*, soldier fly, maggots fly, locust and silkworm show that overall, they are attractive to fish.

The silkworm meal digestibility rate by Asian seabass (73% for energy and 85% for protein) is better than that of meat and bone meal.

Most growth tests conducted on different species (African catfish, river catfish, tilapia, trout, turbot, walking catfish, common carp and Indian carps, chum, Mahseer) indicate that including insect meal in the ration at a rate of about 10-50% (average 25%) does not affect the growth and size of the fish. Beyond these levels, digestibility problems, growth and fertility slowdown are mentioned.

A total replacement of fishmeal by soldier fly meal has been tested in Indonesia with species such as the snakehead fish *Channa micropeltes* and the Giant Gourami without any loss of production.

Fish fillets tasting tests show that they are acceptable in terms of texture and flavour by consumers.

Insect meals have a low environmental impact

In addition to reducing the use of forage fish and subsequent environmental problems associated with this practice, the use of insect protein has several advantages:

- Proteins are produced in a relatively short time on small areas,
- They add value to organic waste, with protein conversion ratios of 2 to 3
- They reduce the impacts related to the transport of raw materials

According to a study conducted by Wageningen University (Netherlands), the wastes produced by insects are less abundant and easier to recycle than the manure produced by pigs or cattle. In addition, weight for weight, crickets and mealworms emit 100 times less greenhouse gases than a cow and 300 times less ammonia than pigs.

A local yet regular supply is possible

Pre-Existence of young start-up companies in Europe including France,
The insect meal production is already in pre-industrial step
An already huge range of insects' species that can still to expand,
Several large research programs at the European and global levels
This should lead towards a greater proximity and improved regularity of supply for fish farms

In short :

Insect meals:
- are a natural feed in many fish diets
- are of nutritional interest because they are close to the fish meal
- are fish feed with a low environmental impact
- and should allow for a local and steady supply of feed

Many research such as the Desirable project (Development of an insect bio-refinery in France on an industrial scale and in a sustainable system) will allow us to address several challenges: to control and optimize production and processing, to formulate feed, to conduct production performance, digestibility and growth tests, to assess the sustainability of value chains, measure the profitability, study the organoleptic impacts, the food safety, as well as the acceptance by farmers and consumers, as well as to make recommendation in terms of needed changes in the legislation.