Insects as alternative raw material for use in fish feeds.

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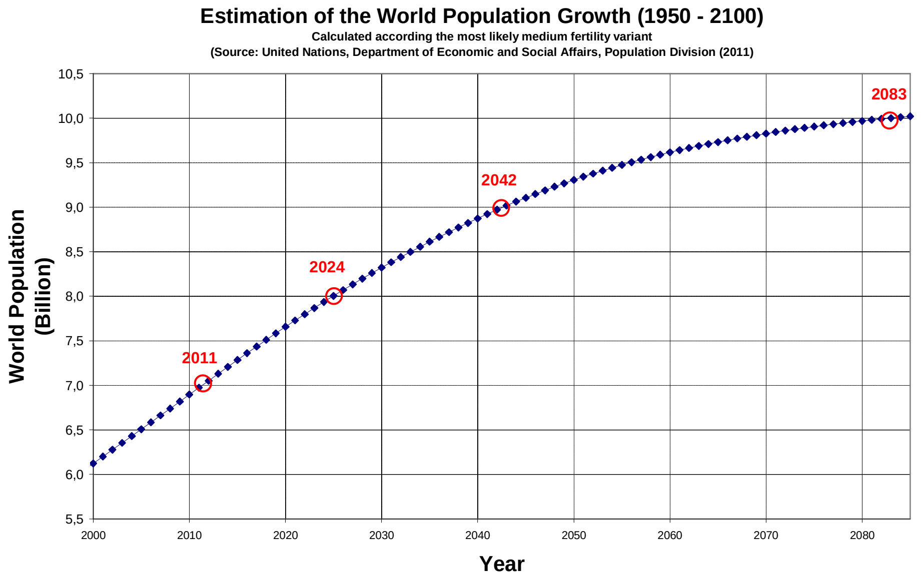
Published in Dutch in "Aquacultuur", January 2013.

Future protein sources

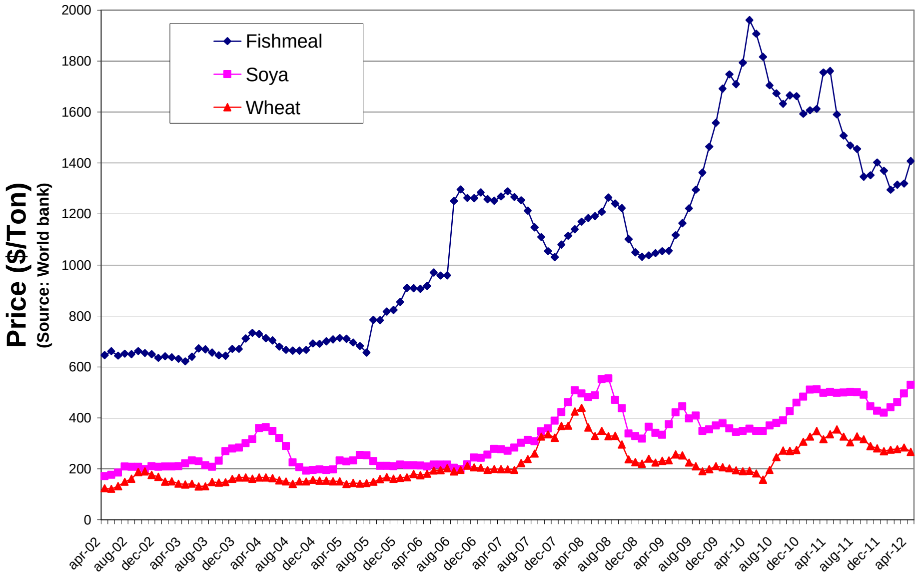
As a result of the growing world population and an increased wealth the request for food is growing. The United Nations have calculated the population growth until 2085 with the help of models. In the year 2024 a world population of 8 billion people are estimated, and in 2083 the number of 10 billion is calculated (see figure 1)

Figure 1 Estimation of the world population until 2100



More food and especially proteins will be needed in the future. Growing wealth usually accords with higher animal protein consumption. To produce animal proteins protein rich raw materials are required. If the demand is high there will insufficient supply of the raw material.
The Consumer may be more economical with the food they buy, but companies can also be more efficient with their production processes and try to minimize their food losses.
Another approach is to search for new and alternative raw materials. Special focus is on raw materials that are rich in proteins, are able to be produced at low energy cost and have a low environmental impact. In other words: economical and sustainable raw materials.
Finding these raw materials is not the biggest problem, a series of potential raw materials like duckweed, algae, lupins and insects have been investigated. The greatest problem is the scaling up of the raw material to the actual quantities needed for use in the animal feed industry.
In the Netherlands each year 14 million Tonnes of animal feed is produced. The increased demand for the raw materials has had an effect on the price. The price of many raw materials for last 10 years has doubled. The price of fishmeal in 2002 was $ 650 per Ton, in 2012 this price increased to $ 1410. The price for soy and wheat have also doubled, see figure 2.

Figure 2 Raw material prices for fishmeal, soy and wheat of the last 10 years



Animal proteins provide people with essential amino acids for the structure and maintenance of the human body. For this purpose aquaculture can play a big role. The Netherlands Nutrition Centre (Voedingcentrum, Den Haag) has judged fish as a healthy product and advises to eat fish twice a week. Fish is easily digested and contains a high level of “healthy fats” ω-3 and ω-6. At the moment a large share of the global fish catch is produced into fishmeal. Protein is being upgraded from low valuable fish, through fish farming, into high value fish proteins in the form of trout, salmon and other farmed fishes. The use of fishmeal for fish feed is not generally acknowledged to be sustainable. Alternatives for these fishmeal applications are therefore welcomed.

Fishmeal is not only used as protein- and lipids source in fish feeds, it is also used in chickenfeed, pig feed and all kinds of pet food (cat and dog food, reptile feed and koi carp feed to name a few examples). The use of fishmeal other than fish feed is limited, due to the relative high price and the source of being an animal protein. The BSE crises of 1996, has lead to very strict European rules for using animal proteins in animal feed.

In recent years the use of krill meal (small shrimp and small crayfish/lobster species) are used for substitution of fishmeal. Unfortunately the use of krill meal is not sustainable. The level of krill in the seas and oceans is crucial for fish stocks around the world. Using krill meal in large quantities will disrupt worldwide fish stock balances.

A possible alternative for fishmeal can be found in the use of insects. Already in the seventies of the previous century insects were mentioned for use as a raw material in fish feed. Only lately, research is done to study the feasibility of using insects in fish feed. Africa, Asia and south-America have especially shown interest in the use of insects for animal but also human consumption. In western countries, the use of insects for human consumption is quite well accepted but not for human food applications.

Insects are a natural feed source for fish. The use of insects for fish is common sense, anglers for years already use insects as bait. For example, mealworm, pinky’s and waxmoth larvae.

In January 2012, FAO, Wageningen University and the Dutch government organized an expert conference meeting for insects in food and feed in Rome. During the conference it became clear that the potential to use insects as raw material for food and feed could be great. To be able to fulfil the expectations a complete new insect sector has to be built. For FAO it is important to stress that raw materials for human food should be received from separate

streams than raw material for use in animal feed. These raw materials should not be in competition with each other. By streams of the food industry can be used for example: wheat bran, maisgluten, brewers spent grain, and for future prospects it would be thinkable to rear insects on side streams like manure.
Increasing and up scaling of the production from kilo's to tonnes will demand the automation and optimisation of the rearing procedure. A complete new chain is needed to produce and quality control from raw material, via rearing insects to the production of products derived from insects.

Which insect species

Around the World more than 2000 different kind of insects are eaten by humans. Xiaoming (2008) has made an overview of the various nutritional compositions of these different kinds of insects.
Whether or not insect meal can replace fishmeal is for a great deal dependent on the nutritional composition. Various kinds of insect meals are listed in table 1. The data from the references are calculated to the same moisture content of 8.2%, which is common for fishmeals. The protein content varies between 37.5% and 69.8%, the fat content varies between 7.3% and 32.1%. Mutual differences in fishmeals are not to neglect, protein and fat levels vary.

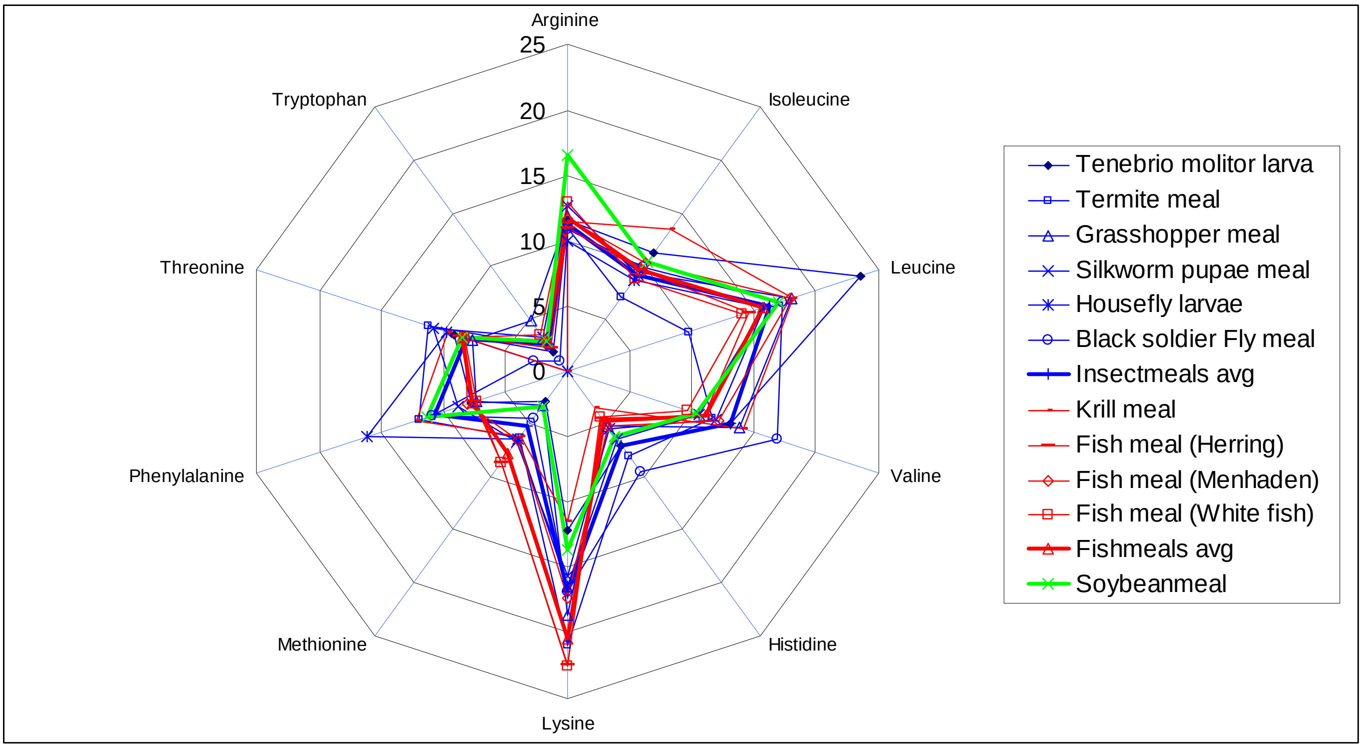
Table 1 Overview of the composition of different kind of insects compared to some fishmeals

Source	Order	Latin name	Moisture g/100g	Protein g/100g	Fat g/100g	Ash g/100g	Reference
Mealworm meal	Coleoptera	Tenebrio Molitor	8.2	59.2	27.9	4.5	1
Termite meal	Isoptera	Macrotermes subhyanlinus	8.2	44.1	28.7	3.4	2
Cricket meal	Orthoptera	Gryllus testaceus	8.2	53.5	9.5	2.7	3
Grasshopper meal	Orthoptera	Caelifera sp.	8.2	69.8	7.3	4.6	4
Black solider fly meal	Diptera	Hermetia illucens	8.2	38.6	32.1	12.9	4
Silkworm pupae meal	Lepidoptera	Bombyx mori	8.2	44.1	24.8	4.6	4
Housfly larvae meal	Diptera	Musca domestica	8.2	37.5	19.8	23.1	5
Krillmeal			8.2	59.2	18.4	13.3	6
Fishmeal (Herring)			8.2	66.1	9.2	9.5	4
Fishmeal (Menhaden)			8.2	56.9	9.2	18.4	4
Fishmeal (White fish)			8.2	56.0	3.7	22.0	4
Soymeal			8.2	49.3	1.9	6.8	7

When fishmeal is replaced by insects the total protein level is important, but even more important is the amino acid composition. In figure 3, the ratio of the essential amino acids of insects, fishmeal and soya are compared with each other. (insect meals are blue, fishmeal's red and soybean meal is green). The bold lines are presenting the average values of meals.
The sustainability of the production methods of soy are discussed. Being a vegetable protein, when soy is used directly for human consumption it is beneficial for the CO2 footprint and many other sustainable values, however the production of soy is controversial with deforestation, loss of biodiversity, and food security.
Soybean meal has a higher level of arginine compared to insect meals and fishmeals.

Insect meals have a higher level of methionine, lysine and valine compared to soybean meal. Fishmeal has a higher level of methionine and lysine, but a lower level of histidine and phenylalanine.
The nutrient demand of the final feed will determine which raw materials are the most valuable to replace soybean meal or fishmeal.
The variation of the blue lines in the figure suggest that levels of components vary between insect species, but also within a species variations can occur due to different life stages of insects.

Figure 3 Amino acid composition (%/total essential aminoacids (100%)) of insect meal, fishemal and sybeanmeal



Besides their high protein level are insects interesting for their fats. The fat level of insects is dependent on the subtrate which they get for food. This phenomenon makes it possible to stear the fatty acid composition of insects dependent on the different substrates. Insects (black soldier fly) which was reared on manure and fish offal turned out to have a significant higher omega-3-fatty acids composition compared to insects reared on only manure (St-Hilaire, 2007). A high level of omega-3 and omega-6 fatty acids is interesting to have as a raw material for use in chicken and pig feed.

Results with insects in fish feed

Sheppard (2007) writes in a review article that minimal 25% of the fishmeal can be replaced by insect meal without lowering the feed conversion. St Hilaire (2007) of the Universtiy of Idaho has a lot of experience of feeding black solider flies (Hermetia Illucense) and house flies (Musca Domestica) to trout. Replacement of 15 to 25% of the fishmeal by insect larvea did not generate any negative effects on the feed conversion.
In Nigeria different trials have been executed with the use of various insect speices in fish feed. Alegbeleye (2011) replaced 25% fishmeal by grasshoppermeal, this did not turn out to

be problem for the African catfish. Recently Jabir (2012) executed a test with superwormmeal (Zophobas morio). It turned out to be possible to rear fish with a replacement of 25% of the fishmeal. Ogunji (2007) even went higher by replacing fishmeal in an increasing ratio of “magmeal” (Musca Domestica) in fishfeed. In a range between replacing 0% to 68% fishmeal by insectmeal. In many instances additional effects like a different fat level in the magmeal (~20%) compared to ~8% fat in fishmeal explained the difference in results.
Besides the growth and the feed conversion rate, also physiological stress factors were analysed in this test. Analysing stress factors give an insight in how well the fish feels and if they react on feeding changes.
No significant differences could be analysed between growth and feed conversion with a replacement of 68% of the fishmeal.
Begum (1994) carried out a trial with dried silkworm pupae in carpfeed. Replacement of 50% of the fishmeal by silkworm meal did not cause any problems with growth.
Sogbesan (2006) replaced fishmeal by magmeal, with an increasing level of 25% to 100%, in this trial replacement of 25% fishmeal gave the best performance of the fish. Higher replacement levels than 25% gave a lower growth, only production of magmeal was 35% cheaper than the fishmeal. For the farmer the cost of this ingredient may turn out to be more important than the maximum feed conversion rate and maximum growth of the fish.
In conclusion these feed trials show that fishmeal may be replaced by insect meal. Up to 25% replacement no problems are expected, only at higher replacement levels growth and feed conversion effects are expected. A farmer however might still want to replace all the fishmeal due to the lower production costs, the lower growth of the fish will be seen as an unpleasant side effect.
The exact cause of the lower growth and feed conversion rate is not yet known, but the possibility it is related to the fat level seems to be quite obvious. The differences in chitin levels, shortage of certain amino acids, vitamin or other nutrients can also be a cause.
Instead of using the whole insect, when insects are separated into components of protein and fat, the nutritional value of these components will be higher, a higher level will probably be added to the feed. The level of chitin will be lowered due to these components and the total digestibility of insects will be increased. The final price will increase due to the separation process.

Chitin and chitosan

The exoskeleton of crayfish, crabs, shrimps but also of insects consist of chitin, a polysaccharide comparable to cellulose, but with an extra amine (NH2) group. Chitin is strong and gives the skeleton its structure, it is difficult to digest. Undigested chitin can function as fibre when it is not broken down in the digestion tract.
Chitosan is a derivative of chitin, where a certain percentage of the acetyl groups ($CH3CHO^{-}$) have been removed. The number (or ratio) of removed acetyl groups gives specific functional properties to the molecule based on chemical and physical properties (water solubility and reactivity).
It is possible to attach different kind of chemical groups to the chitosan molecule, the properties of the chitosan will vary because of this; reactivity, solubility of charge. In literature the “term” chitosan is used for all treated chitin samples. However this is confusing as if “chitosan” is one specific molecule. In practice a great variety exists in various chitosan molecules. In case literature speaks of “chitosan” usually one deals with a variety which is water soluble and a great percentage of the acetyl-groups have been removed.

The effect of the presence of chitin in fish feed is not fully known and investigated. Chitin can function as functional fibre. Just like many other food fibres chitin increases the viscosity in the intestines due to its low digestibility, which has generally a cholesterol lowering effect. The effects of chitin on immune stimulation and growth are now being researched; a general positive effect of the use of chitin cannot be given at this moment. Many secrets of chitin and chitosan in relation to fish feeding have not been revealed yet, but are to be discovered in the coming years.

<u>Taste</u>

A consumer finds it important that fish tastes the same, even if fit eats different feeds. The taste of fish meat depends on the species, the salinity of the water where it was caught, and the food it has been eating, how it is handled after caught and prepared. The presence of free amino acids and peptides especially give taste to meat and fish. Especially glycine and glutamate give fish an “umami” taste. Umami is a savory taste, it is one of the five basic tastes (together with sweet, sour, bitter and salty).
A consumer finds it important that the taste of fish is constant, no matter if it has had a different diet. The taste of fish will depend on species, the salinity of the water, the food that it has been eating and the way it has been caught and treated afterwards.
The presence of free amino acids and peptide give meat and fish their specific taste. Especially glycine and glutamate give fish an “umami” taste. The reason for the presence of free amino acids is sea fish is the balance they have to keep between the internal fish environment and the salinity of salt water of the sea (McGee, 2007).
In recent research no taste difference could be detected in a taste trial of fish that had eaten black soldier flies and fish that had consumed the control diet (Sealey, 2011).

<u>What are the steps that have to be taken before insects can be used in fish feed?</u>

The first step is that food and feed regulations for using insects as an animal protein must be adapted. Presently the use of insects in animal feeds that are used for human consumption is prohibited. It will only be a matter of time before the regulations are changed. Usually laws and regulations follow new inventions, trends and market innovations. When safety of the

new raw materials is mapped and quality control is in place, it is expected that legislation will be organised and that it will be possible to feed insects to fish in the near future.
Up to now, insect rearing companies have focused on insects as feed for animals like reptiles, snakes and other insect eating pets. But insect rearers will have to focus on scaling up the production. At this moment the price for insects is still much too high to compete with fishmeal or soybean meal. Automating the rearing process is the most important step to decrease the costs of labour. Many insect rearing companies expect that the price will drop to the fishmeal price within 5 to 10 years.

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