Nutritive Specifications of Meat-meal-based Aquaculture Diets

Growth in aquaculture and aquafeeds

Aquaculture is the fastest expanding food-producing sector in the world, growing at a rate of almost 10% between 1984 and 1995. Over the same time period livestock meat increased by 2.8% worldwide and captured fish increased by 1.6%. Fish supplies from traditional marine and inland capture are unlikely to increase substantially in the foreseeable future as it is commonly believed that they are already being exploited at, or beyond, their sustainable level. To allow for maintenance of the current per capita consumption of fish, aquaculture production must increase by between two and three times over the next 25 years.

Industry production data shows that, world wide, approximately 40% of farmed sea foods are from species that are strictly or essentially carnivorous. As a result they require aquafeeds that are rich in protein and preferentially those based on animal rather than plant meals. In Australia approximately 55% of aquaculture production is from species that are fed on compounded aquafeeds. Within developed and developing countries it is this group of farmed marine species that have shown the greatest growth over the last 10 years.

Compounded feeds for carnivorous species presently contain from 50 to 70% (by weight) of fishery product. This material is in the form of low-value trash fish, fishery waste or rendered fish meal. Aquaculture competes against other food sectors, including pet food, for the limited amount of fish meal available. Approximately 30% of fish meal available on the export market ends up in aquaculture feeds. In Australia 90% of the fish meal used in aquaculture feeds is imported. Aquaculture's expansion cannot be sustained if fishery products are relied upon as the feedstock since wild fisheries are already fully exploited and world fish-meal production has been static for the past decade.

Fish meal alternatives in aquaculture diets

The clearly apparent shortfall in fishery materials for aquaculture diets in the near future, has prompted the search for suitable non-marine-produced protein sources. Fortunately Australia has an abundant supply of terrestrial animal and vegetable proteins that are potential fish-meal replacements. Animal protein sources include meat meal and blood meal. Vegetable protein sources include grains and legumes such as lupins, canola, soy beans and peas.

Studies of aquafeed substitutions have been conducted internationally on a large range of fish species. In Australia, the Fisheries Research and Development Corporation instigated a nationally coordinated program to develop improved aquaculture diets that had a reduced reliance on fish meal. Other research funding bodies, along with feed manufacturers and aquaculture farmers, have contributed significantly to the work. The Meat Research Corporation supported work to investigate, in particular, the substitution of fish meal with meat meal. Three Australian species were used as aquaculture models for the substitution:

- giant tiger prawn
- barramundi
- silver perch.

These species were selected for study as they represent the major sub-groups within the Australian aquaculture industry and represent a range of marine living conditions and feeding styles.

Nutritive value of meat meals

In establishing the nutritive value of any feed material, it is essential to determine its composition, its energy content and its apparent digestibility and level of assimilation by the

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animal. Meat-meal compositions vary considerably with protein content ranging from a low of 45% to a high of 80% for some specialised meat meals. Fat content ranges from 7 to 15% and ash content ranges from 10 to 40%. In comparison, fish meals are generally high in protein (50 to 70%), moderate in fat (10 to 13%) and low in ash (<15%). Vegetable protein meals are low in ash and fat, and moderate in protein content (30 to 50%). On a cost-per-protein-unit basis, meat meals are similar to vegetable meals but significantly (about 40%) less expensive than domestic and imported fish meals.

To be nutritively useful in a feed, the protein and energy must be in a digestible form. The apparent protein digestibility of meat meals is generally less than fish meals and with the model species investigated, up to 20% lower for some meals that were high in ash or fat. Similarly, the energy digestibility of meat meal was shown to be approximately 10 to 20% less than for fish meal. Protein and energy digestibilities between meat meals appeared to be more variable than between fish meals. Also, protein and energy digestibilities between fish species studied appeared to be more variable for meat meal than for fish meal.

The nutritive requirements of the three species studied are only superficially known. For many of the micronutrients—including vitamins, essential fatty acids and essential amino acids—requirements have not been well defined and even optimum protein-to-energy relationships are, at best, working estimates rather than precise quantitative requirements. However, a broad awareness of the requirements of the different species to be farmed is necessary to evaluate the extent to which alternative protein meals may be able to substitute for fish meal. Key nutrient specifications for the three 'model' species are given in Table 1.

Table 1. Key nutrient specifications for giant tiger prawn, silver perch and barramundi

	Giant tiger prawn	Silver perch	Barramundi
% fish meal in feed (65% protein)	40–45	30–35	40–45
Digestible protein %	>35	>33	>40
Digestible energy kjkJ/g	13–14	13–14	15+
Fat %	8–10	8–10	10+
Ash %	<12	<12	<12
EPA + DHA % *	~1	<0.8 (?)	>1.2

* Essential omega-3 fatty acids: EPA – Eicosapentaenoic acid (20:5n–3); DNA – Docosahexaenoic acid (22:6n–3)

Nutrient utilisation of meat meal

It has been demonstrated in a number of studies, particularly with pigs, that a considerable proportion of amino acids from heat-damaged proteins can be absorbed in a form that is not metabolised, leading to their poor utilisation by the animal. Lysine is the amino acid most susceptible to this type of damage, with meat meals and high-temperature-processed vegetable meals often suffering during heat processing—with resultant poor biological availability utilisation. Consequently digestibility alone may not be a reliable guide to the nutritive value of a meat meal. In the study on the 'model' species, experimental evaluations were made to determine nutrient utilisation and retention following the feeding of diets with fish meal substituted by incremental increases in meat meal.

Barramundi

With barramundi, both the inclusion rate of meat meal and fish meal were individually and incrementally substituted in a basal diet that was known to provide all nutrients required for rapid fish growth. The way in which the fish's retention of dietary nutrients changed as the substitution rate of each test meal was increased in the basal diet provided information about their biological value. Data for the particular meat meal and fish meal used showed that the retention of protein from the meat meal was as good as, if not better than, the fish meal. The overall retention of dietary protein was low (30 to 38%) but was comparable with results from studies on other similar species. The energy retention was the reverse, with a slightly improved retention of energy with the fish meal. Protein and energy retention did not decline for either meat meal or fish meal until they comprised in excess of 40% of the basal diet.

Low protein retention is expected for strictly carnivorous species, such as barramundi, because much of the protein is used as a metabolic energy source. The lower essential-amino-acid composition of the meat meal compared to fish meal was not a problem since a large proportion of the dietary amino acids are metabolised for energy, while those that are the less abundantly supplied (such as lysine), are preferentially conserved for protein synthesis. Consequently, the essential amino acid composition of the diet is not as important for strictly carnivorous marine species as it is for land-based monogastric animals such as pigs and poultry.

Silver perch

With silver perch, fish meal was incrementally replaced with meat meal in a reference-diet formulation. Diets were balanced to hold the ratio of digestible protein to digestible energy constant, and the essential-amino-acid content was adjusted using crystalline amino acids. Fish were grown in 10-tonne tanks for 65 days and growth rate, food conversion, protein efficiency and protein-retention data were collected.

Growth rates of the fish declined with diets containing less than 13% fish meal but the efficiency of overall food use and of protein retention was not affected, even with diets containing no fish meal. A lower rate of food consumption by fish fed the higher meat-meal diets was the reason for the reduced fish growth rate. The reduced palatability of these diets was most likely due to the increased level of dietary saturated fat. Loss of palatability with high-meat-meal diets has not been observed with other species. In fact, meat meal has been found to be particularly attractive to barramundi.

Giant tiger prawns

A similar approach was used with giant tiger prawns—to test how much meat meal could replace fish meal in the diet. Two meat meals were investigated: one a high-protein meal (76%); the other a moderate-protein meal (52%). The energy content of diets using the high-protein meal remained constant for all substitutions whereas it progressively declined with the moderate-protein meal as it increasingly replaced the fish meal. Diets were fed to a small number of prawns in an aquarium environment.

For the moderate-protein meat-meal diets, replacing the fish meal in the diet with meat meal resulted in a slight improvement in prawn growth rate. Analysis of the results indicated that the optimum growth occurred when meat meal made up 50% of the formulation and fish meal made up only 10%. For the high-protein meat-meal diets there was no significant change in prawn growth at low levels of meat-meal inclusion. However at meat-meal inclusion rates above 40% in of the formulated diet, growth declined significantly. The difficulty in obtaining an accurate measurement of food consumption with prawns prevented any firm conclusions to explain these different responses between the two meat meals. Although palatability effects cannot be excluded, it is thought more likely that the high content of saturated fat in the high-protein meat meal was detrimental to the prawns.

Both the high-protein and moderate-protein meat meals could, however, be used to substitute at least two thirds of the overall protein in the prawn diets without adversely affecting growth.

Other species

Similar studies in Australia demonstrated that meat meal can be substituted for fish meal at inclusion rates up to 50% in diets of rainbow trout without compromising growth rates and environmental parameters.

Meat meal in aquaculture diets under farm conditions

The replacement of fish meal with meat meal in aquaculture diets has been extended to commercial farm conditions to verify the feasibility of substitution indicated in the research studies. Farm trials have been conducted with silver perch and barramundi. For prawns, commercial conditions were simulated by confining 15 animals in one-cubic-metre, net cages—with these being placed in a raceway serviced with water recirculated from a commercial prawn pond.

Silver perch

With silver perch, two formulations in which fish meal was partially replaced by meat meal were compared against a standard reference diet based on fish meal. The fish-meal content of the reference diet was 27% and this was reduced to 10 and 5% respectively in the trial diets. At the conclusion of 6-months feeding, sample fish were analysed for chemical composition and their eating qualities determined using trained taste panels.

Fish survival rates were excellent and unaffected by the inclusion of meat meal. Growth rate, food conversion and total pond productivity were significantly better with the diets containing meat meal and with no significant difference between the different two levels of meat-meal inclusion. The sensory evaluation of the fish showed only minor differences between diets. The fish fed the high-meat-meal replacement diet were assessed as being less yellow in colour while those fed the low-meat-meal replacement diet were assessed as being more flaky than the other diets. Most importantly, the overall liking of fish from all diets was extremely high and unaffected by the meat-meal substitution level.

Barramundi

For barramundi, a high-fish-meal control diet was evaluated against a commercial grow-out diet and trial diets containing partial or total substitution of fish meal with meat meal. Trial diets included a conventional high-ash meat meal (52% protein) and a low-ash meat meal (66% protein). At the conclusion of 66 days feeding, sample fish were analysed for chemical composition and sensory evaluation as for silver perch.

Important findings from the study were as follows.

- Growth rates, fish survival and dressing-out yield of fish were unaffected by the complete replacement of fish meal with meat meal in the diet, but a 7 to 18% worsening of food conversion efficiency was observed. However, replacement of all but 10% of fish meal with meat meal resulted in fish productivity that was equivalent to feeding the high-fish-meal reference diet.
- The low-ash meat meal gave no advantage over the conventional high-ash meat meal when included to provide similar protein contributions.
- Fish fed the total fish-meal-replacement diet using the high-ash meat meal performed best of all in terms of growth rate and food conversion.
- Sensory differences between fish on the different diets were minimal with fish from all diets, including those without any fish meal, rating highly for 'overall liking'.

Published international studies on other species of cultured carnivorous fish, in which fish-meal protein was 30 to 90% replaced by meat meal, have given similar results confirming that the replacement of all, or a large proportion of, fish meal with meat meal is commercially acceptable.

Giant tiger prawns

The efficacy of using a high-protein (59%), moderate-ash (21%) and low-fat (11%) meat meal at inclusion rates of either 15 or 30% as a partial substitute for fish-meal protein was appraised on a commercial prawn farm. Growth rates of prawns fed the meat-meal diets (1.1 to 1.2 g/wk) were not significantly different from those obtained with the high-fish-meal reference diet (1.1 g/wk) or with a commercial diet (1.2 g/wk) that was used as a benchmark. Average survival was >92% and not significantly affected by dietary treatment. There were also no significant differences between diets in food-conversion efficiency. One of the problems associated with culturing prawns is an accumulation of waste in the form of sludge on the pond bottom. From visual inspection of the substrate under the cages, there did not appear to be a difference between the amount of sludge under the cages fed the meat-meal diets compared to those receiving the reference or commercial diets. This suggests that the meat-meal diets are unlikely to create a significant waste problem when used in a pond environment.

Environmental Issues

Nutritionally and economically there is no advantage in using high-protein, low-ash meat meals over conventional high-ash meat meals. However, the potential pollution impacts of aquaculture feeds can be significant. Phosphorus, in particular, is a major environmental-pollution issue in Australia and internationally. As phosphorus comprises about 15% of the ash content of meat meal, the level of ash in the final aquaculture diet can potentially have a significant environmental impact. For this reason low-ash meat meals that are highly digestible and nutrient dense are recommended for aquaculture use.

Farm trials with rainbow trout fed a diet with fish meal partially substituted with a low-ash meat meal against commercially available aquaculture feeds showed that the level of phosphorus in the discharge water from the ponds was often above the allowable EPA license parameters for mean and maximum phosphorus concentration. However ponds containing fish on the meat-meal-containing diet were no worse than those ponds in which the fish were fed other diets, and were significantly better than those fed a common commercial trout diet. Similarly, the in-pond feeding of meat-meal-based diets to caged prawns did not result in any greater build up of sludge beneath the cages compared to a fish-meal-based diet.

Ideally meat meals for aquaculture diets should be high in protein (>60%), low in ash (<20%) and low in fat (<7%), to ensure environmental impact is minimised. Meat meals must also be economically competitive with other protein sources. Meat meals must be no more expensive on a per-unit-of-digestible-protein basis than high-quality vegetable proteins, such as soy-bean meal.

Commercial opportunities

Research in Australia and internationally has clearly demonstrated that there is an opportunity to continue the current expansion of controlled farming of a number of marine species by extending the aquaculture food supply. Current limitations with fish meal can be overcome by substituting up to two thirds of the fish meal with meat meal in the diets of silver perch and giant tiger prawns. Complete substitution of fish meal with meat meal is possible for barramundi diets. These substitutions can be achieved without compromising the growth rate nor eating quality of the fish, economical performance of the farm, or environmental sustainability.

As the use of meat meals in aquaculture diets is still being researched and validated, it is recommended that commercial trials be conducted on any meat meal that is being considered for use—to confirm its suitability and acceptability for the target species.

Further reading

This information is a summary of project reports from Meat Research Corporation Projects M.783 and M.744 and PRCOP.011; and Fisheries Research and Development Corporation Project 93/120. New South Wales Fisheries carried out the silver-perch research, CSIRO Marine Research carried out the prawn work while the barramundi studies were carried out jointly by CSIRO Marine Research, Queensland Department of Primary Industries and the University of Queensland. Individual reports are available for the research conducted on each of the model species investigated.

Meat and Livestock Australia, in conjunction with the Fisheries Research and Development Corporation, has published further detail in a paper taken from the Australian Renderers Association Fourth International Symposium Proceedings entitled 'Fish meal replacement in aquaculture diets using rendered protein meals'. This extract is available from Meat and Livestock Australia.

Related information is given in the following MLA Co-products brochures.

- Preparation of Meat Meals for Inclusion in Aquaculture Feeds
- Utilisation of the Ash Component of Meat Meal
- Techniques for Separation of Meat Meal into its Components

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