Abalone

Development of artificial diets for abalone, one of the highest valued seafood, is critical. Not only is there an increase in cultivation of abalone species due to a depletion of natural resources, but the use of natural feed resources (seaweeds) cause logistic problems during processing. The slow feeding behaviour of abalone species complicated determination of nutrient requirements and evaluation of feed ingredients for use in artificial diets. A combination of knowledge about nutritional principles and the unique rearing conditions of abalone is crucial in development of effective artificial diets.

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Abalone is one of the most highly valued seafood in the world. The prime demand is in Asia where it forms part of the traditional cuisine. There are approximately 90 species of abalone worldwide. About 15 are harvested commercially in countries such as Japan, China, Australia, New Zealand, South Africa, Korea and Taiwan (Sales & Janssens, 2004). Over the past 10 years, the abalone fisheries have declined

approximately 30%, mainly due to poaching, whereas cultured abalone production has increased by 600% (Gordon & Cook 2001). Abalone farming is highly capital-intensive with high operating costs. Animals are stocked at high densities in small shore-based, man-made structures and reared on seaweeds and/or artificial diets. During the early phases of abalone cultivation, most abalone farms had used natural algal feeds. However, a regular supply of large volumes of seaweeds often presents logistics problems. Because of this, and also due to the high proportion of feed in production costs, the development of a convenient and cost-effective, formulated diet for abalone has received major attention from the start of research on abalone farming (Britz 1996).

Feeding behaviour and digestive physiology

The abalone are herbivorous species with a nocturnal pattern of grazing behaviour. They tend to remain inactive by day (Barkai & Griffiths 1987), however, this does not mean that all abalone would be actively feeding at night. Once abalone become post-larvae, they are fed benthic (bottom growing) algae. At 4 to 6 months of age they are weaned on a diet of either seaweed or an artificial diet. Daily intake of artificial diets, depending on species, diet, body size and husbandry, varies from 0.9 to 5.7 % of body weight (Fleming et al. 1996).

As abalone consume a natural diet consisting of 40-50% carbohydrate, they have many types of polysaccharide hydrolases and bacteria (Fleming et al. 1996) in the digestive system capable of hydrolysing a variety of complex polysaccharides in algae. However, evidence shows that the digestive physiology of juvenile abalone can readily adapt to artificial diets (Knauer et al. 1996).

Nutrient requirements

Protein and amino acids

Although work has been conducted on the determination of optimum dietary crude protein levels for some abalone species (Table 1), artificial diets are formulated according to tissue amino acid patterns, without any knowledge about the rate of turnover of each amino acid or the identity of limiting amino acids (Fleming et al. 1996). Attempts to identify growth responses in juvenile *Haliotis midae* fed on graded levels of synthetic amino acids have failed, despite effective encapsulation techniques to prevent leaching of amino acids into water (Shipton et al. 2002).

Table 1: *Optimum dietary protein levels (dry matter basis) for juvenile (0.2 4.9 g live weight) abalone according to total body weight gain, using either casein or fish meal as main protein source*

Species	Optimum dietary level (%)	Reference
H. discus hannai	35.6	Mai et al.(1995a)
H. kamtschatkana	30.0	Taylor (1997)
H. laevigata	27.0	Coote et al. (2000)
H. midae	35.9	Sales et al. (2003a)
H. tuberculata	32.3	Mai et al.(1995a)

Lipid and fatty acids

Dietary lipid content of more than 3% in the form of either fish oil, vegetable oil or a combination of both, had a negative influence on amino acid digestibility (Van Barneveld et al. 1998). In *H. discus* both 18:2n-6 and 18:3n-3 fatty acids contribute to faster growth, whereas growth in *H. tuberculata* appeared to depend largely on n-3 polyunsaturated fatty acids (Mai et al. 1995b). The optimum n-3:n-6 fatty acid ratio for growth in *H. asinina* was found to be 0.35 (Tamtin et al. 2003).

Minerals and vitamins

Despite the current practice to use mineral and vitamin premixes in abalone diets based on the requirements of fish (Uki et al. 1985), new information on requirements for abalone has become available (Table 2). Dietary calcium supplementation appears to be unnecessary in abalone, in accordance with the well-known fact that aquatic species are able to absorb calcium directly from the surrounding water (Coote et al. 1996).

Feed ingredients

Protein sources

The importance of protein as a dietary component for animal growth, and its high cost in commercial feeds, have stimulated studies into the evaluation of the effects of different protein sources on abalone performance. Several studies with different abalone species have identified fish meal, defatted soybean meal and casein as the protein sources that result in the fastest growth (Fleming et al. 1996). Protein sources and inclusion levels used in abalone diets by different countries are presented in Table 3.

Because of the very complex gut structure and the enzymatic capability to digest some complex carbohydrates it should not be assumed that the digestibility values of feedstuffs for abalone will necessarily be similar to the values for other aquatic animals (Wee et al. 1992). Protein and mean amino acid digestibilities of several feed ingredients evaluated with sub-adult *H. laevigata* and *H. midae* are shown in Table 4. In the

Table 2: Mineral and vitamin requirements (dry matter basis) of juvenile (0.5 - 1.2 g live weight) H. discus hannai *(Adapted from Sales and Janssens, 2004)*

Nutrient	Recommended dietary level
Minerals	
Phosphorus	1.15 % available (1.25 % total)
Iron (from either iron methionine or iron	65 - 70 ppm
Zinc	
(from zinc methionine)	16 - 18 ppm
(from zinc sulphate)	32 - 35 ppm
Vitamins	
Vitamin K	10 ppm (as Menadione sodium bisulfite)
Thiamin	51-61 ppm

South African species, *H. midae*, apparent protein digestibility was a good predictor of the mean apparent amino acid digestibility. Relatively high digestibility of amino acids in legumes (e.g. lupins) by abalone has been confirmed in several studies.

Energy sources

Energy in commercial artificial abalone diets is supplied primarily in the form of carbohydrate (wheat flour, maize flour, sodium alginate, dextrin, starch, bran), making up between 30 and 60 % of the diet (Fleming et al. 1996).

Minerals

Dibasic calcium phosphate as phosphorus supplement presented a lower apparent phosphorus digestibility (28%) than monobasic sodium phosphate (67%), monobasic calcium

Table 3: Inclusion levels (% dry matter) of protein sources in commercial abalone diets (Adapted from Fleming et al. 1996)

Source	Japan	China	South Africa	New Zealand	Australia	Mexico	USA	Korea
Fish meal	15	32	55	2-3				
Soybean meal/flour	20	32			17.3	17	12	25
Casein				42	13	10	16	15
Whey							7	
Bloodmeal					4.3			
Abalone viscera silage						20		
Shrimp meal							20	

phosphate (73%) and a 3:1 mixture of mono- and dibasic calcium phosphate (66%) in sub-adult *H. midae*. (Sales et al. 2003b). Comparable relative iron bioavailabilities were derived with either iron methionine or iron sulfate (Mai & Tan 2000). However, the relative bioavailability of zinc from zinc methionine was approximately three times as high as that of zinc sulfate in juvenile *H. discus hannai* (Tan & Mai 2001).

Table 4: *Apparent protein and mean amino acid digestibility (%) of different feed ingredients determined in sub-adult* H. laevigata *(Fleming et al. 1998) and* H. midae *(Sales and Britz, 2003)*

Source	Protein content (%, drymatter)	Protein digestibility (%)	Mean amino acid digestibility (%)
H. lavigata			
Fish meal	64	43	37
Barley	8	54	43
Semolina	10	71	63
H. midae			
Fish meal	71	83	83
Corn gluten meal	62	76	77
Soybean meal	48	96	97
Cottonseed meal	45	86	85
Sunflower meal	43	92	93
Canola meal	32	94	94
Peanut meal	43	87	87
Lupins	34	97	96
Faba beans	26	93	93

Binders

One of the most important requirements of artificial diets for a slow aquatic feeder like the abalone, is that the feed should remain stable and that loss of water-soluble nutrients is minimized for at least two days under water. Achievement of this high level of water stability is so crucial to the development of a successful abalone feed that information on binders, and factors influencing the properties of binders including processing techniques, appear to be the most guarded, and are often patented (Fleming et al. 1996).

Starch plays a major role as both an energy source and a binder in many commercial abalone feeds. Dry matter loss after 16 hours in seawater of diets containing 45% of different protein sources and bound with 40% pre-gelatinised maize starch is presented in Table 5. The considerable high dry matter loss for legumes, particularly lupins and faba beans, might have contributed to the high amino acid digestibilities reported (Table 4). However, confirmation of this would only be valid by determination of loss of individual amino acids of feed in water, and accounting for amino acid losses from corresponding feces.

Water stability in aquatic feeds can be improved by fine-grinding feed ingredients, a time-consuming feed processing step which could account for up to 60% of feed production cost (Sorenson & Phillips, 1992). According to Sales & Britz (2002) reducing soybean meal particle size to 150-450 µm resulted in a significant reduction in dry matter loss and an increase in apparent digestibility in comparison with a particle size above 450 µm. However, sieving ingredients to a particle size less than 150 µm in compound abalone diets did not yield an additional benefit in terms of dry matter loss or apparent digestibility compared with an ingredient particle size of 150-450 µm.

Feed stimulants and attractants

Proteins, amino acids, lipids and nitrogenous bases in algae eaten by abalone, feeding stimulants such as digalactosyldiacylglycerols and phosphatidylcholines, glycerolipids isolated from the methanol extracts of some marine algae, and novel ingredients, such as spices and herbs,

***Table 5:** Mean dietary dry matter losses after 16 h in water (18 ºC, 2 L/min flow rate) of diets containing 45% of different protein sources and bound with 40% pre-gelatinised maize starch (Sales and Britz, 2003).*

Diet	%
Fish meal	1.6
Corn gluten meal	1.1
Soybean meal	5.4
Cottonseed meal	2.4
Sunflower meal	1.8
Canola meal	7.9
Peanut meal	4.3
Lupins	12.0
Faba beans	12.8

have been identified as possible feed attractants for abalone (Harada et al. 1996). However, these are yet to be tested for their effectiveness in promoting feed intake when incorporated into artificial diets.

Conclusions

Challenges exist in both understanding nutrient requirements of, as well as developing an appropriate feed for abalone due to the slow feeding nature of the species. Dietary requirements are still ill-defined for animal sizes at the early stages of the life cycle, with no information available on changes as the animal grows. The requirement that the feeds must remain intact in water for nearly two days is perhaps the most stringent in aquatic feed preparation and delivery. The measures of feed response, such as feed intake, growth rate, feed conversion efficiency, and protein efficiency ratio could

be erratic when feeds have to remain submerged in water for long periods of time. Furthermore, growth is often measured as an increase in shell length, and justified by a correlation between shell length and live weight. So, development of effective and inexpensive solution to bind the feeds will be important in the development of feeds for abalone.

References

List of references cited in the article may be obtained from the author or downloaded from the magazine's website at *www.feedware.com*.

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