

Feed Formulation and Evaluation for Semi-intensive Culture of Fishes and Shrimps in the Tropics

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Abstract

Semi-intensive farming systems account for about 70% of fish and crustacean aquaculture production in the tropics, employing semi-intensive feeding methods ranging from the use of low-cost pond fertilization techniques to high-cost complete diet feeding strategies. The paper reviews the major feeding methods employed within semi-intensive farming systems, and emphasizes the importance of natural food organisms in the nutritional budget of pond-raised fish and shrimp. It also discusses the need of the aquaculture sector to reduce farm production costs through the use of improved feed formulation and on-farm feeds and new methodological approaches towards fish and crustacean nutrition research within semi-intensive pond farming systems.

Introduction

Although the growth and production of all farmed fish and shrimp species are dependent upon the intake of food containing 40 or so essential nutrients (i.e., essential amino acids, fatty acids, minerals, vitamins, etc), the form in which these nutrients are supplied varies depending upon the farming system and feeding strategy used. For example, within extensive farming systems these nutrients are supplied in the form of live natural food organisms endogenously produced within the pond ecosystem, whereas within semi-intensive farming system they are supplied by a combination of endogenously produced natural food organisms (the production of which is usually augmented through the application of fertilizers/manures or substrate enhancement) and exogenously supplied supplementary feed. In contrast, within intensive farming systems, these nutrients are usually

exogenously supplied in tanks or cages in the form of a nutritionally 'complete' artificial farm-made or commercial diet (aquafeed) or in the form of food items of high nutrient value such as 'trash fish' or *Artemia*.

Simple as these different nutrient pathways may appear, the majority of researchers and government research laboratories still consider aquaculture nutrition as being only concerned with the formulation, manufacture and use of artificial or processed diets for use within intensive farming systems. Since over 70% of total Asian fish and crustacean aquaculture production is currently realized within semi-intensive and extensive pond-based farming systems, research emphasis must also be given to semi-intensive and extensive feeding methods such as endogenous live food production through pond fertilization or substrate enhancement, and supplementary feeding. The aim of this paper is to briefly review the different feeding methods currently available for the production of fish and crustaceans within semi-intensive farming systems (SIFS), and to highlight those feeding methods and research areas which would be most suited for use within SIFS in Asia, with particular reference to the Philippines.

Semi-Intensive Farming Systems and Feeding Methods

Concepts

Of the different dietary nutrient pathways currently employed by farmers for the production of fish (and to a lesser extent crustaceans), by far the most common has been the use of semi-intensive feeding methods involving the use of a combined fertilization and supplementary diet feeding strategy. Moreover, within the two largest Asian and world aquaculture producing countries (i.e., China and India) these SIFS are largely based on the polyculture of warmwater herbivorous and/or omnivorous fish feeding low on the aquatic food chain (i.e., Chinese carp and Indian major carp); freshwater herbivorous and/or omnivorous fish species (i.e., cyprinids, tilapias, etc.) constituting 87.6% of total fish production in the Asian region in 1991 (Csavas 1993).

Since the majority of SIFS are usually restricted to the culture of low value and therefore relatively cheap (from an international marketing viewpoint) fish species for local human consumption, it follows that the feeding strategies employed by farmers are usually low-cost and based on the use of traditional, locally available technology and agriculture wastes and by-products. The farming activity is usually small-scale in nature and generally 'integrated' with the production of agricultural crops or livestock as a secondary activity within an integrated agriculture-aquaculture farming system (Edwards 1993; Tacon and De Silva 1993). One of the unique facets of SIFS is the fact that fish growth is not dependent upon a single feed source (as in the case of intensive farming systems), but rather on a combination of different feed types (i.e. endogenously produced natural food organisms and exogenously supplied supplementary feeds). In fact it is essential that SIFS have this flexibility as fertilizer, feed, and labour inputs may vary over the farming cycle depending upon the availability of agricultural inputs and the financial resources of the farmer.

Moreover, the use of polyculture production systems in which a carefully mixed population of different fish and crustacean species with complementary feeding habits (i.e., non-competitive) are cultured together maximizes the possible utilization of the natural food (i.e., phytoplankton, zooplankton, bacteria-laden detritus, macrophytes, and benthic algae and animals) and water resources within a pond ecosystem. Consequently, pond productivity and fish yield per unit area are increased. For example, Figure 1 shows the latest reported production statistics of the top four most farmed fish species in China (and the world) which are usually cultivated together as a polyculture within SIFS. The four species include silver carp *Hypophthalmichthys molitrix* (a phytoplankton filter feeder), bighead carp *Aristichthys nobilis* (a zooplankton filter feeder), grass carp *Ctenopharyngodon idella* (a herbivorous macrophyte feeder), and common carp *Cyprinus carpio* (an omnivorous bottom feeder).

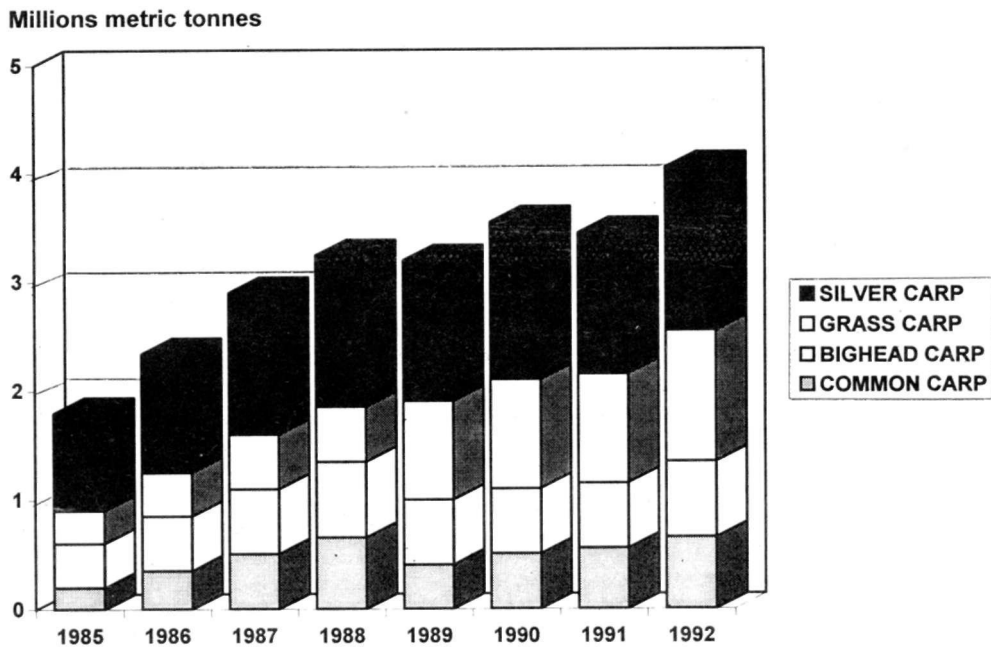


Fig. 1. Aquaculture production of Chinese carp in China. Total farm production of the above carp species has increased from 2,069,900 mt to 4,248,956 mt from 1985 to 1992; representing 79.6% and 78.7% of Inland and Total Chinese fish production, respectively. Total Chinese finfish aquaculture production in 1992 was 5,396,616 mt (FAO, 1994; in preparation).

Supplementary feeds

Supplementary feeding strategies are based on the use of exogenous live and/or processed feeds as a supplementary source of dietary nutrients for direct consumption by the cultured fish. The dietary nutritional requirements of the cultured fish are supplied by a combination of endogenously produced live food organisms and exogenously supplied supplementary feed. Figure 2 shows the major types of supplementary feeds which have been used. Supplementary feeds can include all feedstuffs which can be directly consumed by cultured fish, ranging from live or fresh natural food items (i.e., macro-invertebrates foods - insects, annelid worms, crustaceans, molluscs; terrestrial and aquatic macrophytes, leaves; animal slaughterhouse offal), kitchen waste, single processed feedstuffs (i.e., mill sweepings, rice bran, cereal grains and byproduct meals, oilseed residues, etc.), on-farm produced feed mixtures (composed of several processed feedstuffs in mash, dough ball or pellet form) to factory-manufactured pelleted aquafeeds. At present, the majority of small-scale farmers operating SIFS prepare their own supplementary feed mixtures on-farm using locally available technology and feed ingredient sources, ranging from the production of simple feed mashes, moist dough balls to dry pelleted aquafeeds (New *et al.* 1993). In general, feed ingredient selection by farmers is usually dictated by availability and cost rather than by quality or nutritional value (Jantrarotai and Jantrarotai 1993; Nuov and Nandeessa 1993). In view of this selection method, it is not surprising that the number of feed ingredients used by SIFS farmers has been very diverse, even within a single region. The diversity is further increased when the number of possible combinations of

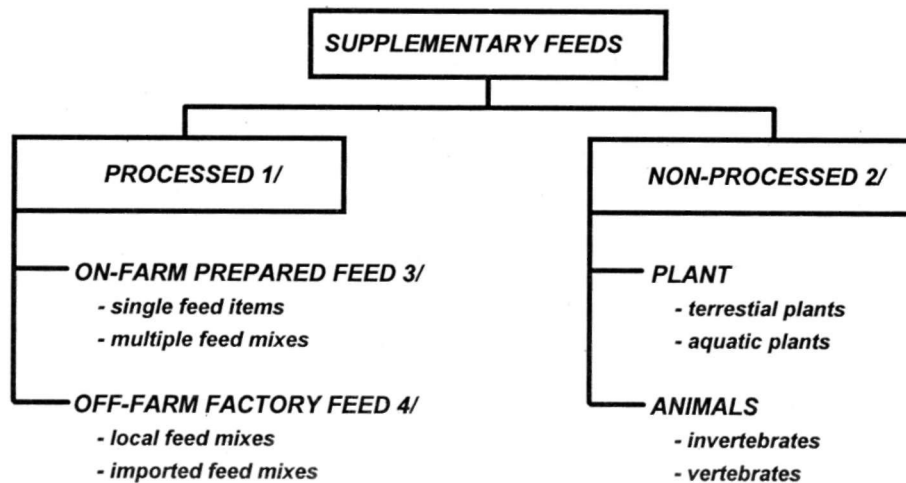


Fig. 2. Supplementary feeds used in aquaculture. ¹Processed feeds include all animal and plant food items which have been physically processed prior to feeding either by drying, fermenting, ensiling, grinding, mixing, or pelleting; ²Live or fresh natural food items; ³Feeds produced 'on-farm' and not for cash sales; ⁴Commercial factory feeds.

ingredient mixes are taken into consideration (Nandeesh 1993; Tacon and De Silva 1993). For a review of different supplementary feeding regimes used within SIFS see De Silva (1993), De Silva and Davy (1992), Edwards (1993), New *et al.* (1993), Tacon (1988), Vincke (1988) and Yakupitiyage (1993).

Nutrient requirements

Despite the fact that silver carp, common carp, grass carp, bighead carp, milkfish (*Chanos chanos*), Nile tilapia (*Oreochromis niloticus*), and the giant tiger shrimp (*Penaeus monodon*) are among the top ten most cultivated species in Asia and the world, little or no information exists concerning their dietary nutrient requirements under practical, semi-intensive pond farming conditions. The majority of dietary nutrient requirement studies to date have been performed under controlled indoor laboratory conditions. Whilst the information generated from laboratory feeding trials may be useful for the formulation of complete diets for use within intensive clear-water farming systems, this information cannot be applied to the formulation of diets for use within SIFS since the fish or shrimps also derive a substantial part of their dietary nutrient needs from naturally available food organisms (Figure 3). Unfortunately, in the absence of published information on the dietary nutrient requirements of fish and crustaceans within SIFS, almost all of the commercially available aquafeeds produced for these farming systems are usually overformulated as nutritionally complete diets irrespective of the intended fish stocking density employed and natural food availability (Akiyama 1991; Chamberlain 1992; De Silva and Davy 1992; Tacon 1993). Clearly, this situation will have to be rectified if farmers are to reduce production costs and maximize economic benefit from their semi-intensive pond farming systems.

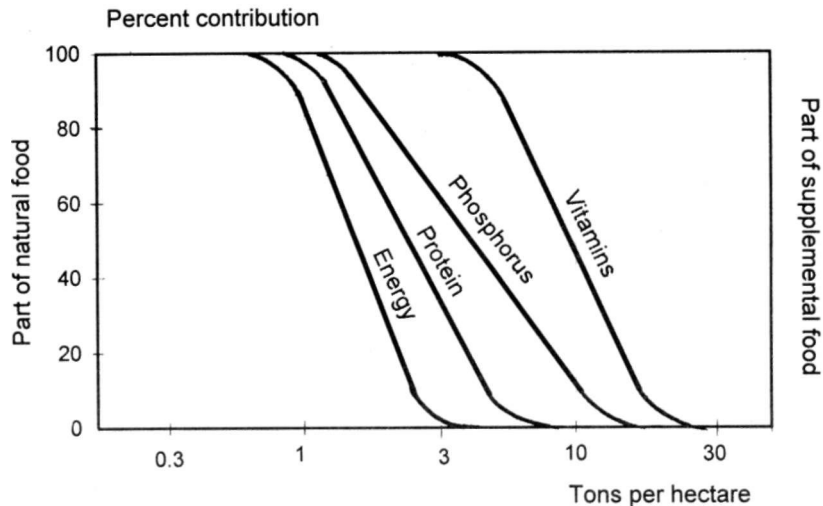


Fig. 3. Schematic model of the contribution of nutrients from natural and supplemental food for increasingly intensive carp culture in Israel (Viola 1989).

Nutritional contribution of natural food organisms in pond and formulated feed

Although the nutritional and economic importance of natural food organisms within the overall nutritional budget of pond-raised fish have been well documented by researchers in Israel (Hepher 1988, 1989; Schroeder *et al.* 1991; Viola 1989), little of this information has trickled down to researchers, feed compounders, and farmers in other countries. For example, despite the dietary essentiality of vitamins for *Tilapia* sp. under indoor laboratory conditions, field studies in Israel have shown no beneficial effect of dietary vitamin supplementation with *Tilapia* sp. in ponds, cages or concrete tanks at densities of 100 fish/m² with yields of up to 20 tons per hectare (Viola 1989). The apparent non-essentiality of dietary vitamin supplements for *Tilapia* (even within intensive farming systems such as cement tanks or floating net cages) has also been observed by many other workers under practical farming conditions (Tacon 1991). From a nutritional standpoint it is important to remember that many farmed fish species are filter-feeders and therefore have the ability to filter fine particulate matter (i.e., bacteria-laden detritus, phytoplankton, zooplankton, etc.) directly from the water column. These are silver carp, bighead carp, *Tilapia* sp., catla *Catla catla*, rohu *Labeo rohito*, mrigal *Cirrhinus mrigala*, kissing gourami *Helostoma temmincki* common carp, Thai silver carp *Puntius gonionotus*, milkfish, and nilem carp *Osteochilus hasseltii* (Colman and Edwards 1987; Perschbacher and Lori 1993).

The importance of natural food organisms has also been shown in pond-raised crustaceans. For example, Anderson *et al.* (1987) reported that natural pond biota accounted for 53-77% of the growth carbon of the cultured shrimp *P. vannamei* (stocking density, 20/m²), as compared with 23-47% supplied exogenously by pelleted shrimp diet. Similarly, the study of Cam *et al.* (1991) with pond reared *P. japonicus* (stocking density, 20/m²; PL₂₀₋₂₅: 25 mg body wt) showed that natural productivity accounted for 86.7, 42.7, 41.7 and 34.4% of the growth carbon of shrimp after 30, 60, 90 and 120 days, respectively. All cultured shrimp were fed a 57.4% protein pellet from day 15 after stocking until the end of the 120-day experiment. Interestingly, the studies of Leber and Pruder (1988) and Moss *et al.* (1992) have also demonstrated the growth-enhancing effect of unfiltered shrimp pond water on the growth of laboratory-reared shrimp. *P. vannamei* reared in microcosm tanks receiving flow-through pond water and fed artificial diets grow over 50% faster than the shrimps receiving clear well water and fed identical diets. Similarly, Bostock (1991) recently reported that there was no difference in the growth of pond-reared shrimp (*P. monodon*; 10/m²) in India fed a high-nutrient pelleted diet or a locally produced dough-ball costing one third of the price. For additional information of the importance of natural food organisms in the overall nutritional budget of pond-reared crustaceans see also Bombeo-Tuburan *et al.* (1993), Boonyaratpalin and New (1982), Lilyestrom *et al.* (1987), and Triño *et al.* (1992).

In general, the relative contribution of natural food organisms in the overall nutritional budget of pond-raised fish or shrimp will depend upon 1) the natural

feeding habit of the farmed species in question (i.e., herbivore, omnivore or carnivore; filter-feeder, etc.), 2) fish or shrimp stocking density and total fish or shrimp biomass or standing crop present, 3) pond fertilizer and feed input (i.e., type, quantity and application method), 4) water quality and water management (i.e., climatic effect, water exchange rate, water circulation pattern, aeration), 5) pond characteristics (i.e., pond size, depth, soil, surface area, pond history), and 6) the natural productivity and consequent availability of natural food organisms in the water.

Generally, the contribution of natural biota in the overall nutritional budget of the pond-cultured fish or shrimp will be highest at low stocking densities and at the start of the pond production cycle when the total fish or shrimp biomass or standing crop is lowest; the subsequent availability and relative contribution of natural pond biota decreases over the course of the production cycle with increasing fish or shrimp size and standing crop (for review see De Silva 1993; Hephher 1989; Luquet 1989; Moore 1986; Moriarty and Pullin 1987; Piedrahita and Giovannini 1991; Schroeder *et al.* 1991; Steffens 1990; Tacon 1988; Yakupitiyage 1993). For example, Figure 4 shows the influence of shrimp (*P. monodon*) market size and pond stocking density on the reported performance (indicated as apparent food conversion ratio or FCR) of a pelleted shrimp feed within commercial shrimp farms in Thailand (ponds stocked with ca. 30-50 postlarvae/m²; Tacon 1993a). From the data it is clear that the lower FCRs observed at the lowest shrimp market sizes and stocking densities was almost certainly due to the higher contribution of natural pond biota toward the overall nutritional budget of the farmed shrimp at these lower densities and market sizes.

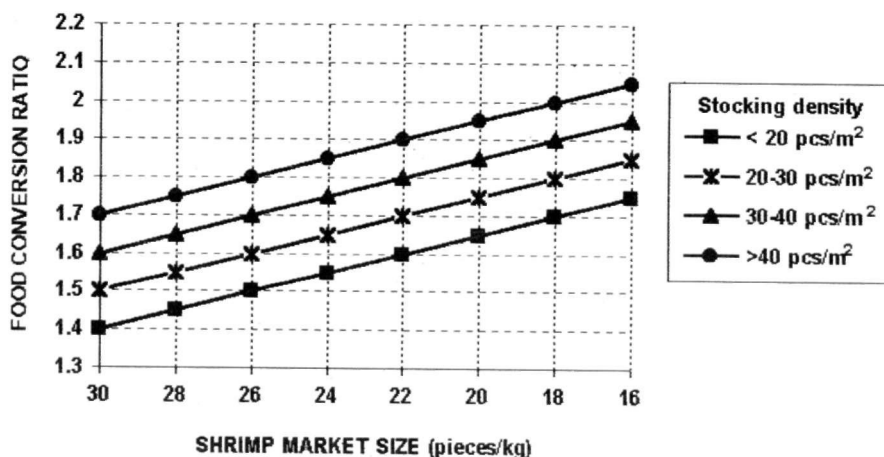


Fig. 4. Influence of shrimp market size and stocking density on the food conversion ratio of pond cultured *Penaeus monodon* fed 'CP' shrimp feed in Thailand.

Recommendations

On the basis of the above discussions, some general recommendations can be made regarding possible future research approaches for the development of semi-intensive feeding methods for fish and crustaceans:

1. Since all farming systems, including SIFS, depend upon the supply of nutrient inputs (either in the form of fertilizers or manures or supplementary or complete feeds), it is essential that national agricultural feed surveys (NAFS) be conducted within SEAFDEC Member Countries so as to ascertain where the agricultural resources are geographically located, how much is available and when, who is currently using this resource and how, the composition and cost of these resources at source and with transportation, together with an assessment of the existing animal feed manufacturing industry and its regulations. Such an approach is essential if Member Countries are to maximize the utilization of locally available agricultural resources and reduce their reliance on imported feed ingredients and feed lines. Guidelines for conducting NAFS are given in Tacon (1993b).
2. In view of the shortage of conventional feed ingredient sources within the rural communities, and the low cash income and purchasing power of most small-scale rural farmers (as compared with commercial farmers), fertilizer and feed selection for fish and/or shrimp feeding by these rural farmers should be based on the following criteria in order of importance: 1) cost - the material should be available at little or no cost to the farmer, 2) local availability, 3) handling and processing requirements prior to feeding, including transportation, should be minimum or negligible, and 4) nutritional value. Furthermore, by utilizing low quality and value agricultural products, and agricultural and industrial by-products which are not usually used for human or livestock feeding, aquaculture could be seen to be an asset to the rural community by increasing land productivity rather than a competitor with the traditional agricultural and livestock farming activities (Tacon 1988).
3. At present almost all of the available information on the dietary nutrient requirements of cultured fish or shrimp is derived from indoor laboratory feeding trials in which the animals are usually kept under controlled environmental conditions with no access to natural food organisms. Although essential for the formulation of complete diets for use within intensive farming system, this information cannot be directly applied to the formulation of supplementary diets for use within SIFS.

Thus, dietary nutrient requirement studies and feeding trials for the development of aquafeeds (including the nutritional evaluation of feed ingredient sources and feed lines) for use within SIFS must be conducted under on-farm conditions (Tacon 1995). Furthermore, it is recommended that a combination of food-web isotope tracer studies (for methodology see Parker *et al* 1991; Schroeder 1993; Wada *et al* 1991, Mizutani and

Minagawa 1991) and mathematical modelling studies (Cuenco 1989; Van Dam 1990; Delince 1992; Moriarty and Pullin 1987; Piedrahita 1988; Zweig 1991) be undertaken so as to understand pond nutrient dynamics and study the nutritional contribution of natural pond biota in the overall nutritional budget of pond-reared fish and/or shrimp. In this respect there is also a need to reduce farm production costs by maximizing the role played by natural food organisms in the overall nutritional budget of the pond-raised fish through the use of improved pond fertilization techniques (including integration with livestock), and improved pond sediment and water management techniques.

4. Concerning methodological approaches to nutrition research, it is recommended that:
 - The experiments be conducted under conditions mimicking as far as possible those of the intended farm production unit and environment (i.e., on-farm conditions). These include holding facility (indoor or outdoor tank, cage or pond), feed preparation technique (grinding, pelleting, drying; diet texture, form, shape, size, buoyancy, and water stability), feeding method (hand, demand or automatic feeding) feeding frequency and feeding rate (fixed or satiation feeding), water quality (temperature, turbidity, salinity, oxygen, and mineral concentration); water exchange rate, water circulation pattern and artificial aeration, photoperiod (artificial or natural) and fish and/or shrimp stocking density.
 - Full feed ingredient descriptions, including International Feed Number (IFN), chemical composition, and particle size be provided when reporting the results of nutritional feeding studies.
 - The growth performance of experimental fish or shrimp be at least equal to or greater than that of the target fish/shrimp species under practical farming conditions so that dietary nutrient requirements can be ascertained under conditions of maximum attainable growth.
 - Nutrient digestibility studies should ensure that a range of feed ingredient inclusion levels and ingredient particle sizes be tested. Digestibility measurements should be separated on the basis of feed preparation method employed (i.e., cold pelleted feeds, conventional steam pelleted feeds, and extrusion pelleted feeds), and that fish and/or shrimp be fed to satiation per day under similar on-farm conditions. In addition, it is also recommended that research efforts be focused on the further development of simple in-vitro digestion techniques for the rapid estimation of nutrient digestibility (Eid and Matty 1989; Grabner 1985).
5. Since food and feeding (including fertilization) usually represent the largest cost item of SIFS, particular attention must be focused on the development of research strategies aimed at reducing fertilizer and feed costs and

improving on-farm fertilizer and feed management technique. A logical step towards this end is to make a detailed appraisal of the fertilizer and feeding strategies currently employed by the fish farming community within the country, through the use of farm questionnaires and field visits, and then to publish this information as national aquaculture feeding profiles for subsequent distribution to the public sector. Guidelines for structuring a farm questionnaire are given in Tacon (1993a). The survey can identify fertilizer/feeding deficiencies and constraints which in turn serve as the subject of future on-farm field research investigations.

Emphasis within government/public support staff must be placed on trying to find local solutions and improvements for the existing problems of the resident aquaculture sector within SEAFDEC Member Countries by supporting on-farm research rather than just conducting pure or fundamental research. However, the key to the success of on-farm research is participation of the farmers themselves, not only assisting in the identification of research needs and priorities, but also in the actual implementation of on-farm research programmes. Sadly, in most instances the R & D programmes of most public sector support agencies are aimed more on the particular research interests of individual government scientists and/or donor agencies rather than those of farmers.

6. The nutritional performance and success of an aquafeed is dependent upon several factors which can be broadly considered under two major headings, namely, 1) feed formulation and manufacture, and 2) on-farm feed and water management (Figure 5). It follows that if feed intake and feed efficiency are to be improved and feed wastage and water quality deterioration minimized, strict attention should be given by both feed manufacturers and farmers to optimize these factors (Tacon 1993a).

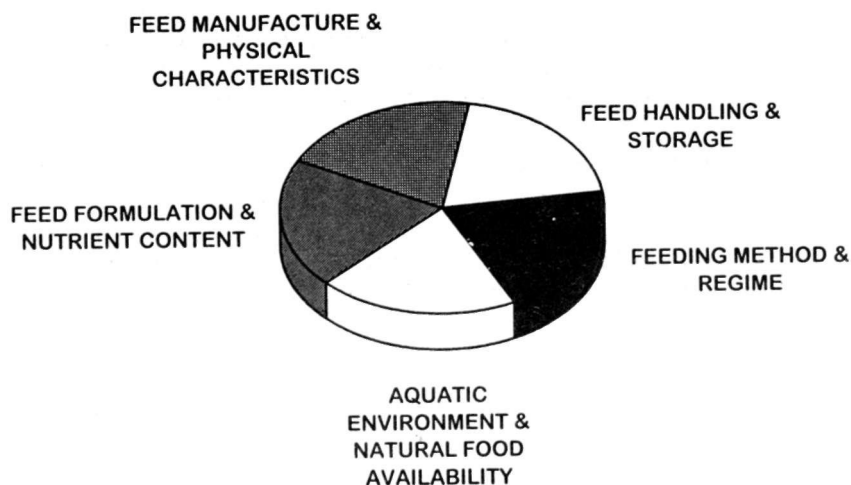


Fig. 5. Factors determining the nutritional performance of an aquafeed.

7. At present aquafeeds are totally dependent upon the use of fish meal and other fishery by-products (Tacon 1994). Although these products have high nutritional value and digestibility, there is a need to reduce reliance on these finite commodities with more sustainable protein sources.
8. One of the most exciting developments that have occurred in recent years is the application of the brush-park or 'acadja-enclosure' fishing method to extensive and semi-intensive farming systems. The farming practice is based on the introduction of woody material (i.e., branches, twigs, bamboo) into a pond or pen enclosure as an artificial substrate or habitat to stimulate the growth and production of periphyton and associated flora and fauna as live food organisms for the cultured fish (for review see Hem 1992; Konan-Brou and Guiral 1994; Shrestha and Knud-Hansen 1994).

A related but different approach has recently been developed in the USA and the Dominican Republic (Philips *et al.* 1994) using grass cuttings as a substrate for the production of a nitrogen-fixing microbial food web (i.e., microbial mat, dominated by blue-green algae within 'feeding lanes') as a complete feeding system for tilapia. Researchers in Australia (De Silva *et al.* 1993) used nitrogen-fixing leguminous crops (i.e., clover, lupin, etc. grown within the fish pond and on the pond dikes) as a supplementary feed source and/or a substrate for the increased production of natural food organisms within the pond ecosystem. Considerable further research is required concerning the use of artificial substrates and nitrogen-fixing microbial mats and plants (including certain aquatic macrophytes) within SIFS. However, the ultimate success of these novel feeding systems will depend, to a large extent, upon the feeding habits of the fish and/or shrimp species chosen and their stocking densities.

9. If aquaculture, and in particular SIFS, is to play any significant role in food security in Asia, it is imperative that the fish and crustacean species chosen for mass production have herbivorous or detritivorous feeding habits (feeding low on the aquatic food chain) and not dependent upon high quality, protein-rich feed inputs such as fish meal and other protein concentrates. Whereas the majority of aquaculture production within 'developed' countries is based on the culture of high value carnivorous fish or shrimp species within intensive farming systems, the bulk of aquaculture production within 'developing' countries is based on the culture of low value (from a marketing point of view) omnivorous and/or herbivorous fish or shrimp species within semi-intensive and extensive farming systems. The important point to learn from the approach of 'developing' countries (which also happen to produce over 70% of total world aquaculture production) is that their semi-intensive farming systems are more energy-efficient than the intensive farming systems, are based on the polyculture of complementary fish species, have little or no adverse effect upon the aquatic environment, and require only fertilizer or low-protein feed inputs (Hughes and Handwerker 1993; Rumsey 1994; Tacon 1993d).

References

- Akiyama DM. 1991. Future considerations for the aquaculture feed industry, pp. 5-9 In: Akiyama DM, Tan RKH (eds) *Proceedings of the Aquaculture Processing and Nutrition Workshop, Thailand and Indonesia, September 19-25, 1991*. Am. Soybean Assoc., Singapore.
- Anderson RK, Parker PL, Lawrence AL. 1987. A 13C/12C tracer study of the utilization of presented feed by a commercially important shrimp *Penaeus vannamei* in a pond growout system. *J. World Aquaculture Soc.* 19:148-155.
- Bombero-Tuburan I, Guanzon NG, Schroeder GL. 1993. Production of *Penaeus monodon* (Fabricius) using four natural food types in an extensive system. *Aquaculture* 112:57-65.
- Boonyaratpalin M, New MB. 1982. Evaluation of diets for *Macrobrachium rosenbergii* reared in concrete ponds, pp. 249-256. In: New MB(ed) *Giant Prawn Farming*. Elsevier Science Publ. Corp., Amsterdam, Holland.
- Bostock T. 1991. Better feeds for small-scale shrimp farmers. *Bay of Bengal News* 42:22-26.
- Cam D, Rollet PE, Mariotti A, Guillaume J. 1991. Contribution relative de la productive naturelle et de l'aliment composé dans la nutrition de *Penaeus japonicus* élevé en conditions semi-intensives. *Aquatic Living Resources* 4:175-180.
- Chamberlain G. 1992. Shrimp culture in Indonesia - 4. Feeds for the shrimp industry. *World Aquaculture* 23:38-40.
- Colman JA, Edwards P. 1987. Feeding pathways and environmental constraints in waste-fed aquaculture: balance and optimization, pp. 240-281. In: Moriarty DJW, Pullin RSV, (eds) *Detritus and Microbial Ecology in Aquaculture*, August 1985, Bellagio, Italy, ICLARM Conference Proceedings 14, International Center for Living Aquatic Resources Management; Manila, Philippines.
- Csavas I. 1993. Status of aquaculture in Asia. *FAO Aquaculture Newsletter*. 5:12-16. Rome, Italy: FAO.
- Cuenca ML. 1989. Aquaculture systems modelling: an introduction with emphasis on warm water aquaculture. *ICLARM Studies and Reviews No. 19*. Manila, Philippines: International Center for Living Aquatic Resources Management, 46 pp.
- Delince G. 1992. *The Ecology of the Fish Pond Ecosystem*. Dordrecht, The Netherlands, Kluwer Academic Publishers, 230 pp.
- De Silva SS. 1993. Supplementary feeding in semi-intensive aquaculture, pp. 24-60. In: New MB, Tacon AGJ, Csavas I (eds) *Farm-made Aquafeeds*. *Proceedings of the FAO/AADCP Regional Expert Consultation on Farm-made Aquafeeds, 14-18 December 1992, Bangkok, Thailand*. Bangkok, Thailand: FAO-RAPA/AADCP.
- De Silva SS, Mitchell BD, Nandeesha MC. 1993. Reducing feed costs in semi-intensive finfish culture: An update on mixed feeding schedules and an idea for enhancing food supply in ponds. *NAGA, The ICLARM Quarterly* 16:24-26.
- De Silva SS, Davy FB. 1992. Fish nutrition research for semi-intensive culture systems in Asia. *Asian Fisheries Science* 5:129-144.
- Edwards P. 1993. Environmental issues in integrated agriculture-aquaculture and wastewater-fed fish culture systems, pp. 139-170. In: Pullin RSV, Rosenthal H, Maclean JL (eds) *Environment and Aquaculture in Developing Countries*. ICLARM Conference Proceedings No. 31. Manila, Philippines.
- Eid AE, Matty AJ. 1989. A simple *in vitro* method for measuring protein digestibility. *Aquaculture* 79:111-119.
- FAO Fishery Information, Data and Statistics Service. 1993. *Aquaculture production 1985-1991*. FAO Fisheries Circular No, 815, Rev. 5. Rome: FAO. 213 pp.

- Grabner M. 1985. An *in vitro* method for measuring protein digestibility of fish feed components. *Aquaculture* 48:97-110.
- Hem S. 1992. Acadja-enclos:de la peche de cuelllette a la peche de culture, pp. 101-113. In: Bernacsek GM, Powles H (eds) *Aquaculture Systems Research in Africa. Proceedings of a workshop held in Bouake, Cote d'Ivoire, 14-17 November 1988.* IDRC-MR308e,f March 1992, International Development Research Centre, Ottawa, Canada.
- Hepher B. 1988. *Nutrition of pond Fishes.* England: Cambridge University Press 387pp.
- Hepher B. 1989. Principles of Fish Nutrition, pp. 121-141. In: Shilo M, Sarig S (eds) *Fish Culture in Warm Water Systems: Problems and Trends.* CRC Press Inc., Boca Raton, USA.
- Hughes SG, Handwerker TS 1993. Formulating for tilapia: all-vegetable protein feeds. *Feed International* 14:55-60
- ISTA III., 1991. The Third International Symposium on Tilapia in Aquaculture, 11-16 November 1991, Adidjan, Cote d'Ivoire, 137 pp. (abstracts).
- Jantrarotai W, Jantrarotai P. 1993. On-farm feed preparation and feeding strategies for catfish and snakehead, pp. 101-119. In: New MB Tacon AGJ, Csavas I (eds) *Farm-made Aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consultation on Farm-made Aquafeeds, 14-18 December 1992, Bangkok, Thailand.* FAO-RAPA/AADCP Bangkok, Thailand.
- Konan-Brou AA, Guiral D. 1994. Available algal biomass in tropical brackishwater artificial habitats. *Aquaculture* 119:175-190.
- Leber KM, Pruder GD. 1988. Using experimental microcosms in shrimp research: the growth enhancing effect of shrimp pond water. *J. World Aquacult. Soc.* 19:197-203.
- Lilyestrom CG, Romaine RP, Aharon P. 1987. Diet and food assimilation by channel catfish and Malaysian prawns in polyculture as determined by stomach content analysis and stable carbon isotope ratios. *J. World Aquacult. Soc.* 18:278-288.
- Luquet P. 1989. Practical considerations on the protein nutrition and feeding of tilapia. *Aquatic Living Resources* 2:99-104.
- Moore LB. 1986. Input of aquatic materials into aquaculture systems: emphasis on feeding semi-intensive systems. *Aquacultural Engineering* 5:12-133.
- Moriarty DJW, Pullin RSV (eds) 1987. *Detritus and Microbial Ecology in Aquaculture*, August 1985, Bellagio, Italy. ICLARM Conference Proceedings 14. International Center for Living Aquatic Resources Management, Manila, Philippines.
- Moss SM, Pruder GD, Leber KM, Wyban JA. 1992. The relative enhancement of *Penaeus vannamei* growth by selective fractions of shrimp pond water. *Aquaculture* 101:229-239.
- Nandessha, M.C. 1993. Aquafeeds and feeding strategies in India, pp. 213-254. In: New MB, Tacon AGJ, Csavas I (eds) *Farm-made Aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consultation on Farm-made Aquafeeds, 14-18 December 1992, Bangkok, Thailand.* FAO-RAPA/AADCP, Bangkok, Thailand.
- New M, Tacon AGJ, Csavas I. (eds). 1993. *Farm-made Aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consultation on Farm-made Aquafeeds, 14-18 December 1992, Bangkok, Thailand.* FAO-RAPA/AADCP Bangkok, Thailand.
- Nuov S, Nandeesha MC. 1993. Aquafeeds and feeding strategies in Cambodia, pp. 181-200. In: New MB, Tacon AGJ, Csavas I (eds) *Farm-made Aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consultation on Farm-made Aquafeeds, 14-18 December 1992, Bangkok, Thailand.* FAO-RAPA/AADCP, Bangkok, Thailand.
- Parker PL, Anderson RK, Lawrence AL. 1991. Stable isotope methodology for evaluation of nutritional requirements of shrimp, pp. 157-171. In: DeLoach PF, Daougherty WJ, Davidson MA (eds) *Frontiers of Shrimp Research. Development in Aquaculture and Fisheries Science No. 22.* Elsevier, Amsterdam, The Netherlands.
- Pershbacher PW, Lorio WJ. 1993. Filtration rates of catfish pond phytoplankton by Nile tilapia *Oreochromis niloticus*. *J. World Aquacult. Soc.* 2:434-437.
- Philips P, Russell A, Bender J, Munoz R. 1994. Management plan for utilization of floating microbial mat with its associated detrital gelatinous layer as a completed tilapia *Oreochromis niloticus* feed system. *Bioresource Technology* 47:239-245.

- Piedrahita RH, Giovannini P. 1991. Fertilized non-fed pond systems, pp. 1-14. In: Aquaculture Systems Engineering. Proceedings of the World Aquaculture Society (WAS) and the American Society of Agricultural Engineers, WAS 22nd Annual Meeting, 16-20 June 1991, San Juan, Puerto Rico. American Society of Agricultural Engineers.
- Piedrahita RH. 1988. Introduction to computer modelling of aquaculture pond ecosystems. *Aquacult. Fish. Mgt.* 19:1-12.
- Rumsey G. 1994. Fish feed ingredients. What is the future of fish meal use. *Feed International* 15:10-17.
- Schroeder GL. 1993. Sources of fish and prawn growth in polyculture ponds as indicated by ^{13}C : ^{12}C analysis. *Aquaculture* 35:29-42.
- Schroeder GL, Alkon A, Laher M. 1991. Nutrient flow in pond aquaculture systems, pp.489-505 In: Brune DE, Tamasso JR (eds) *Aquaculture and water quality. Advances in World Aquaculture, Volume 3.* World Aquaculture Society, Baton Rouge, USA.
- Shrestha MK, Knud-Hansen CF. 1994. Increasing attached micro-organism biomass as a management strategy for Nile tilapia (*Oreochromis niloticus*) production. *Aquacultural. Engineering* 13:101-108.
- Steffens W. 1990. Interrelationships between natural food and supplementary feeds in pond culture, pp. 218-229. In: Berka R, Hilge V (eds) *Production enhancement in still-water pond culture. Proceedings of the FAO/EIFAC Symposium on Production Enhancement in Still-water Pond Culture, Prague, 15-18 May 1990.* Research Institute of Fish Culture and Hydrobiology, Vodnany, Czechoslovakia.
- Tacon AGJ. 1995. Application of nutrient requirement data: special problems of intensive and semi-intensive fish farming systems. *J. Appl. Ichthyol.* 11:215-224.
- Tacon AGJ. 1994. Dependence of intensive aquaculture systems on fishmeal and other fishery resources - trends and prospects. *FAO Aquaculture Newsletter.*
- Tacon AGJ. 1993. Aquaculture nutrition and feeding in developing countries: A practical approach to research and development, pp. 731-741. In: Kaushik SJ, Luquet P (eds) *Fish Nutrition in Practice. IVth International Symposium on Fish Nutrition and Feeds.* Les Colloques No. 61, INRA, Paris, France.
- Tacon AGJ. 1993a. Feed formulation and on-farm feed management, pp. 61-74. In: New MB, Tacon AGJ, Csavas I (eds) *Farm-made Aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consultation on Farm-made Aquafeeds, 14-18 December 1992, Bangkok, Thailand.* FAO-RAPA/AADCP Bangkok, Thailand.
- Tacon AGJ. 1993b. National agricultural feed surveys (NAFS) for aquaculture planning and development: guidelines. *FAO Newsletter. No.4, pp.2-7; Rome, FAO. August 1993.*
- Tacon AGJ. 1993d. Feed ingredients for warmwater fish. Fish meal and other processed feedstuffs. *FAO Fisheries Circular No. 856, Rome, FAO. April 1993, 64 pp.*
- Tacon AGJ. 1993e. Feed ingredients for crustaceans. Natural food and processed feedstuffs. *FAO Fisheries Circular No. 866, Rome, FAO. November 1993, 67 pp.*
- Tacon AGJ, De Silva SS. 1993. Feed preparation and feed management strategies within semi-intensive fish farming systems in the tropics. Paper presented at the 6th International Symposium on Fish Nutrition and Feeding, 4-7 October 1993, Hobart, Australia.
- Tacon AGJ. 1991. Vitamin nutrition in shrimp and fish, pp. 10-14. In: Akiyama DM, Tan RKH (eds) *Proceedings of the Aquaculture Processing and Nutrition Workshop, Thailand and Indonesia, September 19-25, 1991.* American Society Association, Singapore.
- Tacon AGJ. 1991a. Kenya: development of tilapia feeds. *FAO Field Document. Report prepared for the Small-scale Fish Farming in the Lake Basin Project KEN/86/027, Field Document 1, FAO, Rome, Italy. 31 pp.*
- Tacon AGJ. 1988. The nutrition and feeding of farmed fish and shrimp - A training manual. 3 Feeding methods. *FAO Field Document, Project GCP/RLA/075/ITA, Field Document No. 7, Brasilia, Brazil. 208 pp.*
- Triño AT, Peñaflorida VD, Bolivar EC. 1992. Growth and survival of *Penaes monodon* Juveniles fed a diet lacking vitamin supplements in a modified extensive culture system. *Aquaculture* 100:25-32.

- Tacon AGJ. 1994. Dependence of intensive aquaculture systems on fishmeal and other fishery resources - trends and prospects. FAO Aquaculture Newsletter.
- Tacon AGJ. 1993. Aquaculture nutrition and feeding in developing countries: A practical approach to research and development, pp. 731-741. In: Kaushik SJ, Luquet P (eds) Fish Nutrition in Practice. IVth International Symposium on Fish Nutrition and Feeds. Les Colloques No. 61, INRA, Paris, France.
- Tacon AGJ. 1993a. Feed formulation and on-farm feed management, pp. 61-74. In: New MB, Tacon AGJ, Csavas I (eds) Farm-made Aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consultation on Farm-made Aquafeeds, 14-18 December 1992, Bangkok, Thailand. FAO-RAPA/AADCP Bangkok, Thailand.
- Tacon AGJ. 1993b. National agricultural feed surveys (NAFS) for aquaculture planning and development: guidelines. FAO Newsletter. No.4, pp.2-7; Rome, FAO. August 1993.
- Tacon AGJ. 1993d. Feed ingredients for warmwater fish. Fish meal and other processed feedstuffs. FAO Fisheries Circular No. 856, Rome, FAO. April 1993, 64 pp.
- Tacon AGJ. 1993e. Feed ingredients for crustaceans. Natural food and processed feedstuffs. FAO Fisheries Circular No. 866, Rome, FAO. November 1993, 67 pp.
- Tacon AGJ, De Silva SS. 1993. Feed preparation and feed management strategies within semi-intensive fish farming systems in the tropics. Paper presented at the 6th International Symposium on Fish Nutrition and Feeding, 4-7 October 1993, Hobart, Australia.
- Tacon AGJ. 1991. Vitamin nutrition in shrimp and fish, pp. 10-14. In: Akiyama DM, Tan RKH (eds) Proceedings of the Aquaculture Processing and Nutrition Workshop, Thailand and Indonesia, September 19-25, 1991. American Society Association, Singapore.
- Tacon AGJ. 1991a. Kenya: development of tilapia feeds. FAO Field Document Report prepared for the Small-scale Fish Farming in the Lake Basin Project KEN/86/027, Field Document 1, FAO, Rome, Italy. 31 pp.
- Tacon AGJ. 1988. The nutrition and feeding of farmed fish and shrimp - A training manual. 3 Feeding methods. FAO Field Document, Project GCP/RLA/075/ITA, Field Document No. 7, Brasilia, Brazil. 208 pp.
- Triño AT, Peñaflores VD, Bolivar EC. 1992. Growth and survival of *Penaeus monodon* Juveniles fed a diet lacking vitamin supplements in a modified extensive culture system. Aquaculture 100:25-32.
- Van Dam AA. 1990. Modelling of aquaculture pond dynamics, pp. 24-30. In: Proceedings of EIFAC-FAO Symposium on Production Enhancement in Still-Water Pond Culture, Prague, 15-18 May 1990.
- Vlcnke MMJ. 1988. Developing productive systems under village conditions, pp. 39-57. In: King HR, Ibrahim K (eds) Village Level Aquaculture Development in Africa. Proceedings of the Commonwealth Consultative Workshop on Village Level Aquaculture Development in Africa., Freetown, Sierra Leone, 14-20 February 1985. Commonwealth Secretariat, London, UK.
- Viola S. 1989. Production of commercial feeds for warm water fish, pp. 143-162. In: Shilo M, Sarig S (eds) Fish Culture in Warm Water Systems: Problems and Trends. CRC Press Inc., Boca Raton, Florida.
- Wada E, Mizutani H, Minagawa M. 1991. The use of stable isotopes for food web analysis. Critical Reviews in Food Science and Nutrition 30:361-371.
- Yakupltiyage A. 1993. On-farm preparation and feeding for carps and tilapia, pp. 87-100. In: New MB, Tacon AGJ, Csavas I (eds) Farm-made aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consultation on Farm-made Aquafeeds, 14-18 December 1992, Bangkok, Thailand. FAO-RAPA/AADCP. Bangkok, Thailand.
- Zweig RD. 1991. Principles and methodology of ecological-economic modelling of integrated agriculture-aquaculture farming systems, pp. 17 (abstract). In: Costa-Pierce BA, Lightfoot C, Ruddle K, Pullin RSV (eds) Aquaculture Research and Development in Rural Africa. ICLARM Conference Proceedings No. 27. International Center for Living Aquatic Resources Management, Manila, Philippines.