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Fish Nutrition Research for Semi-Intensive Culture Systems in Asia

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Abstract

Asia, considered the cradle of aquaculture, accounts for over 80% of the world's production. Most finfish production is of omnivorous/herbivorous species, cultured ex-tensively and/or semi-intensively. In the light of increasing, conflicting demand for land and water, to be cost-effective, culture practices need to be intensified to varying degrees, mostly through increasing levels of supplemental feeding. Feed cost is one of the highest, if not the highest, operational cost in aquaculture.

Because of these developmental trends, fish nutrition research has become in-creasingly important. However, most research has followed basic nutrient requirement approaches often based on developed-country priorities. There is increasing evidence that the gross nutrient requirements of cultured species groups are close to one an-other. Equally, diet development aimed at reducing feed cost by substitution of the fishmeal component, an ingredient not readily available in rural Asia, by agricultural by-products has been mostly confined to laboratories and findings are difficult to ex-tend to farm conditions.

This paper considers the above aspects and suggests strategies for fish nutrition research, particularly where funding and personnel are increasingly limited. These strategies essentially encompass a holistic approach to research on feed-cost savings carried out on farm at minimal cost, primarily through research on improved hus-bandry, and taking into consideration the natural environmental inputs under tropical culture conditions.

Introduction

Recently there is increasing interest among researchers and funding agencies involved in tropical aquaculture and fisheries to develop new strategies for research (Troadec and Christy 1990). This renewed interest is timely as we feel that research progress in this sector has been hampered by the overtly wide range of research needs, species cultured and production systems used in developing countries. Coupled with the limited information base, even for major culture species, there is a great deal of confusion on the optimum allocation of scarce resources and future directions for research and development (see Cho et al. 1985; De Silva et al. 1989).

In this review, we focus on the species of importance to low- and middle-income consumers, i.e., finfish such as milkfish, tilapia and carps, in Asia where most aquaculture is carried out, and on the semi-intensive systems in which they are commonly farmed.

Predominant Culture Systems

Present nutrition research programs in developing countries follow the nutrient requirement approaches used primarily in intensive culture systems that are often based on developed-country priorities. These are not appropriate in extensive and semi-intensive systems (usually pond culture systems) in the developing countries of the tropics where the major producers are large numbers of small farmers. We define extensive production systems as those involving no external feed inputs while semi-intensive systems involve partial feed addition, usually consisting of on-farm by-products often supplemented with fishmeal as a protein source. A more detailed definition of extensive, semi-intensive and intensive culture systems is given by Edwards et al. (1988). However, for our purposes, the above definition suffices. Asia, historically the cradle of aquaculture, is the largest aquaculture producer at present, accounting for nearly 84% of global production (FAO 1989). However, Asia still depends to a large extent on semi-intensive and extensive practices as is the case globally. In Asia, the major research need will be for increases in yields through intensification.

Intensive culture systems are often associated with monoculture practices with high-input requirements where single preferred "luxury" species are cultured mostly on high quality pelleted feeds. The culture systems are often supported by mechanization, such as the provision of aeration. Such systems appear to have encouraged nutrition research focused on developing complete diets prepared in large central feed mills utilizing computer-based least-cost diet formulations of available ingredients. These diets usually have little relation to the more numerous extensive and semi-intensive production systems. Projected limitations on the fishmeal supply, which is the nutritional backbone in intensive aquaculture, particularly of high-valued marine products (Wijkstrom and New 1989) make it even more desirable to concentrate nutrition research effort towards on-farm conditions, particularly with respect to semi-intensive culture.

Species

The species cultured are broadly divisible into two groups: the high valued "luxury" shrimp and finfish species including the groupers, seabass and the low-valued ones, such as milkfish, carps and the tilapias. The latter group provides a relatively cheap animal protein source for the low- and middle-income consumers in most Asian countries. The high-valued finfish species are carnivorous; preferences varying between species even of the same family. The exact nature of the food habits of most of the species cultured extensively and semi-intensively is ill-defined and variable depending on the stage of the life-cycle, food availability and even the composition and density of the piscine community (Hepher et al. 1989). One would have expected that the basic food habits of the commonly cultured species would have been adequately known. However, it is not so, confirming the lack of focus on the major species and culture systems. For example, only recently have studies demonstrated the high adaptability of tilapiine fish with respect to their food habits and the morphological mechanisms that are associated with dealing with different food types (Maitipe and De Silva 1985; Beveridge et al. 1988). Very little is known of the nutritional quality of the naturally ingested food material of cultured species, as well as others, except for some studies on the tilapias from different natural habitats (Bowen 1979, 1982; De Silva 1985; Getachew and Fernando 1989).

The feed cost, irrespective of whether a culture practice is intensive or not, is a major, if not the highest, operational cost in most types of practice (Edwards et al. 1988). For example, the cost of supplementary feed in a flowing water system and in cage culture is estimated to reach 60% of total cost of production (Collins and Delmendo 1979). The high feed cost is attributed to: (a) the relatively high protein requirement of fish (Cowey 1975), recently disputed by Bowen (1987), in comparison to other terrestrial animals (see Table 1); and (b) the significant portion of the protein requirements which have to be provided by fishmeal (Tacon and Cowey 1985). Fishmeal is expensive compared to plant protein sources, and is not readily available in most rural areas in developing countries. Longer-term storage is not possible under rural farm conditions in most of Asia.

Table 1. Dietary protein levels resulting in the highest growth rates of selected fish species (for further details see Hepher 1988 and De Silva et al. 1989).

Species	Protein (%) (by dry weight)	Source
Chanos chanos	40.0	Lim et al. (1979)
Ctenopharyngodon idellus	22.8-27.7	Ding et al. (1980)
Cyprinus carpio	31.0	Takeuchi et al. (1979)
	33.0	Sin (1973)
	35.0	Jauncey (1981)
	38.5	Ogino and Saito (1970)
Labeo rohita	45.0	Sen et al. (1978)
	29.5	Singh et al. (1979)
Oreochromis aureus	34-56	Winfree and Stickney (1981)
	36.0	Davis and Stickney (1978)
O. niloticus	30.0	Appler (1985)
	30.0	De Silva and Perera (1985)
	35.0	Santiago et al. (1982)
	35.0	Teshima et al. (1985)

The Problem

There will be a growing need to make the profit margins more attractive even in semi-intensive and extensive culture practices because of the increasing competition for common resources such as land and water and inputs such as feed and fertilizer. Extensive culture practices which are generally subsistence level farming activities will tend towards semi-intensiveness, where supplementary feeding of some sort will be adopted.

A number of approaches, either singly or collectively, can be adopted to increase profitability. Cost-effective application of fertilizer is one (Hepher 1988). From a fish nutritionist's point of view, the more obvious are associated with improvements in feeding practices such as improving husbandry practices that lead to more efficient utilization of supplementary feed, reducing the cost of the feed, improving its nutrient quality without appreciable increases in costs and the like. None of the above lead towards an intensification of culture practices, but are essentially improvements that could result in increased profitability without incurring extra operational or capital expenditure. Our aim is to recognize priorities in nutrition research that will enable the average fish farmer in Asia to achieve this end.

Nutritional Requirements

All organisms have specific nutrient requirements and fish are no exception. The nutritional requirements are broadly divisible into two groups: gross requirements, including gross protein, carbohydrate, lipid and energy requirements; and micronutrient requirements, including essential amino and fatty acids, vitamins and minerals.

Research on nutritional requirements is a relatively recent science and has progressed rapidly since the pioneering work of Halver (1972) on amino-acid and vitamin requirement studies on salmonid fishes (NRC 1973). Research on nutrient requirements is the backbone of nutritional research and essentially involved dose-response studies. The nutrient requirements of most commonly cultured temperate species is relatively well understood. Present research is directed more toward understanding the interactions amongst nutrients, development of feeds which cause minimal environmental damage through nutrient release, defining deficiency symptoms, more clearly evaluating immune-response mechanisms in relation to dietary nutrient deficiencies and the like. Basic nutrient requirements of commonly cultured fishes have been reviewed (Cowey and Sargent 1972; Halver 1972, 1988; NRC 1973; Cowey 1979). In spite of extensive and concerted research effort, particularly on the nutrient requirements of salmonids, there are a large number of unknowns especially for culture of tropical species.

In a climate of limited resources, particularly technical expertise and research funding in developing countries, the question arises whether there is a need to expend considerable research effort on evaluation in detail of the macro- and micronutrient requirements of all culturable species in the tropics. Hepher (1988), in his treatment on feeding of pond fishes, remarked that in spite of the gaps in the knowledge of nutrition of fish, there is sufficient information now available to define, however crudely, the nutritional requirements of various fish species.

The dietary protein requirements for highest growth have been recorded for a number of fish species. Results of a few such investigations are given in Table 1. It is evident that, for a particular species or a species group, the level at which highest growth is reported by different authors varies significantly. Some of this variation can be attributed to real biological differences due to fish size, age, temperature, etc. However, to a certain extent, the variation is a result of differences in experimental procedure and methodology.

De Silva et al. (1989) demonstrated that the growth responses of four tilapia species of any particular size-group (fed to satiation at least twice a day), for which data were available (in relation to the dietary protein levels reported by different authors), fall within a well-defined curve. From this curve, using the methodology of Zeitoun et al. (1976), they computed the dietary protein level (Fig. 1) which results in maximum growth, and also the economically optimal dietary protein level. Preliminary analysis has shown that a similar trend exists for three species of Indian major carps which are commonly cultured (De Silva and Gunasekera 1989). These observations indicate that, in general, specific differences in optimal protein requirements within a group are very narrow. We believe that the specific differences between the micronutrient requirements are even narrower within a group. For example, the amino-acid requirements of those fish species investigated to date are almost the same. In a recent review on the significance of lipids and essential fatty acids to aquaculture, Castell et al. (1988) were being pragmatic when they concluded, "it is unlikely that severe EFA (essential fatty acids) deficiency will be encountered in aquaculture practice."

In our assessment, there have been a considerable number of studies carried out on gross protein requirements in commonly cultured tropical species. A great majority of these studies remain

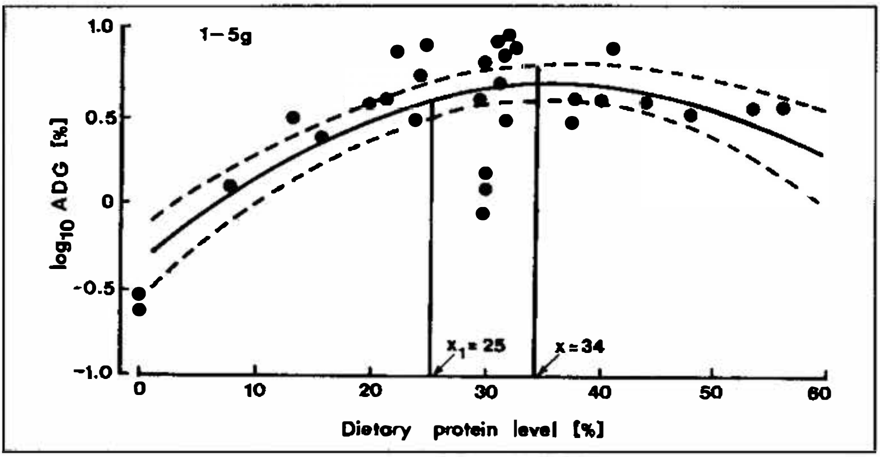

Fig. 1. The relationship of average daily growth (ADG) to dietary protein level in tilapiine fish (De Silva et al. 1989).

uncomparable due to differences in experimental conditions, and most of all because of the inadequacy of information published, particularly on the quality and the quantity of feed(s) used. Therefore, as a first step, it would be worthwhile to collate the available data, obtain additional information from the authors where necessary, and attempt to develop general concepts as has been done in the case of tilapias (De Silva et al. 1989), on gross nutrient requirements (especially for protein) for the other species. Some outstanding issues are whether requirements amongst species of a particular group and intraspecific differences in relation to age and size differ significantly. Initial examination of available data suggests limited differences in protein requirements. The preferred option for the average small farmer may be to use the same supplementary diet no matter what production system or species is being used.

Therefore, we do not advocate basic research *per se* on nutrition requirements for most of the above species. However, in view of the increasing importance of euryhaline species in semi-intensive culture in Asia (e.g., the milkfish *Chanos chanos*) some research on such species is still needed. For instance, there is very little known on the response of euryhaline species to different salinities, in relation to their feeding behavior and nutrient requirements (see De Silva and Perera 1985; Chiu et al. 1987). This is an area which needs research.

Research on Development of New Diets

Over the last decade or so, there has been considerable research on the development of new practical diets. These studies are largely laboratory-based and we are surprised by the scant effort to determine the types, ingredients and quantities of practical diets presently used by farmers. Such surveys need not be costly as Rapid Rural Appraisal (RRA) techniques are now available. In contrast, most studies have attempted to determine the extent to which the primary protein source, fishmeal, could be substituted by readily available agricultural by-products and by low-cost cereals and pulses. Such investigations have not been entirely confined to tropical species (Jackson et al. 1982; Viola and Arieli 1983; Robinson et al. 1984; Hilton and Slinger 1986; Wee and Ng 1986; Chiu et al. 1987; De Silva and Gunasekera 1989). Although a wide array of ingredients have been tested for their suitability for incorporation into practical diets for a variety of species, to our knowledge, no proper guidelines have been developed to extend these research findings to 'on-farm conditions.' Considerable research effort has also been expended to screen such ingredients in digestibility studies and through determination of proximate and amino-acid composition. Unfortunately, the data remain scattered in the literature and it is not uncommon to find new evaluations being carried out on ingredients very closely related to those already assessed. In contrast, for terrestrial animals such data are available in monographic form (Devendra 1985), minimizing duplication of scarce research effort. In India, a multitude of readily available ingredients have been tested for their suitability for incorporation into practical fish diets for all stages of growth of the Indian major carps (Shetty and Nandeesha 1988). However, no concerted effort has been made to synthesize this information and set broad guidelines for small-scale farmers. In our view, the urgent need is to take stock of available information on agricultural by-products reported suitable for incorporation into practical fish diets and, on this basis, to set research priorities for diet development of species cultured in tropical waters.

The influence of feeding level and frequency on digestibility has received limited attention and results reported so far have been contradictory. For example, Windell et al. (1978) did not find feeding level to influence digestibility in rainbow trout, while Henken et al. (1985) found apparent dry matter and protein digestibility to be negatively correlated to feeding level in the African catfish *Clarias gariepinus*. It will be useful to investigate the influence of feeding level and frequency on the apparent dry matter and nutrient digestibility in selected, commonly cultured tropical species.

Reducing Feeding Costs in Semi-Intensive Culture

In animal husbandry, a substantial saving in feed costs has been achieved by adopting proper husbandry practices, such as the time and frequency of feeding. It is known that at high levels of intake in terrestrial animals, substantial quantities of dietary proteins and simple carbohydrates may pass unaltered and undigested (Tamminga et al. 1979). Fish have less efficient and more primitive digestive systems than terrestrial vertebrates and similar tendencies in protein and carbohydrates digestion can be expected.

Husbandry practices in tropical, semi-intensive fish culture have not been widely studied. Studies have shown that frequent feeding results in better utilization of the same quantity of feed than a single feeding. However, the response of different species and different stages of growth of a species to feeding frequency may vary considerably (Table 2). There is a paucity of information (see Chiu 1989) on these aspects of tropical species under culture conditions, and we recognize this as an important area of research which could be carried out effectively on-farm.

The influence of feeding level on food conversion ratio (FCR) is also dependent on the quality of the diet and these interactive effects were graphically represented by Hepher (1988) (see Fig. 2). Hepher also suggested that, from an economic point of view, it is important to consider the marginal FCR which is the ratio of feed level increment to fish weight gain increment. It would be useful to investigate the utility of this approach under different culture conditions for different species and species combinations and to attempt to define the economic limit of FCR when the cost of marginal feed is equal to the income from the marginal gain. Such approaches, we believe, will result in adoption of husbandry techniques which will bring about savings in feed costs and also entail challenging research under farm conditions with least capital input in the form of equipment.

A serious gap in our knowledge is the contribution made to the nutrition of cultured fish by natural food in the system, particularly

Table 2. Summary of observations on response of feeding frequency on growth and food conversion efficiency in different species.

Species	Observation(s)	Authority
Channel catfish	Pond fed; consumption and weight gain higher when fed twice daily than once	Andrews and Page (1975)
Channel catfish	Better growth when fed 8 times/day	Murai and Andrews (1976)
>1.5 g	No difference when fed 8 or 4 times/day	- do -
Common carp	Continuous feeding by demand feeder; did not affect FCR	Hepher (1988)
Chanos chanos (0.60 g)	Optimal growth and feed efficiency when fed 8 times a day	Chiu et al. (1987)

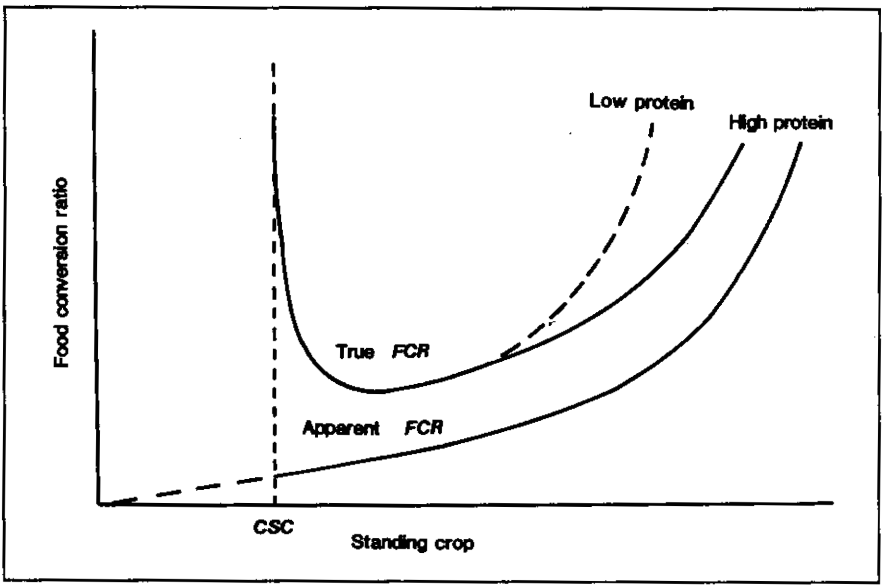

Fig. 2. The interrelationship of standing crop, the supplementary feed composition and the true and apparent FCR in ponds (From Hepher 1988, with permission from Cambridge University Press). CSC = critical standing crop.

in ponds under tropical conditions. In the tropics, in ponds and in enclosed bays or coves where cages and pens are located, natural production can be significant, the nutrients for this production being furnished by leaching, run-off from the catchment or from biodegradation of excess food and fecal matter. Albrecht and Breitsprecher (1969) reviewed the composition of fish food organisms in ponds, and showed that the average protein, carbohydrate and lipid content by dry weight was 52.1, 27.3 and 7.7%, respectively; the calorific value ranged from 1.6 to 5.7 $kCal{\cdot}g^{-1}$ dry matter (mean 3.9 $kCal{\cdot}g^{-1}$). The dietary protein requirement of most fish species cultured in the tropics (Table 1) is 28-35% by dry weight with a protein:energy ratio of 96 $mg{\cdot}kCal^{-1}$ (Prus 1970). Therefore natural food contains an excess of protein, the costliest nutrient of supplementary feeds. Schroeder (1980) demonstrated that natural food can represent 50-70% of total available food for tilapia in pond culture, even when a complete diet is provided. Santiago et al. (1989) successfully reared milkfish fingerlings in freshwater ponds by combining natural and artificial feeds. Hepher et al. (1989) demonstrated the influence of stocking density and species combinations on growth and utilization of natural food in ponds. The need to assess the effect of natural food in open systems, both qualitatively and quantitatively, has been stressed (Hepher 1988; Luquet 1989). Legendre et al. (1989) went further and pointed out that even under intensive conditions in the tropics, natural food plays a significant part in the growth of cultured fish.

Admittedly, natural food production will vary from system to system, region to region, with the type and extent of fertilization, and will depend on biological factors such as the species or species combinations and stocking densities used, quality and quantity of supplementary feed and a host of other factors. Research on the qualitative and quantitative aspects of the contribution of natural food to the growth of cultured species will enable general concepts to be defined. These will provide guidelines for the optimization of feed utilization and production.

Such research could also assess the requirement for costly additives, such as vitamin and mineral mixtures, in supplemental feeds. For example, Dickson (1987) demonstrated that incorporation of vitamins into a supplemental diet in tilapia culture had no influence on growth and production.

There is increasing evidence from laboratory studies on digestibility (De Silva and Perera 1985) and in small-scale culture conditions that mixed feeding schedules, a high-protein diet alternated with a low-protein diet, result in production comparable to that of providing a costly high-protein content diet throughout (Srikanth et al. 1989). Hale and Newton (1986) reported that in swine there was no significant difference in growth or carcass quality when a high-protein diet was alternated with a low-protein diet; but there was significant decrease in feed costs when such a strategy was adopted. A similar approach has been adopted to buffer the 'shock syndrome' caused by an EFA-deficient artemia strain on seabass larvae by alternating its use with different proportions of a strain rich in EFA (Navarro et al. 1988). De Silva (1985) discussed the possible physiological mechanisms for comparable growth performances when fish are maintained on alternating dietary schedules, as opposed to a single dietary schedule. Whatever the physiological mechanisms that govern the phenomenon, there is need to extend the initial laboratory and pilot-scale trials to on-farm culture systems to further confirm and determine the most suitable schedule for each culture system.

Such research can be done on-farm under both researcher and farmer management. Apart from the expected, direct relevance of such research to rural aquaculture *per se* it will also be attractive to donor agencies for funding; the experiments will need little or no equipment, are easy to design and the logistics should be relatively straightforward but should be as challenging to the researcher as in a laboratory experiment.

Role of Microbes

Detrital aggregates and associated microbial flora constitute an important component of the diet of some tilapia species, at least in the wild (Bowen 1979, 1982). Schroeder (1980) reported that in polyculture systems with competition for natural food sources, fish of different feeding characteristics tend to depend on food sources such as detrital and the microbial flora, which are not ingested under normal conditions.

Very little is known on the role of microbes in the nutrition and digestive processes of fish. Yet there is an increasing effort to develop diets using aquatic macrophytes, particularly under semi-intensive conditions (Edwards et al. 1985). Undoubtedly, microbial degradation can play an important part in the steps that lead to making some aquatic macrophytes suitable for ingestion and in the preparation of suitable pelleted diets for fish. However, the nature of this role is not understood. The microbial flora itself could provide a nutritious, easily assimilable food source. Research on aspects of microbial ecology of fishponds could lead to improvision of simple methods to enhance microbial flora which, in turn, could lead to increased growth rates and production in tropical pond culture.

Conclusion

We are advocating a holistic approach to fish nutrition. Fish nutritionists should work in conjunction with fisheries biologists and economists to test concepts and apply existing knowledge to important real production systems. In addition, as fertilization is widely practiced in semi-intensive and extensive culture practices in Asia, there is a growing need to obtain the expertise of botanists, microbiologists and limnologists in order to understand the intricacies of fertilization on natural food production in pond ecosystems.

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