

Analysis of feeds and fertilizers for sustainable aquaculture development in India

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Ayyappan, S. and Ahmad Ali, S. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in India. In M.R. Hasan, T. Hecht, S.S. De Silva and A.G.J. Tacon (eds). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No. 497. Rome, FAO. pp. 191–219.

SUMMARY

Fisheries and aquaculture contribute significantly towards the Indian agricultural economy. Total fisheries production during 2003–04 was 6.4 million to which aquaculture contributed about 2.37 million tonnes. The share of fisheries in the national GDP is 1.4 percent and in the agricultural GDP its share is 4.5 percent. Aquaculture has been growing rapidly over the last two decades, contributing 37–38 percent of total fish production. India has substantial aquatic resources to diversify and expand its aquaculture sector. The major species groups that are farmed in India are fresh water fishes, freshwater prawns, penaeid shrimps, mud crabs and brackish-water fishes. Aquaculture is practised in a variety of agro-climatic zones ranging from tropical to temperate areas. Freshwater aquaculture is the largest contributor to aquaculture production and has grown at an average rate of 6.6 percent per annum. The most important species are the Indian major carps (*Catla catla*, *Labeo rohita*, *Cirrhinus cirrhosus*), common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), and giant freshwater prawn (*Macrobrachium rosenbergii*). Fish species such as snake heads (e.g. snakehead murrel *Channa striata*) and catfishes (e.g. walking catfish *Clarias batrachus*, North African catfish *C. gariepinus*, stinging catfish *Heteropneustes fossilis*, sutchi catfish *Pangasius hypophthalmus*) are farmed, but to a lesser extent. Cold-water fish such as trout (rainbow trout *Oncorhynchus mykiss*, brown trout *Salmo trutta fario*, snow trout *Schizothorax richardsonii*) and golden mahseer (*Tor putitora*) are cultured in the uplands of northern India, mainly for sport fisheries. Freshwater fishes are cultured and produced in diverse farming systems (extensive to intensive) and farming practices are tailored to match the availability of inputs and the investment capabilities of the farmers.

Brackish-water aquaculture in India is synonymous with penaeid shrimp aquaculture. Because of its rapid growth rate and better market price, black tiger shrimp (*Penaeus monodon*) is the most important penaeid aquaculture species. Indian white shrimp (*Fenneropenaeus indicus*) is another important species and farmers have begun to show interest in Pacific white shrimp (*Litopenaeus vannamei*), though the culture of this species is currently not permitted. Species like *P. semisulcatus*, *Marsupenaeus japonicus* and *P. merguensis* are available as alternatives, but have not become very popular. Extensive shrimp culture has been practised in India for over 100 years. Traditional shrimp aquaculture is based on wild juveniles that are trapped in ponds. Because of the demand for shrimp, farmers have changed their farming approach. Small and marginal farmers use improved extensive and semi-intensive systems, while large farmers and corporate companies practise semi-intensive and intensive shrimp culture. The total area under shrimp culture is around 150 000 ha and shrimp production has grown at an average of seven percent per annum during the last 15 years. Except for traditional farming systems, shrimp farming is not permitted within the Coastal Regulation Zone. Shrimp farming in India is a regulated activity under the auspices of the Aquaculture Authority of India, which ensures that the development of the industry progresses in an environmentally sustainable manner. Low-density shrimp culture with a stocking density of 6 PL/m² and production targets of 1 000–1 500 kg/ha/crop is advocated to achieve the goals of sustainable shrimp culture. The mud crabs *Scylla tranquebarica* and *S. serrata* are the most popular brackish-water crab species cultured in India.

Asian seabass/barramundi (*Lates calcarifer*), grey mullets (*Mugil* spp.), milkfish (*Chanos chanos*) and pearlspot (*Etroplus suratensis*) are the important brackish-water finfish species farmed in India. Seed of all species is collected from the wild and this limits the growth of brackish-water fish farming. Recent advances in seabass propagation are likely to stimulate the growth of this sub-sector.

Nutrients from fertilizers (organic and inorganic) and feeds are used in Indian aquaculture. While fertilizers are used mainly for initiating and maintaining natural productivity, feeds are used only under semi- and intensive culture conditions. Poultry

manure is rapidly becoming the fertilizer of choice. Of the total N and P fertilizers produced in the country, aquaculture uses only about 0.53 and 4.27 percent of nitrogen and phosphorus fertilizers, respectively.

Fishmeal production in India is split into the production of sterile fishmeal (crude protein 55–60 percent) and a lower quality fishmeal, which is made from sun dried trash fish. The quantity of sterile fishmeal produced in the country is only about 5 000–6 000 tonnes while 176 400 tonnes of dried trash fish is available for the production of lower grade fishmeal. Besides this, mantis shrimp (57 940 tonnes), shrimp head (31 235 tonnes) and sergested shrimp (48 000 tonnes) are available for inclusion into aquafeeds. Among the plant protein resources, approximately 5.0–5.5 million tonnes of soybean meal is available per annum. Groundnut cake is generally accessible and readily available. Other important plant ingredients that are available for aquafeeds are cottonseed meal, coconut cake, sesame cake, mustard cake, rape seed cake and sunflower cake meal. Cereals such as wheat, rice, maize, sorghum and other millets are cultivated in the country. Cassava is also cultivated in some parts of the country. Rice bran and wheat bran are conventionally used in aquafeeds. Non-conventional aquafeed ingredients such as blood meal, meat meal, bone meal and poultry feather meal and silkworm pupae are also available. Vegetable oils such as groundnut oil, coconut oil, sunflower oil, sesame oil, mustard oil, soybean oil, soy lecithin, palm oil and, of late, rice bran oil are produced in the country. Fish oil is also produced, but on a very limited scale.

The farm-gate price of fish determines the choice of culture system, feeds and feed management practices. For carps, farmers use the mixture of rice bran and/or wheat bran and oilseed cake feed along with natural plankton production through periodic organic and inorganic fertilization. Shrimp farmers use a variety of feeds and feeding practices, ranging from single item feeds to farm-made feeds, using three to four ingredients, to “made to order feeds” and industrially manufactured extruded shrimp feeds. The “made to order” feeds are manufactured by small-scale manufacturers who make the feeds according to the customers’ requirements and choice of the ingredient. Shrimp feed production in the country has increased from 30 000 tonnes in 1990 to 193 500 tonnes in 2004.

Aquaculture production is expected to reach 6.282 million tonnes by 2020. It has been calculated that the estimated fertilizer demand for aquaculture can be met comfortably. The requirement for nitrogen and phosphorus fertilizers will be about 1.0 and 8.2 percent, respectively of their total production. The position with regard to the availability of rice bran, wheat bran and oil cakes is also more than adequate for the future expansion of aquaculture.

Shrimp production is projected to reach 236 000 tonnes by 2020. It has been shown that the industrial and small-scale feedmills will be able to supply the future feed demands, although fish oil may be in short supply. There is a need to explore the replacement of fish oil with vegetable oils.

Several priority issues have been identified that may require attention for aquaculture to develop on a sustainable basis. These include improved feed formulation, the production of high quality, water stable feeds and improved methods of feed management. Such advances will ensure a reduced environmental impact of aquaculture and will contribute greatly towards satisfying consumer demands. Moreover, the promulgation of the Coastal Aquaculture Bill (2005) empowers government agencies to regulate and monitor for the sustainable development of the sector.

1. GENERAL OVERVIEW OF AQUACULTURE PRACTICES AND FARMING SYSTEMS

India's total fish production in 2004 amounted to 6.4 million tonnes, to which aquaculture contributed 2.37 million tonnes (37.0 percent). The fisheries sector (capture fisheries and aquaculture) contributes significantly to the Indian agricultural economy (Table 1). More than seven million fishers and fish farmers depend on fisheries and aquaculture for their livelihood. It is estimated that a further six million people are engaged directly and indirectly in related industrial activities.

Aquaculture has shown significant growth in the last two decades and has transformed itself into an industry contributing substantially to food production, both in terms of quantity and value. Capture fisheries are stagnating. Fortunately aquaculture has been making increasing and significant contributions to the national fish supply. The country is endowed with substantial aquatic resources (Table 2) and a diverse fish fauna. Both freshwater as well as brackish-water aquaculture are practised in the country.

TABLE 1
Facts and figures about fisheries and aquaculture in India. Information refers to the period of 2003–04 except where otherwise indicated

Parameter	Value
Total fish production (million tonnes)	6.40
Inland fish production (million tonnes)	3.46
Marine fish production (million tonnes)	2.94
Area under freshwater aquaculture (thousand ha)	600.00
Area under freshwater prawn culture (thousand ha)	41.87
Area under shrimp culture (thousand ha)	151.00
Annual growth (%) rate of inland fisheries (1991–2000)	6.60
Annual growth (%) rate of marine fisheries (1991–2000)	2.20
Share of aquaculture (%) in total fish production	37.00
Share of fisheries in gross domestic product (GDP) (%)	1.40
Share of fisheries in agriculture GDP (%)	4.50
Total quantity of fish export (thousand tonnes)	461.33
Export earnings of fisheries products (US\$ billion) ¹	1.48
Share (%) of shrimp of total fisheries export	63.50
Share (%) of fish of total fisheries export	34.62

Source: Ayyappan and Biradar (2004); Agricultural Research Data Book (2004); MPEDA² (2004)

TABLE 2
The available aquatic resources for fresh and brackish-water aquaculture in India, 2003

Name of water resource	Area available (million hectares)	Area utilized for aquaculture (%)
Freshwater resources		
Ponds	2.25	11.0
Natural depressions	1.30	10.0
Reservoirs	3.00	9.0
Brackish-water resources		
	1.24	12.0

A wide range of freshwater, brackish-water and marine aquatic organisms are cultured in India (Table 3). The major groups are freshwater fish and prawns, penaeid shrimps, crabs and brackish-water fishes (Figure 1).

¹ US\$1.00 = Rs 43.00 (Indian Rupee, INR) (May 2005)

² Marine Products Export Development Authority

1.1 Freshwater Aquaculture

Freshwater aquaculture is the largest contributor to aquaculture production in the country. During the 1990s this sector grew at a rate of 6.6 percent per annum. The establishment of the Freshwater Fisheries Development Agency (FFDA), which operates at the state level, has helped to increase the total production as well as yield from 600 kg/ha/year in 1975 to 2 200 kg/ha/year in 2000 (Ayyappan and Biradar, 2004). The most important species cultured are the Indian major carps, common carp, grass carp, silver carp and giant freshwater prawn. Air breathing fish such as clariid catfish are cultured to a lesser extent. Cold-water fish such as rainbow trout, snow trout and mahseer are cultured in the uplands of northern India. The latter however is a small-scale activity that caters mainly for the needs of sport fishing.

Freshwater fishes are produced in a variety of systems, each of which has developed in relation to the availability of inputs in the region and the investment capabilities of the farmers (Ayyappan, 1997). Culture systems mainly consist of polyculture of Indian major carps (mixed farming) and the culture of exotic carps along with Indian major carps (composite fish culture). These combinations are practised under various conditions, including fertilizer and feed based systems, waste water based systems, biogas slurry systems, aquatic weed systems, agriculture/horticulture based systems and live-stock based systems, also known as integrated fish farming. Air breathing fishes are cultured either in mono or polyculture systems. Based on the criteria above,

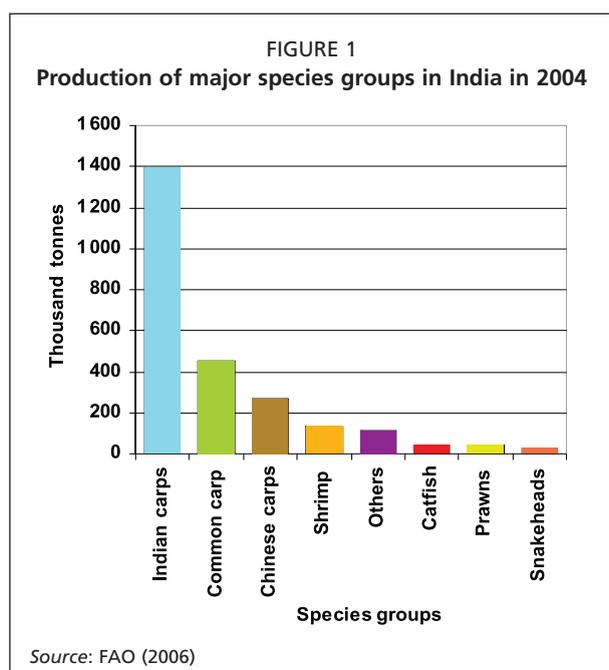


TABLE 3
Major groups of fish and shellfish cultured in India during 2003

Group/sector	Species	Annual production (million tonnes)	Domestic market value (million US\$)
Freshwater finfish			
Indian major carps	<i>Catla catla</i> , <i>Labeo rohita</i> and <i>Cirrhinus cirrhosus</i>	2.61	3 035
Common carp	<i>Cyprinus carpio</i>		
Grass carp	<i>Ctenopharyngodon idella</i>		
Silver carp	<i>Hypophthalmichthys molitrix</i>		
<i>Others*</i>			
Brackish-water finfish			
Milkfish, mullets, Asian seabass, pearlspot		0.01	0.02
Freshwater crustaceans			
Giant freshwater prawn	<i>Macrobrachium rosenbergii</i>	0.036	356
Monsoon river prawn	<i>Macrobrachium malcolmsonii</i>		
Brackish-water Crustaceans**			
Penaeid shrimp	<i>Penaeus monodon</i> and <i>Fenneropenaeus indicus</i>	0.10	1 480
Mud crabs	<i>Scylla tranquebarica</i> and <i>Scylla serrata</i>	0.05	6.4

*Others primarily include snakeheads, cat fishes, coldwater fish and mahseer; **Estimated market value of brackish-water crustaceans are based on export earnings;

Source: Ayyappan and Biradar (2004); Agricultural Research Data Book (2004); MPEDA (2004); Kathirvel, Pandian and Balasubramanian (2004)

TABLE 4
Culture systems and production levels of freshwater carps, 2004

Culture System	Yield (tonnes/ha/year)
Composite fish culture	4 – 6
Sewerage based fish culture	3 – 5
Weed based polyculture	3 – 5
Biogas slurry fish culture	3 – 5
Integrated fish farming	3 – 5
Intensive culture (with feed and aeration)	10 – 15

TABLE 5
Area under freshwater prawn culture and production in different states, 2004

State	Area developed (ha)*	Area under culture (ha)**	Total production (tonnes)	Yield (tonnes/ha/year)
West Bengal	4 532	4 450	2 435	0.55
Orissa	3 000	470	450	0.96
Andhra Pradesh	32 290	27 286	32 085	1.18
Tamil Nadu	380	159	133	0.84
Kerala	886	886	238	0.27
Karnataka	256	206	113	0.55
Maharashtra	7 139	6 981	306	0.04
Gujarat	1 440	1 430	106	0.07
Total	49 920	41 870	35 870	0.86

*Area developed and ready for prawn culture; **area presently used for prawn culture

Source: MPEDA (2004)

aquaculture is practised at three levels of intensity. Large waterbodies of 20–25 ha are used for extensive aquaculture. In these systems the fish are produced on natural food production without the application of external inputs. Semi-intensive fish production systems are those in which supplementary feeding is provided in addition to the application of fertilizers to improve natural productivity. Intensive fish production systems are those in which the fish are fed balanced feeds, while pond water is aerated and exchanged at predetermined intervals. The various culture systems adopted for Indian carp culture have been well standardized and the production levels achieved in these systems are summarized in Table 4.

In recent years, giant freshwater prawn (*Macrobrachium rosenbergii*) culture has become an important aquaculture activity in many states of India and particularly in Andhra Pradesh. This was mainly driven by the closing of the culture cycle and the commercial scale production of prawn seed. It is estimated that 41 870 ha are currently used for prawn culture (Table 5) and approximately 35 870 tonnes were produced in 2003/04. Prawns are produced in extensive, mixed and semi-intensive culture systems. Organic manures and fertilizers are applied in ponds and the prawns are fed with formulated pellet feeds. In extensive culture systems ponds are stocked with nursery reared juveniles (3–5 g) at 8 000 to 15 000/ha. In mixed culture systems prawns are reared together with Indian major carps (catla and rohu). Under semi-intensive, monoculture conditions ponds are stocked at 50 000/ha and production levels are in the range of 350 to 2 000 kg/ha/crop. Production levels of prawn under mixed culture conditions are highly variable depending upon the stocking density used and the fish production ranged from 150 to 2 500 kg/ha/year (Rao, Anandakumar and Sinha, 1999).

1.2 Brackish-water Aquaculture

Brackish-water aquaculture in India is synonymous with penaeid shrimp aquaculture. Black tiger shrimp (*Penaeus monodon*) is the most popular species for aquaculture, while Indian white shrimp (*Fenneropenaeus indicus*) is also cultured. Recently there has been interest in the farming of Pacific white shrimp (*Litopenaeus vannamei*), though the culture of this shrimp is not officially endorsed.

TABLE 6
Area under shrimp farming in different states and shrimp production, 2004

State	Potential area available (ha)	Area developed (ha)*	Area under aquaculture (ha)**	Total production (tonnes)	Yield (tonnes/ha/year)
West Bengal	40 500	50 405	49 925	29 714	0.60
Orissa	31 600	12 880	12 116	12 390	1.02
Andhra Pradesh	150 000	79 270	69 638	53 124	0.76
Tamil Nadu	56 800	5 416	3 214	6 070	1.89
Kerala	65 000	16 323	14 029	6 461	0.46
Karnataka	8 000	3 435	3 085	1 830	0.59
Goa	18 500	1 001	963	700	0.73
Maharashtra	80 000	1 056	615	981	1.60
Gujarat	376 000	1 537	1 013	1 510	1.49
Total	1 190 900	171 320	154 600	112 780	0.73

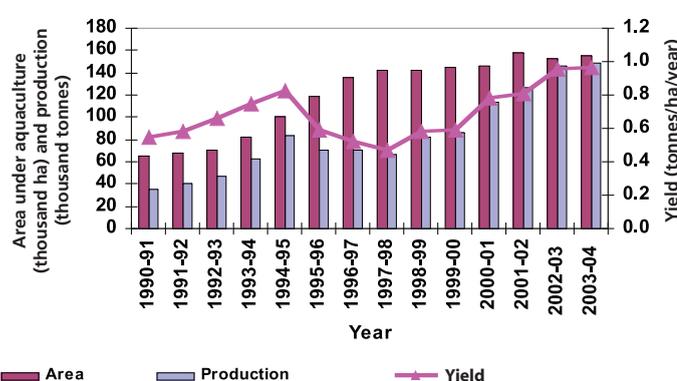
*Area developed and readily available for shrimp culture; **area presently used for shrimp culture.

Source: MPEDA (2004)

Shrimp aquaculture in India has been practised for more than 100 years, in the 'pokkali'³ fields of Kerala state and under 'trap culture' conditions in 'Bheries'⁴ in West Bengal, Karnataka and Goa. These traditional culture systems are shallow ponds used for paddy cum shrimp/fish culture, where tidal inflow provides the seed stock. Because of declining shrimp stocks farmers are supplementing the wild shrimp seed with hatchery reared PLs. Since there is no selective stocking of the ponds with a particular species, the systems are best described as multi-species polyculture of shrimp and finfish. Harvesting occurs during the spring tides by fixing a bag net in the sluice gate during the outgoing tide. The shrimp species harvested from these systems are predominantly *Fenneropenaeus indicus*, *Penaeus merguinenis*, *Metapenaeus dobsoni* and *M. monoceros*. Miscellaneous fish species such as mullet (*Mugil* spp.), milkfish (*Chanos chanos*), and pearlspot (*Etroplus suratensis*) are harvested along with shrimp. It is estimated that some 50 000 ha are used for traditional shrimp farming. Economically shrimp are the most important species in these systems and production ranges from 200–500 kg/ha/cycle.

The advent of hatchery production of shrimp seed and the subsequent adoption of shrimp monoculture systems in the 1980s transformed shrimp farming into a billion dollar industry in India. Small and marginal farmers mainly practise improved extensive and semi-intensive farming at stocking densities of 3–5/m² and 10–20/m², respectively, while larger farmers and corporate farms use semi-intensive and intensive technologies at stocking densities of 20–100 PL/m². The principal culture species are *P. monodon* and *F. indicus*. Production levels in the various systems ranges from 500 kg/ha/crop in extensive systems, 2 000–4 000 kg/ha/crop in semi-intensive systems

FIGURE 2
Expansion of area under shrimp culture and shrimp production in India



Source: MPEDA (2004)

³ Tall growing variety of paddy commonly cultivated in the state of Kerala

⁴ Traditional farming system of shrimp with a large water spread area

and 5 000–16 000 kg/ha/crop in intensive culture systems. The total area under shrimp culture systems has expanded rapidly in different states (Table 6) and production has shown rapid growth (Figure 2).

Shrimp farming in India took a negative turn in 1995 with the occurrence of WSSV (white spot syndrome virus) disease outbreak. Simultaneously environmental and legal issues also surfaced. The Supreme Court of India in its judgement in 1996 directed that construction of shrimp culture ponds and shrimp culture activity should not be permitted within the Coastal Regulation Zone, except for traditional and improved traditional types of culture practised in low lying coastal areas. In pursuance of the directive of the Supreme Court, the Govt. of India set up a statutory body 'The Aquaculture Authority of India' under the Environmental Protection Act (1986). The main functions of the Aquaculture Authority are to regulate shrimp culture in the coastal areas and to promote sustainable and environmental friendly shrimp farming in the country. Since then, low-density shrimp culture with a stocking density of 6 PLs/m² and production targets of 1 000–1 500 kg/ha/crop is advocated. However, a large number of farmers are still using stocking densities of 20/m² and above. Recently parliament has passed the Coastal Aquaculture Bill (2005), which empowers the government to regulate and monitor the sector's sustainable development.

Parallel to these transformations in the industry there has been a search for alternative shrimp species. This is mainly because the entire shrimp farming industry is largely dependent on tiger shrimp. However, due to the superior growth and value of the tiger shrimp this is proving to be difficult.

1.2.1 Finfish aquaculture

Asian seabass (*Lates calcarifer*), grey mullets (*Mugil* sp.), milkfish (*Chanos chanos*) and pearlspot (*Etroplus suratensis*) are the most important species. The non-availability of seed on a commercial scale is the most limiting factor for finfish aquaculture. Breeding and larval rearing technologies have recently been developed for Asian seabass (Arasu, Abraham and Kailasam, 2004) and this is expected to stimulate the sector.

1.2.2 Mudcrab aquaculture

The mud crab species, *Scylla serrata* and *S. tranquebarica* are the most popular brackish-water crab species cultured in India. Mud crabs are cultured in traditional shrimp culture fields in the states of West Bengal, Kerala, Karnataka and Tamil Nadu. Production is reported to be within the range of 10–35 kg/ha/year (Kathirvel, Pandian and Balasubramanian, 2004). Juvenile mud crabs are also collected from the wild and cultured on a small scale in fenced earthen ponds and in cages. They are stocked at 1–2 juveniles/m² and fed fresh trash fish, clam meat and slaughterhouse waste at 5–10 percent of biomass. Crabs are cultured for 7–10 months and harvested at 500–600 g weight and production in these systems range from 500–1 000 kg/ha/crop. Mud crabs are also farmed in polyculture with milkfish and grey mullets in some areas (Kathirvel, Pandian and Balasubramanian, 2004). Fattening of soft, post-moulted mud crabs is also practised in earthen ponds and cages. Fattening and hardening is normally undertaken for a period of 25–30 days, during which they are fed with feeds, as previously mentioned, and then exported. Crab fattening is very profitable and is becoming increasingly popular. Exported figures for crabmeat and live crabs in 2004 were 141 tonnes (US\$1.0 million) and 1 896 tonnes (US\$5.36 million), respectively. Large scale hatchery propagation still needs to be perfected.

2. REVIEW AND ANALYSIS OF AQUACULTURE FEEDS AND FEED INGREDIENTS

Nutrients from both fertilizers and feeds are used in Indian aquaculture. Fertilizers are used primarily for initiating and maintaining natural productivity and feeds are used in semi-intensive and intensive culture practices.

TABLE 7

Manures and fertilizers used in freshwater fish aquaculture

Manure/fertilizer	Application rate (tonnes/ha/year)	Remarks
Lime	0.10–1.25	Applied prior to fertilization
Cow dung	20.0–25.0	50% of total amount is used as an initial dose, mixed with 10–25 kg of single super phosphate and the remaining amount in monthly intervals
Poultry manure	8.0–10.0	As above
Urea or di-ammonium phosphate, Single superphosphate	0.2–0.5	Applied in monthly/fortnightly intervals

2.1 Use of fertilizers and manure in aquaculture

The major aquaculture activity in India is the culture of freshwater fish, which is principally based on natural food production through the use of fertilizers and manures. The culture technology of Indian major carps and other carps in different types of culture systems (Veerina *et al.*, 1993), involves the periodical application of fertilizers and manures in ponds. Prior to the application of fertilizers some farmers apply agricultural lime and dolomite at 100 kg/ha. After two to three days of liming, fertilizers are applied. Both organic manure (including cow dung slurry from bio-gas plants) and chemical fertilizers are used. The present trend is that more farmers are using poultry manure. In recent years, farmers have also started using bio-fertilizers at 1–2 tonnes/ha. The type of commonly used fertilizers and application rates are presented in Table 7.

Freshwater prawn ponds are fertilized with manures and inorganic fertilizers. Ponds are dried for 4–8 weeks after harvest and then ploughed using tractors. Once every two years the surface soil is removed and used for agricultural purposes. Lime is applied at variable application rates (100–1 200 kg/ha), depending on soil pH. Some farmers also apply dolomite at 100 kg/ha. Cattle manure is applied at 0.5–5.0 tonnes/ha and poultry manure at 2.0 tonnes/ha. Inorganic fertilizer application rates are urea 5–50 kg/ha, single superphosphate 6–85 kg/ha and ammonium phosphate 8–125 kg/ha (Rao, Anandakumar and Sinha, 1999).

In shrimp aquaculture, manure and fertilizer are also used during pond preparation. The primary function of fertilization in semi-intensive and intensive shrimp ponds is to develop green water (phytoplankton) before stocking and to maintain the same throughout the culture period. Based on the nutrient availability in the soil, the recommended application rates are: nitrogenous fertilizer (urea or ammonium phosphate) 15–20 kg/ha/year, phosphate fertilizer (super phosphate) 10 kg/ha/year, organic manure (cattle dung or poultry manure) 1 000–1 500 kg/ha/year. No fertilizers are, however, used in traditional shrimp culture systems.

2.2 Availability of fertilizers

Agriculture being the mainstay of the Indian economy, fertilizers and manures are produced on a large scale (Table 8). A total of 19.42 million tonnes of nitrogenous fertilizers and 2.41 million tonnes of phosphate fertilizers were produced in 2002/03. In addition, approximately 615.6 million tonnes of cattle manure and 14.9 million tonnes of poultry manure are available annually. Approximately 16.2 percent of cattle manure is used in aquaculture. Bio-fertilizers are also produced and used in agriculture. Aquaculture uses about 0.53 percent of the nitrogen fertilizer and 4.27 percent of the annual phosphorus fertilizer production.

2.3 Feed ingredients and feeds used in aquaculture

Conventional feed ingredients such as rice bran, wheat bran and groundnut cake are extensively used for feeding carps in freshwater aquaculture. Dried trash fish powder,

TABLE 8
Estimated availability of fertilizers and manures in India (2002/03) and their use in aquaculture

Fertilizer/manure	Nutrient (%)	Quantity available (million tonnes)	Estimated use in aquaculture (million tonnes)
Ammonium sulphate	Nitrogen 20.6	0.54	
Ammonium chloride	Nitrogen 25.0	0.08	
Calcium ammonium nitrate	Nitrogen 25.0	0.17	
Urea	Nitrogen 46.0	18.62	
Total nitrogenous fertilizers		19.42	0.103
Single super phosphate	Phosphorus (P ₂ O ₅) 16.0	2.41	
Total phosphate fertilizers		2.41	0.103
Cattle manure		615.6	100.2
Poultry manure		14.9	
Total organic manure		630.5	150.3

Source: Agricultural Research Data Book (2004)

silkworm pupae and defatted oilseed cakes and meals (soybean, mustard, sesame and cotton seed) are occasionally used. Non-conventional feed ingredients (alternative ingredients other than usually used) from animal by-products such as meat meal, meat and bone meal, blood meal and *Azolla* (Mohanty and Das, 1995), are seldom used due to the uncertainty of supply. Trash fish, poultry offal and other animal by-products are used for carnivorous fish culture. Both conventional and non-conventional feed ingredients are used in formulating feeds for shrimp and giant freshwater prawn (Alagarswami and Ahamad Ali, 2000; Dani, 2000; Pandian, 2000; Paul Raj, 2000). Feed ingredients of marine origin such as fishmeal and fish oil are extensively used in shrimp and prawn feed formulations. Shrimp meal, squid products and mantis shrimp meal are also in great demand.

2.4 Availability of feeds and ingredients

2.4.1 Ingredients of marine and animal origin

The demand for feed ingredients of marine animal origin by the shrimp feed industry is increasing rapidly. Other animal by-products such as meat and bone meal and blood meal are also available, but their use by industrial feed manufacturers is minimal due to limited availability. Table 9 provides estimates of the availability of feed ingredient of marine origin (Table 9).

Approximately 5 000–6 000 tonnes of high quality fishmeal (crude protein (CP) 55–60 percent) is produced annually. In addition, about 176 400 tonnes of low value, sun dried trash fish is available annually. This is known as feed-grade dry fish, which is pulverized and sold as fishmeal. Besides this, mantis shrimp (57 940 tonnes), shrimp head (31 235 tonnes) and sergested shrimp (48 000 tonnes) are available. It is expected that at least 40 percent of these ingredients are used by the aquafeed industry and the rest are used by the poultry and other livestock feed industries. Of the estimated 176 400 tonnes of low value sun dried trash fish, an estimated 100 000 to 130 000 tonnes is powdered as dry fishmeal (with CP <50 percent and 16–20 percent total ash) (Ahamad Ali *et al.*, 1995; Alagarswami and Ahamad Ali, 2000; Pandian, 2000; Paul Raj, 2000). The mixed dry fish consists mainly of juvenile carangids, sciaenids, silver bellies, anchovies, sardines, mackerel and lizardfish. The pulverized fishmeal is used mainly for producing supplementary feeds for shrimp and prawns by small-scale, local feed mills. The increasing demand for marine fish for human consumption has put pressure on the supply of “trash” fish, the availability of which is rapidly declining. The poultry feed industry is the biggest competitor for fishmeal. However, decreasing inclusion rates of fish products in poultry feeds has increased the availability of fishmeal for aquaculture. Mantis shrimp (*Oratosquilla* sp) has emerged as a potential marine protein source (CP 45 percent dry weight) for aquafeeds (Ahamad Ali, 1982; 1992; Ahamad

TABLE 9
Estimated availability and cost of marine and other animal protein resources in India

Ingredient	Crude protein content (%)	Quantity available (thousand tonnes)	Cost (US\$/kg)
Marine ingredients – indigenous			
Fishmeal (sterile CP 60%)	55.0–60.0	5–6	0.82
Dry fish (feed grade) or pulverized fishmeal	45.0–55.0	177	0.58
Mantis shrimp (<i>Squilla</i> sp.)	42.0–45.0	58	0.23
Sergisted shrimp (<i>Acetes</i>)	55.0–60.0	48	0.69
Shrimp head waste	32.0–38.0	31	0.19
Cuttlefish	40.0–45.0	4	1.16
Squid	55.0–68.0	7	1.16
Clam meat	40.0–48.0	4	1.16
Mussel meat	50.0–55.0	1	1.16
Small crabs	38.0–42.0	6	0.16
Marine ingredients – imported			
Fishmeal (CP >60%)	60.0–70.0	20–25	1.05–0.94
Fish soluble	55.0–60.0	3–5	1.63
Squid meal	60.0–65.0	5	1.60
Squid liver meal	45.0–55.0	3–5	1.16

Source: Ahamad Ali *et al.* (1995); Dani (2000); Pandian (2000); Paul Raj (2000); Agricultural Research Data Book (2004)

Ali and Mohamed, 1982) and is now increasingly being used in feeds for shrimp and prawns. The chitin manufacturing industry and the poultry feed industry are the major competitors for this raw material, though the supply is adequate for aquaculture.

Squid, shrimp and mollusc meal (clam and mussel) are primarily used as feed attractants and for growth promoters for shrimp besides being good protein sources. These ingredients are largely not accessible and not available because the resources are small and the product is in great demand for human consumption and for export. Hence these products are imported by the aquafeed industry. Squid and cuttlefish processing waste products are valuable ingredients for shrimp feeds (Ahamad Ali, 1998), though supply is limited.

2.4.2 *Ingredients of plant origin*

Plant ingredients constitute the largest nutrient resources for aquafeeds. Their use as protein, lipid and energy (carbohydrate) sources in feed formulations are shown in Table 10.

Protein sources

Soybean meal is the most important of the plant protein sources. Soybean cultivation is on the increase in the country and hence the outlook for the availability of soybean meal for aquafeeds is positive. Soybean meal contains several anti-nutritional factors (Table 11), though these can be destroyed by heat treatment. Corn (maize) gluten, a by-product of the corn starch manufacturing industry, is another promising plant protein source. It has a 45–50 percent crude protein content but is deficient in some amino acids, especially arginine and lysine. However, it can be used along with other protein sources in aquafeeds. Preliminary studies have shown that corn gluten can partially replace (10–15 percent) fishmeal in Indian white shrimp feed (Ahamad Ali, Syama Dayal and Ambasankar, 2004). Corn gluten has also been evaluated in the diets of Indian carps (Kaur, 2002).

Groundnut oilseed cake is sought after by both the terrestrial animal and the aquafeed industries. Groundnut cake is extensively used in cattle, poultry, fish and shrimp feeds and is readily available. Although its use in high quality shrimp feeds is limited, groundnut cake is utilized in considerable quantities in farm-made feeds and by small-scale feed producers.

Other important available plant protein sources are cottonseed meal, coconut oilseed cake, sesame cake, mustard cake, rape seed cake and sunflower oilseed cake meal. They are readily available to the aquafeed industry but their use in fish and shrimp feeds is limited due to various reasons. Their inclusion levels do not normally exceed 15 percent. With improved processing technology these resources could, in future, play a greater role in aquafeeds.

Energy sources

India produces a variety of cereals. The most of which prominent are wheat, rice, maize, sorghum and other millets. Tapioca tuber (cassava) is also cultivated in some parts of the country. All are excellent energy (carbohydrate) sources. Cereal grains are the primary staple foods in India and competition for their use is high. However, they are accessible and available for use in aquafeeds (Table 10). Wheat is most extensively used in shrimp feeds for its carbohydrate content as well as for its gluten content, which is a good binder, followed by rice and maize products. Sorghum, pearl millet and other coarse cereals such as ragi (milo) and finger millet are available, but not often used in aquafeed formulations.

The rice granaries of India produce large quantities of rice bran, most of which is used by the animal feed industry. Besides being a good source of energy, rice bran contains between 8–9 percent protein, lipids, B-group vitamins and cellulose. Rice bran is readily available for fish and prawn feeds.

Wheat bran is increasingly used in fish and prawn feeds, particularly in the northern states where wheat bran is more abundant compared to rice bran. Tapioca (cassava) is used in shrimp and fish feed formulations as a carbohydrate source and as a binder (Ahamad Ali, 1988).

TABLE 10
Estimated availability and cost of feed ingredients of plant origin for their potential use in aquafeeds in India

Ingredient	Annual availability (million tonnes)	Cost (US\$/kg)	Potential use in aquafeeds (million tonnes)
Protein sources			
Soybean cake	5.0–5.5	0.30	0.0356
Groundnut cake	8.0–8.5	0.23	0.0202
Corn gluten	NA	0.25	NA
Cotton seed cake	0.75–0.80	0.18	0.0096
Sesame cake	0.45–0.50	0.23	0.0062
Sunflower cake	0.8–1.0	0.14	0.0034
Rape seed/mustard cake	5.0–5.8	0.19	0.0152
Linseed cake	0.1	NA	NA
Energy (carbohydrate) sources			
Coconut cake	0.14–0.16	0.23	0.0019
Maize (2002–2003)	14.0–14.7	0.25	0.1476
Sorghum (2002–2003)	7.5–8.0	0.19	0.0102
Pearl millet (2002–2003)	11.0–11.8	0.2	0.0840
Other cereals (2002–2003)	31.8	0.19	0.3816
Wheat (2002–2003)	72.6	0.34	0.8713
Rice (2002–2003)	89.3	0.35	0.5817
Rice bran	3.0–3.5	0.07–0.13	0.0242
(including defatted bran 7%)			
Wheat bran	2.0–2.5	0.19	0.0186
Tapioca	5.6–6.0	0.14	0.0672

NA=No available data

Source: Ahamad Ali *et al.* (1998); Dani (2000); Pandian (2000); Paul Raj (2000); Agricultural Research Data Book (2004)

TABLE 11
Anti-nutritional factors in some plant ingredients

Ingredient	Potential anti-nutrient
Groundnut cake	Phytic acid & protease inhibitor
Soybean meal	Trypsin inhibitor
Mustard cake	Glucosinolates
Cotton seed cake	Gossypol & cyclopropionic acid
Sesame cake	Phytic acid & protease inhibitor
Rapeseed cake	Protease inhibitor and glucosinolates
Sunflower cake	Saponins & protease inhibitor
Lucaene leaf	Mimosin
Cassava leaf (<i>Manihot esculants</i>)	Hydrocyanic acid
Lupin seed cake	Saponins, alkaloid & protease inhibitor
Alfalfa meal (<i>Medicago</i> sp.)	Protease inhibitor, saponins, phytoestrogens

Source: Francis, Makkar and Becker (2001); Pandian (2000)

Lipid sources

India produces 4.87 million tonnes (2002–03) of edible oils (Table 12), such as groundnut, coconut, sunflower, sesame (gingili), mustard, soybean, soy lecithin, palm and to some extent rice bran oil. Fish and shark liver oil is also produced locally.

Because of its HUFA and PUFA composition, fish oil is the most sought after lipid source for aqua feed formulations (Hasan, 2001). The crude local fish oil is mainly used in the manufacture of farm-made feeds and by small-scale aqua feed producers. All major aqua feed companies import fish oil (approximately 5–6 thousand tonnes per annum). Plant oils, though available in the country, are not easily accessible by the aqua feed and animal feed industries because of the high demand for human consumption. Moreover, their fatty acid profiles do not adequately meet the essential fatty acid requirements of most of the cultured species. However, soybean oil and soy lecithin are used as sources of fat and phospholipids in shrimp feeds.

2.4.3 Non-conventional feed ingredients

There are several non-conventional feed ingredients that are suitable and available for aqua feed formulations (Table 13). The usefulness of these ingredients has been tested for some fish species (Dhawan, Kaur and Virk., 2004). Some of these animal by-products are used for the feeding of carnivorous finfish and included, on a limited scale, in prawn and farm-made shrimp feeds. India also has a large sericulture industry and silkworm pupae are utilized for feeding fish, prawns and shrimps (Ahamad Ali, 1992).

TABLE 12
Estimated availability of edible oils and fish oil in India

Type	Availability (thousand tonnes)	Cost (US\$/kg)
Soybean oil	527	1.28
Groundnut oil	1 464	1.28
Sesame oil	227	1.86
Coconut oil	416	1.39
Sunflower oil	262	1.39
Safflower oil	0.45	1.86
Mustard oil/ rape seed oil	1 542	1.39
Cotton seed oil	358	1.28
Palm oil	NA	1.00
Soy lecithin	NA	0.93
Niger seed oil	0.27	1.63
Fish oil (indigenous)	5–6	1.39
Fish oil (imported)	5.0	2.34–3.48
Squid oil (imported)	3.0	3.5

Source: Agricultural Research Data Book (2004); Ahamad Ali et al. (1995)

TABLE 13
Estimated availability of non-conventional feed ingredients in India

Ingredient	Availability (tonnes)	Cost (US\$/kg)
Animal products/by-products		
Meat and bone meal	55 200	0.14
Poultry offal	65 000	0.12
Feather meal	Available	NA
Slaughter house waste	Available	NA
Silkworm pupae	40 000	NA
Poultry hatchery waste	17 406	NA
Single cell proteins		
Spirulina	Available	14.0
Yeast	Available	2.8
Yeast extract (from brewery)	Available	1.16

NA= not available

Single cell proteins

Spirulina and single cell yeasts are used, to a limited extent, in shrimp larval feeds in India. *Spirulina* is rich in protein (60 percent) and contains pigments and antioxidants besides some unknown growth factors (Vaitheeswaran and Ahamad Ali, 1986). *Spirulina* has the potential to replace fishmeal to some extent, but the high nucleic acid content limits its use in aquafeeds. The large scale production of single cell proteins needs to be examined as protein sources for aquafeeds (Dani, 2000).

There are several other non-conventional feed ingredients (Dhawan, Kaur and Virk, 2004), that have been tested for some fish species (Table 14) with encouraging results. Press mud from the sugar cane industry was used to replace 25 percent of the rice bran in common carp feeds, without any adverse effects (Singh and Dhawan 1995; Singh, Dhawan and Saxsena, 1999). Molasses can be included at five percent in common carp diets (Singh and Dhawan, 1993). Poultry hatchery waste, silage from poultry offal meal, slaughter house waste and silk worm pupae have all been tested and found suitable for various fish species (Butt *et al.*, 1988; Sehagal and Sharma, 1991; Swamy and Devaraj, 1995; Chakrabarti, 1996; Borthakur and Sharma, 1998; Singh, Kaur and Dhawan, 2000).

TABLE 14
Experimental use of non-conventional feed ingredients for selected fish species

Feed/Ingredient	Species tested	Reference
Agro-industry products		
Sugar cane molasses	Common carp	Singh and Dhawan (1993)
Press mud	Common carp	Singh, Dhawan and Saxsena (1999); Singh and Dhawan (1995)
Animal by-products		
Poultry hatchery waste	Common carp	Singh, Kaur and and Dhawan (2000)
Poultry offal meal	Common carp	Chakrabarti (1996)
Slaughter house waste	Indian major carp, mrigal Common carp	Sehagal and Sharma (1991) Butt <i>et al.</i> (1988)
Silkworm pupae	Common carp Walking catfish (<i>Clarias batrachus</i>)	Swamy and Devaraj (1995); Borthakur and Sharma (1998)
Aquatic and terrestrial macrophytes		
Otellia	Indian major carps, catla and rohu	Patnaik <i>et al.</i> (1991)
Nymphoides	Indian major carps	Patnaik <i>et al.</i> (1991)
Pistia	Rohu	Ray and Das (1995)
Duck weed (<i>Lemna minor</i>)	Common carp	Devaraj, Krishna and Keshavappa (1981)
<i>Azolla caroliniano</i> <i>Azolla pinnata</i>	Catla, rohu and grass carp	Das, Sikdar and Chotterjee (1994); Mohanty and Das (1995)
Plant leaf & seed meals		
Lucerne (alfalfa) meal <i>Medicago sativa</i>	Common carp	Swamy and Devaraj (1995)
Acacia leaf meal (<i>Acacia auriculiformis</i>)	Rohu	Mondal and Ray (1996)
Sal seed (<i>Shorea robusta</i>)	Rohu	Mukhopadhyay and Ray (1997)

The proximate composition of some of the important feed ingredients is presented in Table 15.

TABLE 15
Typical proximate composition of selected feed ingredients

Ingredient	% dry matter basis						Information source
	Moisture	Crude protein	Crude lipid	Crude fibre	CHO	Ash	
Animal by-products							
Fishmeal (imported) Grade 1	8.1	70.5	8.5	0.1	Trace	12.8	2
Fishmeal (imported) Grade 2	9.1	69.2	6.5	0.1	0.8	14.3	2
Fishmeal (imported) Grade 3	5.0	66.6	9.5	0.2	0.2	18.5	2
Fishmeal (indigenous)	10.3	64.4	4.7	2.5	2.4	15.7	2
Fishmeal (indigenous)	10.8	55.0	5.4	1.7	3.3	23.8	2
Sergisted shrimp meal	9.8	60.2	6.8	4.4	3.6	15.2	2
Prawn head meal	9.9	39.8	9.6	16.4	4.1	20.2	2
Squid meal	8.4	66.5	4.4	3.9	5.9	10.9	2
Mantis shrimp (<i>Squilla</i>)	10.7	44.2	4.4	5.7	4.3	30.7	2
Clam meat meal	7.7	48.1	13.6	trace	23.0	7.6	2
Meat meal	8.0	50.0	4.4	6.8	25.8	5.0	2
Meat and bone meal	-	51.0	10.0	-	-	16.0	2
Blood meal	10.0	65.3	0.5	-	-	-	1
Silkworm pupae	9.8	62.2	7.6	1.3	1.9	17.2	2
Poultry feather meal	-	85.0	3.2	1.5	-	-	3
Poultry hatchery waste	-	40.0	-	-	15.2	18.0	3
Poultry offal	8.6	60.3	10.1	2.5	6.2	12.3	2
Plant and plant by-products							
Soybean meal	10.5	51.5	1.00	8.9	19.7	8.5	2
Corn (maize) gluten	6.8	48.2	2.4	4.8	34.0	3.8	2
Groundnut cake meal	7.7	48.4	7.6	2.1	28.2	6.0	2
Groundnut cake meal	13.1	46.9	5.0	8.9	18.0	8.1	2
Mustard cake	9.2	23.6	9.6	6.3	40.9	10.4	2
Sunflower cake meal	7.0	26.7	2.0	30.1	26.4	7.7	2
Sesame cake meal	4.9	34.0	10.8	13.0	24.8	12.5	2
Sesame cake meal	9.8	38.7	6.0	10.7	15.8	19.0	2
Rape seed cake meal	11.0	35.9	0.9	13.2	32.1	6.9	2
Sal seed cake meal	8.6	8.2	2.9	1.7	68.4	10.2	2
Cotton seed cake meal	7.0	37.0	6.7	13.0	35.3	1.0	2
Coconut cake meal	8.9	25.9	11.2	17.9	27.2	8.9	2
Coconut cake meal	8.4	20.3	11.4	16.2	37.5	6.2	2
Corn meal	10.4	9.5	4.0	3.8	68.7	1.7	1
Sorghum	10.0	9.0	2.8	3.0	75.1	0.1	1
Wheat flour	12.5	12.5	2.0	1.8	70.0	1.3	1
Rice flour	11.5	9.1	0.3	trace	78.6	0.5	1
Refined wheat flour	12.3	11.1	0.3	trace	75.2	1.2	1
Rice bran	8.7	9.0	4.5	13.2	40.8	23.8	1
Wheat bran	10.6	10.8	2.5	9.7	6.4	3.0	1
Tapioca flour	8.5	2.0	0.5	3.5	68.5	2.4	1
<i>Pistia</i> meal	4.9	19.5	1.3	11.7	37.0	25.6	1
<i>Leucaena</i> meal	11.8	33.1	4.7	9.0	34.2	7.2	1
Press mud from sugarcane industry	-	15.4	7.8	23.3	0.8	-	3
Molasses	-	3.2	-	-	60.8	5.0	3
Single cell protein							
Spirulina	7.8	60.9	9.0	7.5	1.8	13.0	1
Yeast (bakers)	1.4	56.1	2.1	0.3	30.2	9.9	1

CHO = digestible carbohydrate; blank indicates data is not available.

Source: 1) Nandeesh (1993); 2) Ahamad Ali, Gopal and Ramana (2000); 3) Dhawan, Kaur and Virk (2004)

3. ON-FARM FEED MANAGEMENT STRATEGIES

3.1 Freshwater fish

There are three recommended polyculture practices with standardized feeding regimens. These are:

- polyculture of catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus cirrhosus*) stocked at 4 000 to 5 000 fingerlings/ha at a species ratio of 2:3:2, respectively;
- polyculture of the three Indian major carps, plus silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and common carp (*Cyprinus carpio*) stocked at a ratio of 40 percent Indian carps (1:1:1 species ratio) and 60 percent other carps at a species ratio of 2:1:1 at a density of 10 000 fingerlings/ha; and
- polyculture of rohu and catla stocked at 10 000 fingerlings/ha at a ratio of 9:1 and or mixed with snakehead (*Chana striata*) at a ratio of (9:0.5:0.5).

For these combinations it is recommended that ponds are fertilized with organic and inorganic fertilizers and the fish are fed on a 1:1 mixed rice bran and groundnut oilseed feed at 2–3 percent of biomass per day. The average estimated production from these systems is about 10 tonnes/ha/year.

However, culture practices are modified to suit local demand, availability and cost of the required inputs and the farm-gate price of the fish. The average farm-gate value of Indian major carps is less than US\$0.5/kg (Rs 25/kg). For example, in Andhra Pradesh farmers quickly modified the recommended culture combinations and soon developed unique fertilization, feeding and feed management practices. Ingredients are selected purely on the basis of availability and cost effectiveness. These adapted local technologies were largely responsible for the early success of fish farming in Andhra Pradesh, which subsequently stimulated fish culture throughout the country.

Fish farmers in Andhra Pradesh only use two species in their combination systems (viz. catla and rohu at a 20:80 ratio). The fish are stocked at 6–12 fry/m² in nursery ponds and reared to 100–150 g. Production ponds are prepared by the application of 20 tonnes/ha/year of cow dung or 10 tonnes/ha/year of chicken manure. Plankton density is judged by the colour of the water and fertilization is regulated accordingly. Fingerlings are stocked at 10 000/ha and the fish are fed on farm-made feeds consisting of a 7:3 mix of rice bran and groundnut oilseed cake, respectively. The feed is presented to the fish in feeding bags. Holes are punched into the bag and up to 20 kg of mixed feed is placed therein; this is then suspended on a pole in the water column (20–25 bags per ha of pond surface area). Feed is replenished once a day in the morning and the fish generally consume the feed in 2–3 hours. Ration size is determined by growth and the feed consumption rate.

The duration of the production cycle in these systems is 9–12 months and fish are harvested when rohu attain 1.5 to 1.75 kg and catla reach 2.0–2.5 kg (Figure 3). Production in these culture systems averages between 5 000–8 000 kg/ha/year, although production rates as high as 14 000–15 000 kg/ha/year have also been reported. Because farmers practise supplementary feeding it is difficult to assess the true feed conversion ratio. However, the apparent feed gain ratio is 2.0–4.5. Moreover, farmers intelligently resort to skilful on-farm feed management strategies. When fish are in an active growth phase during summer they feed protein rich oilcakes in a larger proportion (30–40 percent) (Figure 4). During the slow growth phase in winter and the monsoon season only rice bran fortified with a small proportion of oil cakes is fed to the fish. In this way feed expenditure is kept under control.

There have been some recent attempts to demonstrate (American Soybean Association) the use of extruded pellet feeds in freshwater fish culture in the state of Tamil Nadu (Suresh, 2007), though the results have not been adopted by the farmers.

Broodstock are fed with semi-moist dough feeds consisting of 15–20 percent dry fish powder (fishmeal), 10–15 percent rice flour, 20–25 percent groundnut cake and 15–20 percent pulses. The ingredients are finely powdered and mixed. Water is added (25–30 percent by weight) and the mixture is cooked, cooled and fed to the brood fish in the form of feed balls or meat mincer extruded spaghetti. The cost of cooking amounts to US\$0.04–0.07/kg of feed. Fry in nurseries are fed a mixture of rice bran and oil cake (1:1 ratio) in powder form by broadcasting over the pond.

Carnivorous fishes such as *Clarias batrachus*, *Heteropneustes fossilis* and *Clarias gariepinus* are cultured in some areas in the north-eastern states. In the absence of hatchery reared seed, wild juveniles are caught and used. Carnivorous fish such as catfishes (*Clarias batrachus* and *Heteropneustes fossilis*), snakeheads and the African catfish *Clarias gariepinus* are also reared in manured ponds and fed simple feeds such as fresh trash fish, animal by-products, poultry offal, silkworm pupae and kitchen waste. No attempts have yet been made to produce a formulated water stable pellet for carnivorous fish in India and this is simply related to the absence of an adequate demand.

3.2 Giant freshwater prawn

Two types of aquaculture practices are commonly used for the culture of giant freshwater prawn. One is monoculture of the prawn while the other is polyculture along with Indian major carps (catla and rohu). In monoculture the farmers stock up to 50 000 seed per hectare directly from hatchery. Whereas in the polyculture practice, the seed is stocked in nursery ponds at the rate of 150–200 PL/m² in semi-intensive method and 800–1 000 PL/m² in the intensive method (Vasudevappa 2001). During the nursery phase PL are fed with granular (starter grade) feeds of 35 percent protein that are commercially available and PL are grown to 3.0–5.0 g in about 60 days. These juveniles are stocked in grow-out ponds at 8 000 to 20 000 per hectare. Along with prawns, fingerlings (3–100 g) of catla and rohu are also stocked at 150 to 2 500/ha (Rao, Anandakumar and Sinha, 1999).

FIGURE 3
Partial harvesting of carps from a farm in Thanjavur district,
Tamil Nadu



Thanjavur is in the Cauvery delta and carp culture is practised fairly intensively in this area. The carps produced here are for local consumption and the fish usually fetch a good market price.

COURTESY OF A.V. SURESH

FIGURE 4
Ingredients (groundnut cake, rice bran and maize flour) for
preparing farm-made feed in a carp farm near Thanjavur
district, Tamil Nadu



Freshwater carp farmers in India (particularly in Andhra Pradesh and Tamil Nadu) often resort to different on-farm feed management strategies. During summer, when carp are in an active growth phase they feed protein rich oilcakes in a larger proportion (30–40 percent). During the slow growth phase in winter and the monsoon season only rice bran fortified with a small proportion of oil cakes is fed to the fish. In this way feed expenditure is kept under control.

COURTESY OF P.E. VIJAY ANAND

Prawn pond preparation includes ploughing of the substratum, application of lime and cattle manure at the rate of 500–5 000 kg/ha or poultry droppings at 2 000 kg/ha. Inorganic fertilizers are also used. Urea is applied at the rate of 5–50 kg/ha and single super-phosphate or di-ammonium phosphate at 18–25 kg/ha. Stocking of prawns or prawns and fish occurs after 10–15 days, when the water has taken on a light green or brownish colour. More than 60 percent of prawn farmers use nutritionally complete shrimp feeds, while the remainders use farm-made feeds, which generally contain 20–30 percent crude protein and cost around US\$0.3–0.4/kg. As many as 18 different ingredients are used in prawn feeds, some of which are listed in Table 17. The farmers hire pelleting units for the manufacture of feeds. Prawns are fed 3–4 times per day at a rate of 2 to 5 percent of the body weight. Feed is normally broadcasted over the pond. The fish mainly feeds on the plankton naturally produced in the pond and hence no additional feeding is done. The fish grow to 1–2 kg in weight at the time of harvest.

Freshwater prawn ponds are normally stocked in July. After four months, when the prawns attain an average weight of 40 g, they are partially harvested every fortnight over a period of 4–6 months until the ponds are finally harvested. Prawn production levels, depending on stocking density, vary between 350–2 000 kg/ha/crop, whilst fish production varies from 250–2 500 kg/ha.

3.3 Penaeid shrimp

During the mid 1980s traditional shrimp farmers used a variety of single ingredient feeds such as clams, mussels, oysters, snails, trash fish, chicken offal and beef (Alagarswami and Ahamad Ali, 2000) or mixed *farm-made* feeds consisting of up to three or four ingredients such as dry fish powder, oil cakes (mainly groundnut), rice bran and cereals (wheat, rice or maize). Examples of some farm-made feeds are given in Table 16. The mixed farm-made feeds are cooked and presented as dough balls or in the form of “spaghetti”, both in moist and dry form. These are made by extruding the cooked mix through a hand or electrically operated meat mincer. These practices have largely been phased out and replaced by the “made to order feeds or custom

TABLE 16
Examples of farm-made feed formulations used by shrimp farmers in various states of India during the mid 1980s

Ingredients %	State					
	Andhra Pradesh	Karnataka	Kerala	Maharashtra	Tamil Nadu	West Bengal
Dried fish powder	21.0	20.0	-	50.0	16.0	32.0
Clam meat	-	5.0	50.0	-	-	-
<i>Squilla</i>	-	-	-	-	16.0	-
Snail meat	-	-	-	-	20.0	-
Shrimp waste	20.0	-	-	-	-	-
Bone meal	20.0	-	-	-	20.0	-
Fish oil	1.0	-	3.0	-	-	-
Soybean oil	1.0	-	-	-	-	-
Soybean cake	20.0	-	-	15.0	-	-
Groundnut cake	-	15.0	30.0	10.0	-	-
Mustard cake	-	-	-	-	-	33.0
Rice flour	-	10.0	-	-	-	-
Rice bran	10.0	50.0	15.0	10.0	16.0	33.0
Wheat flour	-	-	-	10.0	-	-
Tapioca flour	6.0	-	-	-	10.0	-
Vitamin/mineral mix	1.0	-	2.0	5.0	2.0	2.0
Form of feed used/ presentation	Ball/pellet	Dry powder	Ball	Pellet	Ball/pellet	Dry powder
FCR	2.5–3.0	3.0	3.5	3.0–4.0	2.5–3.0	2.0–2.5
Production (kg/ha/crop)	500–700	700–900	700–900	700–900	700–900	400–5 000

Source: Nandeesha (1993)

made feeds” and commercially produced, nutritionally complete feeds. The “made to order feeds” are manufactured by small-scale feed manufacturers who custom make the feeds based on the individual formulations as well as the requirement of their clients. Over 20 of these small-scale feed millers operate in Andhra Pradesh alone. These feed manufacturers use mainly low-value dry fishmeal, mantis shrimp (*Squilla*), shrimp waste, peanut and soybean oilseed cake, crude fish oil, cereal flours and rice bran in addition to some low-cost additives such as lecithin, vitamins and mineral mixes (see Table 17 for list of feed ingredients) and orders of between 25 and 1 000 kg of feed are manufactured.

The manufacturer charges the cost of ingredients and a processing cost of US\$58–70/tonne, with the total cost of feed ranging from US\$0.3–0.56/kg. These custom made feeds normally have a protein content of 22–35 percent, FCRs ranging from 1.8–2.5:1 and with which production levels of 400–900 kg/ha/crop are attained. This shrimp feed manufacturing sector has proved to be highly beneficial to the small and marginal farmers who are not in a position to purchase large quantities of commercial feeds. Instead they can buy small quantities of feed and exercise their choice in the selection of feed ingredients.

Larger farmers and corporate companies who practise semi-intensive and intensive shrimp culture use nutritionally complete extruded pelleted feeds. These feeds are manufactured by commercial scale aquafeed-millers or are imported. There are ten feed mills (see Suresh, 2007) manufacturing nutritionally complete shrimp feeds in the country. Minimum and maximum inclusion levels used by commercial feedmills are shown in Table 18. The ingredients used by the commercial feedmills include fishmeal, squid meal, squid liver meal, shrimp meal, fish soluble, fish oil, squid oil, soybean meal, lecithin, cereal flour and other essential and proprietary additives. Most of the ingredients of marine origin are imported while the feed ingredients of plant origin are sourced locally (see also Suresh, 2007).

These extruded feeds have protein levels of 40–45 percent, FCRs of 1.2–1.5:1, cost between US\$1.0–1.5/kg, with which production levels of 4–6 tonnes/ha/

TABLE 17
Ingredients used in the ‘made to order’ shrimp feeds, average inclusion levels and approximate cost. Inclusion levels are expressed in percent except otherwise indicated

Ingredient	Inclusion level (%)	Cost/kg (US\$)
Sergisted shrimp (<i>Acetes</i>)	10.0	0.69
Pulverized dry fishmeal	15.0	0.58
Mantis shrimp (<i>Squilla</i>)	15.0	0.23
Silkworm pupae	3–5	0.19
Meat meal	3–5	0.28
Fish oil	1–2	1.39
Soybean meal	15.0	0.30
Groundnut cake	2–5	0.23
Ragi (millet)	2–5	0.20
Pearl millet	2–5	0.20
Rice bran	2–5	0.18
Maize gluten	5–6	0.25
Chicken egg	As per farmers desire	-
Dicalcium phosphate	0.8–1.0	0.93
Wheat flour	5–10	0.34
Calcium carbonate	0.1–0.15	0.46
Amino acid mix (methionine & lysine)	0.1–0.2	2.32
Vitamin mix	0.5–1.0	3.49
Zeolite	0.01	0.93
Feed probiotic	1.0 kg/tonne	23.25
Yeast extract (brewery residue)	1.0 kg/tonne	0.93
Preservative	0.001	-
Binder	0.8–1.0	3.94

TABLE 18
Common feed ingredients used in commercial shrimp feeds and their inclusion levels

Ingredient	Inclusion level (%)
Protein sources	
Fishmeal (imported)	25–40
Fishmeal (pulverized dry fish)	10–35
Squid meal	3–5
Sergisted shrimp (<i>Acetes</i>)	10–15
Shrimp/head meal	5–15
Mantis shrimp	10–15
Silkworm pupae	7–15
Soybean meal	15–30
Groundnut cake	10–25
Sunflower cake	10–15
Sesame cake	10–15
Mustard cake	10–15
Corn gluten	10–15
Lipid sources	
Fish oil	2–3
Lecithin	0.5–2.0
Carbohydrate/energy sources	
Wheat flour	10–30
Refined wheat flour	10–30
Rice flour	10–30
Rice bran	8–15
Tapioca flour	10–25
Binders	
Guar gum	1–3
Wheat gluten	3–5
Binder	0.5–1.0

FIGURE 5
Indigenous aerator used in a shrimp culture pond



Small and marginal shrimp farmers use indigenously assembled aerators which are less expensive than industrially made aerators. These locally made/assembled aerators are operated using diesel engines where electricity is not available at the farm site.

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FIGURE 6
Shrimp feed top-coated with additives by the farmer



As a common practice shrimp farmers in India coat the feed with different feed additives including probiotics, immunostimulants, vitamin C, fish oil and egg albumin through surface coating of the pellets. These feed additives are perceived by the farmers as feed attractant and growth promoter.

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crop are achieved. All these feeds are readily available in the market (for further detail see Suresh, 2007). The industrial feedmills produce a minimum of three grades of feeds namely, starter, grower and finisher. The shrimp feed industry has grown substantially over the last 15 years and the consumption of shrimp and prawn feeds has increased from 30 000 tonnes during the early 1990s to 193 500 tonnes in 2004 (see Suresh, 2007).

On-farm shrimp feed management campaigns are conducted regularly by different agencies in order to train shrimp farmers and to ensure that they use good management practices (GMP) for sustainable shrimp farming. These campaigns have been successful.

Prior to stocking, farmers ensure proper development of a natural food web (phytoplankton and zooplankton) in the pond through the application of organic manure and fertilizers. Shrimp seed (>PL₂₀) from hatcheries are acclimatized to pond conditions by adding water to the seed containers before they are stocked in ponds. Most commonly in the first two weeks external feed is not provided. Some farmers use a pre-starter powder which is broadcasted over the pond. The rate of feeding at this stage varies from 20 to 100 percent of the estimated biomass of the PLs. After two weeks the shrimp are fed with a starter grade feed (0.5 to 1.0 mm size) at the rate of 8–10 percent of the biomass. The daily

ration is fed 3–4 times a day and feeding trays are used to monitoring consumption and to adjust the ration. Aerators for increasing dissolved oxygen in ponds are used as and when required (Figure 5). Small boats are used to broadcast the feed uniformly. By the time the shrimp reaches a harvestable size, the rate of feeding has gradually been reduced to 2–3 percent of biomass. A typical feeding schedule used in shrimp farms is given in Table 19.

Since the emergence of White Spot Viral Syndrome on Indian shrimp farms, water exchange procedures have changed radically. Farmers now change their water less often for fear of disease outbreaks. Water exchanges are done only when necessary and some farmers practise zero water exchange. In some areas farmers have resorted to the use of reservoir ponds, in which water is treated with chlorine prior to using it in the ponds. It is now also common practice for farmers to coat the feeds with probiotics and immunostimulants (Figure 6). Additional Vitamin C is often added through surface

TABLE 19

A typical feeding schedules used by shrimp farms in India at stocking densities of 5 and 10 PLs/m²

Week	Mean weight (g)	Expected survival (%)	Rate of feeding (% of body weight)*		Quantity of feed (kg/day)*	
			5/m ²	10/m ²	5/m ²	10/m ²
1	0.5	90	nil	-	nil	2.0
2	1.0	89	nil	-	nil	4.0
3	2.0	88	4.0	6.0	3.5	10.5
4	2.9	87	3.8	5.5	4.8	13.9
5	3.9	85	3.6	5.0	5.9	16.6
6	5.0	84	3.4	4.8	7.1	20.2
7	6.2	84	3.2	4.6	8.3	23.9
8	7.5	83	3.0	4.4	9.3	27.4
9	9.0	82	3.0	4.0	11.0	29.5
10	11.0	80	3.0	3.8	13.2	33.4
11	14.0	78	2.8	3.4	15.2	37.1
12	16.0	76	2.5	3.2	15.2	38.9
13	18.5	75	2.4	2.8	16.2	38.9
14	20.0	74	2.3	2.7	17.0	40.0
15	22.5	73	2.2	2.5	18.0	41.0
16	25.0	72	2.0	2.3	18.0	41.4
17	28.0	71	2.0	2.1	19.8	41.7
18	31.0	70	2.0	2.0	21.7	43.4
19	33.0	70	1.9	2.0	22.0	46.2
20	35.0	70	1.8	1.9	22.0	46.2

*The above figures are guidelines. The actual figures should be calculated by periodic sampling and recording the average weight and estimated survival.

Source: Ahamad Ali, Gopal and Ramana (2000)

coating of the feed pellets. Fish oil, egg albumin and gels are used for surface coating. In their anxiety to grow and harvest shrimp successfully farmers are often convinced/persuaded to use various other products, though there is no evidence to show that such products have any beneficial effect.

4. PROBLEMS AND CONSTRAINTS OF AQUACULTURE FEEDS AND FEEDING

4.1 Freshwater aquaculture

Suresh (2007) identified freshwater fish nutrition and feeding as the most important limiting factors for the sustainable development of aquaculture in India. The major constraints faced by carp farmers are problems related to the quality and cost of feed ingredients. Rice bran often contains excess rice husk and oilseed cakes contain an excess of seed shells and the use of commercially manufactured feeds is uneconomical. The constraints faced by carnivorous fish farmers are the supply, transportation, cost and storage of trash fish, poultry offal and silkworm pupae. In the absence of cold storage facilities they also face health risks in handling animal by-products.

Farmers also face constraints in farm-made feed preparation. Due to the lack of proper infrastructure, facilities and equipment and the high cost of fuel, many farmers do not cook the ingredients, resulting in wastage of feed and deterioration of pond water quality. Nevertheless, despite the drawbacks, farmers have demonstrated that Indian carps can be successfully farmed on a commercial scale through proper fertilization and skilful on-farm feed management strategies using locally available low cost feeds.

The most serious constraint facing the aquafeed manufacturing industry is the supply of indigenous marine ingredients and increasing prices of imported ingredients such as fishmeal. Moreover, there are no official prawn or shrimp feed standards. This puts farmers at a disadvantage as the feeds made by small-scale producers are often not formulated according to the nutritional requirements of the species and feeds are often made with poor quality raw materials.

4.2 Brackish-water aquaculture

As mentioned earlier, a total of 193 500 tonnes of shrimp feed are used annually. The major feed companies which produce nutritionally balanced feeds use high quality feed ingredients such as fishmeal, squid meal and other squid products, shrimp meal, fish soluble and fish oil, all of which are imported. The large animal and aquafeed manufacturing companies are exempt from customs duty on many of these imported raw materials.

The small-scale feed companies use dry trash fishmeal, shrimp head meal, shrimp meal, mantis shrimp meal and fish oil, but are facing increasing levels of competition from other users. The pulverized fishmeal used by most of these smaller companies is not of the desired quality and is often contaminated with shrimp head meal, mantis shrimp powder and sand (see Suresh, 2007). Moreover, the local fish oil hardly conforms to international quality standards and is often rancid. Farmers and the smaller feed producers are constrained by access to appropriate machinery when making shrimp feed in accordance with the required quality and water stability. At present, most of the feed producers use imported binders such as wheat gluten and polymethylolcarbamide, although some of the feed manufacturers use indigenously available guar gum.

Small and marginal shrimp farmers often get themselves into credit trap. They obtain feed and other inputs on a credit basis from the feed dealers with a buy-back arrangement upon which the farmer has to sell the harvest to the dealer. If there is a crop failure due to disease, the dealer advances the inputs on credit once again and the farmers have to clear their accumulated debt on harvesting the crop. In this process the farmer receives a lower price than on the open market. The farmer also loses his/her bargaining power and ends up paying a higher price for feed. Most of the larger feed companies can provide credit to farmers and wait for 3–4 months till when the shrimps are harvested for repayment. Smaller shrimp feed producers are unable to compete in this arena as they do not have the capital reserves to deal with crop failure. Moreover, there are no official feed standards for shrimp feeds in the country at present, as there are for other livestock feeds. This places the shrimp farmer at a serious disadvantage. Fluctuating prices of shrimp and stringent quality and food safety standards for shrimp on the global market have been pushing farmers to bankruptcy. With the present scenario, farmers are looking towards developing low cost, high quality feeds for shrimp farming in India so that the activity remains profitable and is environmentally sustainable.

5. RESOURCE AVAILABILITY AND EXPANSION OF THE AQUACULTURE INDUSTRY

Aquaculture provides the only alternative opportunity to supply India's growing demand for fish. In terms of land and water resources aquaculture can expand. However, the increasing demand for feeds and feed ingredients may restrict the development of the sector. Aquaculture production is expected to reach 6.282 million tonnes by 2020 (Table 20). To achieve this goal depends largely on an adequate nutrient resource base. The demand for organic manures is expected to rise to 190.66 million tonnes (Table 21) and approximately 200 000 tonnes of nitrogenous as well as phosphate fertilizers will be required. Given current fertilizer production capacity (19.42 and 2.41 million tonnes for nitrogen and phosphorus fertilizers, respectively during 2003–2004) (see Table 8) it was concluded that the availability of fertilizer will not constrain the expansion and development of the sector. However, there is going to be pressure on the supply of organic manures due to the increasing demand for organic food production, which is gaining popularity.

Freshwater fish culture is expected to continue using current culture and feeding practices. Hence, the projected requirements for rice bran and wheat bran will increase from 85 800 tonnes, which is currently used, to 163 020 tonnes (Table 22). This is

TABLE 20
Present (2004) and projected aquaculture growth by 2020 in India

Sector	Present (2004)			Projected (2020)		
	Area under aquaculture (thousand ha)	Production (million tonnes/year)	Growth rate (%)	Area under aquaculture (thousand ha)	Production (million tonnes/year)	Growth rate (%)
Freshwater fish culture	600	2.640	6.6	1 000	5.020	6.0
Freshwater prawn culture	42	0.035	-	80	0.066	6.0
Penaeid shrimp culture	150	0.115	-	250	0.236	7.0
Brackish-water fish culture	10	0.010	-	40	0.960	6.0
Total	802	2.800		1 370	6.282	

TABLE 21
Present (2004) and projected fertilizer requirements by 2020 in India

Fertilizer & manure	Average application (kg/ha/year)	Quantity used (thousand tonnes)	Total quantity required by 2020 (thousand tonnes)
I- Freshwater fish culture			
a. Nitrogen fertilizer	200	100	190
b. Phosphate fertilizer	200	100	190
c. Organic manure	20 000	100 000	190 150
II- Freshwater prawn culture			
a. Nitrogen fertilizer	45	1.6	3.05
b. Phosphate fertilizer	45	1.6	3.05
c. Organic manure	2500	86.6	164.50
III- Brackish-water shrimp culture			
a. Nitrogen fertilizer	15	1.5	2.25
b. Phosphate fertilizer	10	1.0	1.50
c. Organic manure	1250	125.0	187.50
IV- Brackish-water finfish culture			
a. Nitrogen fertilizer	NA	NA	3.92
b. Phosphate fertilizer			3.92
c. Organic manure			165.50

TABLE 22
Present (2004) and projected use of feeds and feed ingredient and the requirements by 2020 for freshwater aquaculture and marine shrimp culture in India

Major feed/feed ingredients	Present (2004) use per annum (tonnes)	Projected requirement per annum by 2020 (tonnes)
Freshwater aquaculture		
Rice bran & wheat bran	85 800	163 020
Oil cakes	5 980	11 370
Marine ingredients (for prawn feeds)	6 000	10 000
Others	2 600	4 940
Shrimp culture		
Formulated feed	193 500	307 500
Fishmeal	36 000	73 800
Squid meal	2 700	5 535
Shrimp meal	11 250	23 062
Mantis shrimp meal	15 000	30 750
Soybean meal	33 000	67 650
Cereal flour	30 000	61 500
Fish oil	4 500	9 225
Lecithin	750	1 537
Binders	1 500	3 075

possible since the projected requirement is only 3.5 percent of the currently available quantity of rice and wheat bran. Hence it can be assumed that the availability of rice bran and wheat bran will not constrain development.

The demand for oilseed cakes is likely to increase from 5 980 tonnes (current use) to 11 370 tonnes. The current local supply of oilseed cakes amounts to some 22.1

million tonnes per annum. The projected requirement for oil cakes for aquaculture in 2020 constitutes 0.06 percent of the current total supply. There are alternative feeds and feed ingredients which are not fully explored and exploited. Important among these are *Azolla* based aquaculture of Indian major carps and the use of duckweed for carp culture. Table 14 lists some of the non-conventional ingredients that need further exploration and exploitation.

Giant freshwater prawn culture is growing rapidly due to the availability of hatchery produced seed and improved economic returns. The sector is expected to expand to a production level of 55 000–60 000 tonnes per annum by 2020. Freshwater prawn feeds contain approximately 20–25 percent of animal ingredients, besides agricultural by-products such as oilseed cake and cereal bran. The expected increase in prawn production, particularly by smaller farms, will put pressure on the supply of dry trash fish and mantis shrimp meal. The poultry industry is the greatest competitor (Wood and Coulter, 1988; Ahamad Ali *et al.*, 1995) for these ingredients. However, given the reduction in the inclusion rates of fishery products and by-products in poultry feeds it is reasonably safe to assume that the supply will meet the future demand of the aquafeed industry.

Shrimp culture is projected to grow at around 7–8 percent per annum to reach 236 000 tonnes by 2020. The projected feed requirements for this level of production are outlined in Table 22. The currently available total volume of marine ingredients used for animal feeds in India is in the region of 335 191 tonnes. The total projected demand for dry fish, shrimp meal, mantis shrimp meal by small-scale feed producers is in the region of 137 612 tonnes. The demand of the industrial scale feedmillers will continue to be met through imports. Under this scenario both the small-scale and the industrial animal feedmills will be able to supply the needs of the sector in future.

The demand for soybean meal, cereal flour and fish oil is approximately 67 650 tonnes, 61 500 tonnes and 9 225 tonnes, respectively. The soybean meal and cereal flour requirements can easily be met by domestic production. Fish oil will however be in short supply and there is a need to explore the replacement of fish oil with other edible oils especially with vegetable oils.

6. RECOMMENDATIONS FOR IMPROVED UTILIZATION OF FERTILIZER AND FEED RESOURCES AND SUGGESTED POLICY GUIDELINES

For aquaculture to develop in a sustainable manner, India requires focused attention on input needs such as fertilizers, feed and seed. With regard to the distribution of fertilizers, aquaculture should be brought under the same policy umbrella as the agriculture sector. Fish, prawn and shrimp farmers should be able to join co-operatives to improve and ease the supply of fertilizers. With regards to feeds, attention should be focused on the elimination of anti-nutritional factors that are present in certain oilseed cakes and on feed stability. Water unstable feeds lead to waste and water pollution. Farmers should be encouraged to use simple binders to enhance water stability of their farm-made feeds. This would lead to greater profitability and a reduction in nutrient loading. The available information on feed management and economic efficiency of freshwater fish production should be more actively promoted. Whenever possible and profitable, farmers should be encouraged to use extruded pellets to improve feed efficiency. Given the future projections for aquaculture, agriculture should be encouraged to produce crops that are suitable for inclusion into aquafeeds.

Shrimp aquaculture depends heavily on fishmeal and other marine products and the aquafeed industry is already in the grip of the fishmeal trap. To steer clear of this trap, the search for alternative protein sources to replace fishmeal must be aggressively pursued and the production of soybeans for aquafeeds should be actively promoted. Fishmeal in India is a scarce commodity. To improve the quality of the locally produced fishmeal and fish powder there is a need to focus on quality control. This can be achieved by improving the technologies for drying in order to eliminate sand and

other contaminants. Similar measures are required to deal with mantis shrimp, shrimp waste and sergested shrimp.

During the early 1990s some 690 000 tonnes of bycatch was dumped by trawlers per annum (Wood *et al.*, 1992). There is good reason to believe that the situation has not changed much. At an average reduction rate of 23 percent the dumped trash fish during that time would yield approximately 158 700 tonnes of high quality fishmeal. The economic feasibility of on-board fishmeal plants should therefore be investigated.

To improve feed and nutrient utilization there is a need to pay attention to the following:

- investigate the improved utilization of high energy diets (Peisker, 2001);
- improve the digestibility of the current high energy aquafeeds through biotechnological innovations, such as exogenous digestive bio-enzymes, probiotics and solid-state fermentation of selected feed ingredients;
- develop more comprehensive feed management protocols to reduce wastage and to improve the utilization of available nutrients to improve FCRs and reduce environmental health risks; and
- pay greater attention to fish and shrimp health, food safety and environmental standards. This is particularly important with respect to consumer demands such as “green” products, the unacceptable practice of using trash fish as fish feed and the demand for fish and shrimp rich in polyunsaturated fatty acids to meet consumer preference (Rosenlund, 2001).

Globally, environmental issues are going to play a dominant role in how aquaculture will be practised in future. For aquaculture to develop in a sustainable manner in India, fish and shrimp must be produced with minimal environmental impact. For this reason processing technologies, feed formulation and feed management practices have to be improved to optimize apparent digestibility coefficients of the various ingredients.

ACKNOWLEDGEMENTS

The authors express their sincere appreciation to Dr P. Kumariah and Dr P.V. Rangacharyulu for their help and assistance and to Sri. M.V.S. Nagi Reddy, for valuable on-farm discussions.

REFERENCES

- Ahamad Ali, S. 1982. *Relative efficiencies of pelletized feeds compounded with different animal proteins and the effect of protein level on the growth of the prawn *Penaeus indicus**. Proc. Symp. Coastal aquaculture, Marine Biological Association of India, 1: 321–328.
- Ahamad Ali, S. & Mohamed, K.H. 1982. *Utilisation of prawn waste and mantis shrimp for compounding feeds for the culture of penaeid prawns*, pp. 615–616. Proc. Symp. Harvest and post-harvest technology, 24–27 November 1982. India, Soc. Fish. Tech.
- Ahamad Ali, S. 1988. Water stability of prawn feed pellets prepared using different binding materials with special reference to tapioca. *Indian J. Fish*, 35: 46–51
- Ahamad Ali, S. 1992. Evaluation of some animal and plant protein sources in the diet of the shrimp *Penaeus indicus*. *Asian Fishery Science*, 5: 277–289.
- Ahamad Ali, S., Rangaswamy, C.P., Narayanaswamy, D. & Gopal, C. 1995. Marine protein sources availability in India as raw materials for prawn feeds. *CIBA, Bulletin* No.9, March 1995. Chennai, India, Central Institute of Brackish-water Aquaculture. 34 pp.
- Ahamad Ali, S. 1998. *Studies on the use of cuttlefish waste and squid waste in shrimp feed formulations*. Proc. Symp. on advances and priorities in fisheries technology, 11–13 February 1998. Cochin, India, Society of Fisheries Technologists. pp 289–293.
- Ahamad Ali, S., Syama Dayal, J. & Ambasankar, K. 2004. India study: corn gluten can partially replace fishmeal in white shrimp feed. *Global Aquaculture Advocate*, 7(6): 60.
- Ahamad Ali, S., Rangaswamy, C.P., Narayanaswamy, D. & Gopal, C. 1998. Raw material resources for shrimp feed production in India. *Fishing Chimes*, 18(3): 31–33.

- Ahamad Ali, S., Gopal, C. & Ramana, J.V. 2000. Shrimp feed processing and production technology. *CIBA Bulletin* No.13, March 2000. Central Institute of Brackish-water Aquaculture, Chennai, India. 20 pp.
- Alagarwami, K. & Ahamad Ali, S. 2000. Indigenous feeds for shrimp farming – development and assessment in comparison with imported feeds. In G. John and A.S. Ninawe eds. *Aquaculture feed and health*, pp. 56–66. New Delhi, Biotech Consortium India Limited.
- Arasu, A.R.T., Abraham, M. & Kailasam, M. 2004. Hand book of seed production and culture of Asian seabass, *Lates calcarifer* (Bloch). *CIBA Bulletin* No.18. February 2004, Chennai, India, Central Institute of Brackish-water Aquaculture. 58 pp.
- Ayyappan, S. 1997. Freshwater aquaculture – towards blue revolution. National aquaculture week – 1997 Souvenir. Chennai, India, Aquaculture Foundation of India. pp. 28–33.
- Ayyappan, S. & Biradar, R.S. 2004. Indian Fisheries: looking ahead. Present scenario and future needs of Indian Fisheries. *Decennial publication of forum of fisheries professionals*, 7-5-181, pp. 1–16. January 2004, Visakhapatnam, India, Ocean View Layout.
- Borthakur, S. & Sharma, K. 1998. Protein and fat digestibility of some non-conventional fishmeal replacers incorporated in the diet of fish *Clarias batrachus* (Linn). *Environmental Ecology*, 16: 368–371.
- Butt, J.A., Iqbal, M., Shoh, S.A., Latif, A. & Khattak, G.U.R. 1988. Studies on production of cheap feed through the used of wastes as protein and energy sources in the diet of common carp (*Cyprinus carpio*). *Pakistan Journal of Zoology*, 20: 209–224.
- Chakrabarti, M.N. 1996. Efficacy of fish feed formulated with fish and poultry offal. *Environmental Ecology*, 14: 791–793.
- Dani, L.P. 2000. The use of alternate and low cost feed ingredients: viability of approach and cost analysis. In G. John and A.S. Ninawe eds. *Aquaculture feed and health*, pp 45–55. New Delhi, Biotech Consortium India Limited.
- Das, D., Sikdar, K., & Chotterjee, A.K. 1994. Potential of *Azolla pinnata* as biogas generator and as fish feed. *International Journal of Environment and Health*, 36: 186–191.
- Devaraj, K.V., Krishna, D.V. & Keshavappa, G.Y. 1981. Utilisation of duckweed and waste cabbage leaves in the formulation of fish feed. *Mysore Journal of Agricultural Sciences* 15: 132–135.
- Dhawan, A., Kaur, V.I. & Virk, P. 2004. Non-conventional fish feed resources: an overview. *Fishing Chimes*, 23 (10 and 11): 66–72.
- FAO. 2006. *Data and statistics unit*. Aquaculture production: quantities 1950-2004. FAO Fisheries Department, Fishery Information, FISHSTAT Plus (available at <http://www.fao.org/fi/statist/FISOFT/FISHPLUS.asp>).
- Francis, G., Makkar, H.P.S. & Becker, K. 2001. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. *Aquaculture*, 199: 197–227.
- Hasan, M.R. 2001. Nutrition and feeding for sustainable aquaculture development in the third millennium. In R.P. Subasinghe, P. Bueno, M.J. Phillips, C. Hough, S.E. McGladdery & J.R. Arthur, eds. *Aquaculture in the third millennium*, 193–219 pp. Technical proceedings of the conference on aquaculture in the third millennium, Bangkok, Thailand, 20–25 February 2000, Bangkok, NACA and Rome, FAO.
- IASRI (Indian Agricultural Statistics Research Institute). 2004. *Agricultural research data book*. New Delhi, Indian Council of Agricultural Research, Krishi Bhavan. 280 pp.
- Kathirvel, M., Pandian, S.K. & Balasubramanian, C.P. 2004. Mud crab culture in India. *CIBA Bulletin* No. 17. Chennai, India, Central Institute of Brackish-water Aquaculture. 60 pp.
- Kaur, V.I. 2002. *Studies on utilisation of some agro-industrial wastes in carp polyculture system*. Ludhiana, India, Punjab Agricultural University. (PhD dissertation).
- MPEDA (Marine Products Export Development Authority). 2004. The Marine Products Export Development Authority, Ministry of Commerce, Government of India, Cochin, India, website: <http://www.mpeda.com>.

- Mohanty, S.N. & Das, S.P. 1995. Evaluation of *Azolla caroliniana* for inclusion in carp diet. *Journal of Aquaculture in the Tropics*, 10: 343–353.
- Mondal, T.K. & Ray, A.K. 1996. *The nutritive value of Acacia auriculiformis leaf meal in compounded diets for rohu, Labeo rohita fingerlings*. The fourth Indian fisheries forum, 164 p. 24–28 November 1996, Cochin, India, Cochin University of Science and Technology.
- Mukhopadhyay, P.K. & Ray, A.K. 1997. The apparent total and nutrient digestibility of sal sees meal in rohu, *Labeo rohita* (Ham.) fingerlings. *Aquaculture Research*, 28: 683–689.
- Nandeesh, M.C. 1993. Aquafeeds and feeding strategies in India. In M.B., New, A.G.J Tacon, and I. Csavas, eds. *Farm-made aquafeeds*, RAPA Publication 1993/18 and AAD CP/PROC/5: 213–254.
- Pandian, T.J. 2000. Scope for live feed use, synthetic diet and feed development to enhance freshwater fish/prawn production in India. In G. John and A.S. Ninawe eds. *Aquaculture feed and health*, pp. 12–20. New Delhi, Biotech Consortium India Limited .
- Patnaik, S., Swamy, D.N., Raut, M. & Das, K.M. 1991. *Use of Otellia and Nymphoides leaf meal as protein source in the feed of Indian major carp fry*. National symposium on new horizon in freshwater aquaculture. Jan 23–25 1991, Bhubaneswar, India, Central Institute of Freshwater Aquaculture. pp. 100–102.
- Paul Raj, R. 2000. Availability of raw material and marketing of various aqua feeds. In G. John and A.S. Ninawe eds. *Aquaculture feed and health*, 39–44 pp. New Delhi, Biotech Consortium India Limited.
- Peisker, M. 2001. Amino acids in aquafeeds. *International Aqua Feed*, 4(3): 18–21.
- Rao, K.J., Anandakumar, A. & Sinha, M.K. 1999. *Giant freshwater prawn culture in Nellore region of Andhra Pradesh – status and strategy for development*. Orissa, India, Central Institute of Freshwater Aquaculture, Bhubaneswar. 22 pp.
- Ray, A.K. & Das, I. 1995. Evaluation of dried aquatic weed, *Pistia stratiotes* meal as a feed stuff in pelleted feed for rohu, *Labeo rohita* fingerlings. *Journal of Applied Aquaculture*, 5: 35–44.
- Rosenlund, G. 2001. The potential for using vegetable oils in salmon feeds. *International Aqua Feed*, 4(3):12–14.
- Sehgal, H.S. & Sharma, S. 1991. Efficacy of two supplementary diets for Indian major carps, *Cirrhinus mrigala*: effect on flesh composition. *Journal of Aquaculture in the Tropics*, 6: 25–34.
- Singh, R. & Dhawan, A. 1993. *Incorporation of molasses with mustard meal and rice polish for the development of cost effective feed for carps*. Proc. Third Indian fisheries forum, Pantnagar, India. pp. 269–273.
- Singh, R. & Dhawan, A. 1995. *Utilisation of sugar industry by-products in aquaculture*. Nat. Sym. Aqua., Jammu, India, Jammu University.
- Singh, R., Dhawan, A. & Saxena, P.K. 1999. Potential of press-mud a sugar factory by-product in supplementary diets and its impact on fish growth. *Bioresource Technology*, 67: 61–64.
- Singh, R., Kaurand, V. & Dhawan, A. 2000. Utilisation of poultry incubator waste in carp feed. *Fifth Indian fisheries forum*, Bhubaneswar, 17–20 January 2000. 49 pp.
- Suresh, A.V. 2007. The development of the aquafeed industry in India (this volume).
- Swamy, H.V.V. & Devaraj, K.V. 1995. Growth response of common carp fry fed on three formulated feeds. *International Journal of Animal Sciences*, 10: 69–72.
- Vaitheeswaran, S. & Ahamad Ali, S. 1986. Studies on the evaluation of certain substances as growth promoting agents in the diet of the prawn *Penaeus indicus*. *India J. Fish*, 33: 95–105.
- Vasudevappa, C. 2001. *Status and scope for enhancing giant freshwater prawn production in India*. International Symposium on fish for nutritional security in the 21st century. 4–6 December 2001, Versova, Mumbai, India, Central Institute of Fisheries Education (Deemed University). 154 pp.

- Veerina, S.S., Nandeesh, M.C., Rao, K.G. & De Silva, S.S.** 1993. *Status and technology of Indian major carp farming in Andhra Pradesh, India*. Special Publication No. 9, Mangalore, India, Asian Fisheries Society, Indian Branch. 76 pp.
- Wood, J. & Coulter, J.** 1988. India's expanding prawn culture industry – where will the feed materials come from?. *Bay of Bengal News*, 32: 12–18.
- Wood, J., Brown, J.H., Maclean, H.M. & Rajendran, I.** 1992. Feeds for artisanal shrimp culture in India – their development and evaluation. *BOBP/REP/ 52*. 59 pp.

APPENDIX**Dietary nutritional requirement of shrimp species****A.1. Dietary nutrient requirements (percent dry matter unless otherwise indicated) of tiger shrimp and Indian white shrimp**

Nutrients	Tiger shrimp	Indian white shrimp
Crude protein	35–46	30–43
Arginine	3.71	3.06
Histidine	0.69	1.52
Isoleucine	0.61	1.55
Leucine	1.03	2.98
Lysine	3.16	2.40
Methionine	1.24	1.05
Phenylalanine	1.70	1.64
Threonine	1.61	1.47
Tyrosine	0.51	-
Valine	2.06	2.78
Fat	3.5–8.0	6.0–9.0
Linoleic acid	0.05	-
Linolenic acid	0.10	-
Eicosapentaenoic acid	0.01	-
Docosahexaenoic acid	0.005	-
Lecithin	0.1–2.0	0.5–2.0
Cholesterol	0.5	0.5
Total energy (kcal/100g)	280–370	350–400
Calcium	2.0–2.5	0.5–0.6
Phosphorus	1.2–1.4	1.1
Potassium	0.7–0.9	1.3
Magnesium	0.08–0.15	Trace
Iron (mg/kg)	60–80	-
Zinc (mg/kg)	80–100	240
Manganese (mg/kg)	40–50	Trace
Copper (mg/kg)	8–10	13.6
Cobalt (mg/kg)	0.8–1.0	-
Iodine (mg/kg)	4–5	-
Chromium (mg/kg)	0.6–0.8	-
Selenium (mg/kg)	0.17–0.21	-
Riboflavin (mg/kg)	40	80
Thiamine(mg/kg)	120	100
Pyridoxine (mg/kg)	120	200
Pantothenic acid (mg/kg)	100	75
Niacin (mg/kg)	150	250
Folic acid (mg/kg)	5.0	-
Biotin (mg/kg)	1.0	-
Vitamin B ₁₂ (mg/kg)	<0.1	-
Choline chloride (mg/kg)	600	625
Inositol (mg/kg)	2 000	3 000
Vitamin C (mg/kg)	4 000	4 000
Vitamin D (mg/kg)	0.03–0.05	-
Vitamin E (mg/kg)	200	-
Vitamin K (mg/kg)	40	-
Vitamin A	3–6	-

Source: Alagarswamy and Ahamad Ali (2000)

