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ROLE OF NATURAL FOOD IN SUSTAINING AQUACULTURE

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Abstract: Over the past 50 years, world aquaculture has grown at an average annual growth rate of 8.8% and now accounts for nearly 50% of the food fish production. Monoculure or polyculture of compatible species in ponds, providing diets with fish meal as the major protein source is the common method of farming fish. Reliance on intensive feed-driven culture system is not sustainable since over-fishing in the ocean to obtain enough fish meal and fish oil for diets would endanger the global marine environment. Further, this practice also enhances the organic load of the pond effluent as well as the cost of production. Omnivorous/herbivorous species that feed at the lower trophic levels are more eco-friendly, since they can be grown by the judicious use of manures and diets with lower protein and higher carbohydrate content. Manuring is a common practice in Asian countries, including India, aimed at increasing the production of natural food for farmed fishes. Facilitating the growth of biofilm/periphyton by installing substrates in ponds adds a new dimension to natural food production. Periphyton is readily consumed by browsers such as *Labeo rohita* and *L. fimbriatus* and is also helpful in improving water quality by producing oxygen, trapping suspended solids and taking up ammonia and nitrate. Studies have demonstrated comparative growth of carps in periphyton-based systems and feed-driven systems. Growing fish without the use of chemical fertilizers and drugs, depending largely on natural food can be termed organic farming.

Key words: Carp, Manure, Live feed, Fish growth, Substrate, Periphyton, Water quality

INTRODUCTION

Approximately 16% of animal protein consumed by the world's population originates from fish and over one billion people worldwide depend on fish as the main source of animal protein. Capture fisheries and aquaculture supplied the world with about 154 million tonnes of fish in 2011 (FAO, 2012). Growing population and awareness of health benefits associated with the consumption of fish products have increased the demand for fish. The aquaculture industry carries the responsibility of increased fish supply in the face of stagnation in capture fisheries production. In the last three decades (1980–2010), world food fish production from aquaculture has expanded by almost 12 times, at an average annual rate of 8.8 percent. Aquaculture enjoyed high average annual growth rates of 10.8% and 9.5% in the 1980s and 1990s, respectively, but has since slowed to an annual average of 6.3%. Aquaculture contribution to world total fish production climbed steadily from 20.9 percent in 1995 to 40.3 percent in 2010 when the global production of farmed food fish was 59.9 million tonnes (36.9 million tonnes from freshwater aquaculture) and the average annual per capita food fish supply was 18.6 kg. Aquaculture is expected to contribute more effectively to global food security, nutritional well-being, poverty reduction and economic development by producing 85 million tonnes of aquatic food by 2030. In India, fish production has touched 8.67 million tones, aquaculture contributing to nearly 50%. Increased aquaculture production has to be achieved through sustainable development, without degrading the environment.

PLANKTONIC NATURAL FOOD

In India, aquaculture production comes largely from extensive and semi-intensive polyculture systems in freshwater bodies, particularly ponds and carps contribute to nearly 85% of the production. The need for a greater understanding of the role of natural food organisms in semi-intensive farming based on systems that optimize pond fertilization, in order to bring down the cost of fish production has been emphasized by the FAO/AADCP Regional Expert Consultation (NACA/FAO, 2000). Fertilization and supplemental feeding are the two important management measures adopted in the semi-intensive system of carp and tilapia culture in Asia. The share of non-fed species farmed in Asia was 35 percent (18.6 million tonnes) in 2010 which reflects the contribution of natural food to fish production. Since carps and tilapia feed at lower trophic levels, planktonic natural food availability in their culture is ensured through manuring. One of the major objectives of carp polyculture is maximization of natural food utilization, using species that feed at different niches. Polyculture systems efficiently utilize available natural food resources at the surface, pelagic and benthic levels of the pond ecosystem, with the consequent effects of reducing costs and increasing productivity. Some of the most widely cultivated fish species are produced together in this type of systems in China and India, with yields up to 10000kg/ha/yr. Stocking of fish species like common carp that browse in the sediment for food helps to oxidize the pond bottom and enhances the availability of nutrients to phytoplankton (Milstein *et al*., 2002).

A number of studies focus on the role of manures in fish production (Garg and Bhatnagar, 2000; Dhawan and Kaur, 2002; Das *et al*., 2005; Bwala and Omoregie, 2009, Priyadarshini *et al*. 2011). In addition to acting as a food for fish, plankton perform other important functions in pond aquaculture - a net producer of dissolved oxygen, which is indispensable for fish growth (Teichert-Coddington and Green, 1993) and the most important sink of ammonia-nitrogen, which is excreted by fish (Hargreaves, 1998; Jiménez-Montealegre, 2001). Jhingran (1991) observed that natural food also supplies certain digestive enzymes that improve the utilization of artificial diets. According to Moav *et al.* (1977), judicious organic manuring of fish ponds can eliminate the need for supplementary feeding. Employing common carp fry, Priyadarshini *et al.* (2011) recorded similar growth in manure and feed treatments, the growth being 97.46% and 102.86% higher than that of the control without manure and feed. This reflects that nutrient requirement of common carp fry is satiated by natural food alone. Natural food is nutritive and contains 51.1% protein, 27.3% carbohydrate and 7.7% fat, while the calorific value ranges from 6.7 to 23.8 kJ/g (De Silva and Anderson, 1995).

In several countries, it is common to integrate fish culture with poultry, duck, piggery, cattle, *etc*. to take advantage of animal wastes as manure. This works out more economical since manure becomes available right at the pond site.

LIVE FEEDS

Live feeds (microalgae, rotifers, *Artemia*, copepods) are the main item in the diet of cultured finfish and shellfish larvae. Live prey, with a thin exoskeleton and high water content have a lower nutrient concentration and may be more palatable to the larvae once taken into the mouth, compared with the hard, dry formulated diet. Microalgae are also used as an indirect food source, in the production of zooplankton (e.g. rotifers and *Artemia*). Products such as live microalgae concentrates, dried microalgae, frozen and freeze-dried microalgae, microcapsules, yeasts or yeast-based diets, bacteria and algal pastes are commercially available. The dry matter composition of microalgae is highly variable, even within a given species, with protein contents ranging from 12% to 35%, lipid from 7.2% to 23% and carbohydrates from 4.6% to 23% (Becker, 2004). Since the 1970s, the rotifers and more specifically *Brachionus plicatilis* constitute an essential part of the feeding during the fish larval stages (Lubzens and Zmora, 2003). Its body size makes this organism an appropriate prey to start feeding after the resorption of vitelline reserves in many species. According to Lubzens and Zmora (2003), rotifer's protein content ranges between 28% and 63%, lipid from 9% to 28%, and carbohydrate from10.5% to 27% of the dry weight (DW). Copepods and other natural zooplankton organisms have also been used as live feeds, normally with considerably better results in terms of larval survival rates, growth and quality, when compared with rotifers and *Artemia*. In fact, they are the diet for fish larvae of most species in nature. Copepods also have higher protein and free amino acid contents compared with *Artemia* and rotifers. Free amino acids and protein constituted 4.3 to 8.9%, and 32.7 to 53.6% of copepod DW respectively.

Periphyton as Natural Food

Biofilm/periphyton-based fish culture offers a new direction in nutrient utilization since it is effectively utilized by many fish species which thrive low in the food chain (Van Dam et al., 2002), making semi-intensive aquaculture system more nutrient-efficient. It is a promising technology for resource-poor farmers and hence has been gaining importance of late in developing countries. It has economic as well as environmental advantage vis-à-vis fertilization and feeding. Feed accounts for a large percentage of the fish production cost. Further, only about 15 to 30% of the nutrient input in feed-driven pond systems is converted into harvestable products (Gross *et al*., 2000); the remainder is lost to the sediment, effluent and the atmosphere (Beveridge *et al*., 1994). In fertilized systems, on an average, 5 to 15% of the nutrient input ends up in harvestable products (Schroeder *et al*., 1990; Edwards, 1993). Several studies with artificial substrates have shown that periphyton can increase the production of fish compared to systems without substrates. Benthic periphyton has an advantage over phytoplankton because it is closer to the nutrient-rich sediment and the interstitial water. Organic carbon accumulation is stimulated under aerobic conditions on substrates, enhancing microbial activity in the water column, rather than on the pond bottom. Microbial communities containing algae, bacteria, protists, zooplankton and fungi embedded in an extracellular polysaccharide matrix develop on submerged surfaces. Within these communities, autotrophic or heterotrophic biomass dominates, depending on light, dissolved oxygen, and nutrient availability. Vertical installation of natural or synthetic submerged substrates (e.g. bamboo poles, plastic sheets, *etc*.) in ponds at least partially prevents sedimentation and accumulation of organic matter at the pond bottom. Compared to organic matter at the bottom, the organic matter attached to substrates is exposed to oxygen rich water and is aerobically decomposed, thus contributing to a beneficial microbial food web. Results reported on organic tilapia production by Milstein *et al*. (2009) point towards periphyton-based aquaculture as an appropriate technology for reduction in the cost of production.

Bamboo as Substrate

Employing 3 different substrates, Azim *et al.* (2002) obtained 66-71% greater carp production, whereas Azim *et al.* (2001b) had recorded 77% higher production of rohu under monoculture with bamboo substrate at 9 m^{-2} of pond area. Wahab *et al.* (1999) obtained a similar production increase with kalbaush (*L. calbasu*) using sticks of bamboo branches as substrate (700 per 75m^2 pond). Uddin *et al.* (2007) reported that bamboo substrate at 5 m^{-2} contributed 40% to tilapia production in monoculture, whereas, in polyculture with prawn, it contributed 46%. Prawn production increased by 127%. Enhanced production of freshwater fish/prawn (Uddin *et al.,* 2009; Asaduzzaman *et al*., 2010) and brackishwater fish (Jana *et al*., 2006; Garg *et al*., 2007) has been realized in periphyton-based pond culture studies. Even the African catfish, *Clarias gareipinus* has been to shown to utilize periphyton from bamboo substrate. Fish stocked at 0.8 m^{-2} with bamboo poles at 4 m^{-2} resulted in 70% higher yield (Amish *et al*., 2008). All these findings imply wider applicability of the periphyton technology in culture fisheries.

Substrate density influences production, but the effect varies between species. With mahseer (*Tor* *khudree*), a substrate density of 98 (5-7 cm diameter bamboo poles in 25m^2 tank) increased production by 41% compared to pole-free tanks. Doubling the pole density to 196 poles led to a production increase of 51% (Keshavanath *et al*., 2002). With tilapia (*Oreochromis mossambicus* × *O. niloticus*) using similar densities of poles, the production increased 112% and 116% with the low and high substrate densities respectively (Keshavanath *et al*., 2004). Further, the fish production increase due to feeding a quality pellet-feed with mahseer and tilapia was less than that obtained by providing substrate for periphyton development. Thus, providing substrate for periphyton development in stagnant ponds contributed more to fish production than adding formulated feed. Uddin *et al*. (2009) obtained similar combined net yields of tilapia and prawn in the feed alone and periphyton alone treatments.

Sugarcane Bagasse as Substrate

Umesh *et al*. (1999) reported that the production of common carp, Mozambique tilapia and rohu reared in tanks manured with cattle dung and urea was 45–50% higher with sugarcane bagasse (SB), compared to tanks without substrate. This increment in growth was attributed to the biofilm grown on bagasse, which acted as an additional source of food and the higher production of zooplankton in the water as a result of the biofilm. Rohu and common carp grew best in the tank with SB, yielding 3.09 kg/tank, as against 2.87, 2.40 and 1.86 kg in tanks with paddy straw, water hyacinth and no substrate, respectively (Ramesh *et al*., 1999). Mridula *et al*. (2003) evaluated SB and paddy straw for enhancing the growth of *Labeo fimbriatus.* The growth of fish was significantly higher in substrate-based tanks, the percentage increase over control being 30 and 29 in bagasse and paddy straw treatments, respectively. Dharmaraj *et al*. (2002) investigated the effect of bagasse and/or feed on growth and production of *L. fimbriatus.* The results indicated that *L. fimbriatus* effectively utilizes biofilm grown on SB and provision of substrate reduces the need for artificial feed. In an on-farm polyculture trial with catla, rohu and common carp, using SB as substrate, total fish production of 8.08 kg/100 m^2/180 days was obtained without feed and periphyton (control). Feeding alone increased yield by 20%. Bagasse substrate alone increased yields by 38, 61 and 62% in the 39, 78 and 156 bundles/100 m^2 treatments, respectively, while the combination of feeding and periphyton resulted in 45, 67 and 84% increase in yield. At the highest bagasse dose total fish yield was 13 and 15 kg/100 m^2 without and with feed, respectively (Keshavanath *et al*., 2001). When loose SB was used in the pond bottom at 1.5, 2.0, 2.5 and 3.0 t/ha, the growth and production of rohu was similar in 2.0, 2.5 and 3.0 t/ha treatments and was higher than the control (Gangadhar and Keshavanath, 2012).

Periphyton Quality and Digestibility

Studies conducted with locally available bio-degradable and non-degradable substrates revealed that periphyton dry matter per unit area was high on PVC pipe, glass and bamboo and the periphyton grown on bamboo and tyre had higher protein and fat contents than the other substrates tested (Gangadhar and Keshavanath, 2008). When dry matter digestibility of periphyton was compared among the cultivable carp fingerlings, mahseer recorded the highest (42.54%) and catla, the lowest (20.63%) value (Gangadhara *et al*., 2004).

Periphyton and Water Quality

The relation between periphyton and water quality was explored by Azim *et al.* (2003) using factorial analysis. Attached algal development positively influenced oxygen availability and biofilm decomposition. In turn, nutrients released through decomposition stimulate autotrophic production by suspended and attached organisms. There is always competition between periphyton and phytoplankton for nutrients, but provided there is no nutrient limitation, the combined primary production by suspended and attached algae in periphyton-based systems is higher than in substrate-free ponds. Periphyton improves water quality by taking up ammonia and nitrate, trapping suspended solids, producing oxygen, breaking down organic matter and increasing nitrification.

Carbohydrate addition in periphyton-based culture systems

Manipulating the microbial community developing on substrates using C/N control in a way equivalent to the biofloc technology system is comparatively a recent trend in aquaculture. Asaduzzaman *et al.* (2008) showed that a feed input along with an additional carbohydrate (tapioca flour) application to maintain a C:N ratio of 20 in combination with substrate addition for periphyton development improved the net yield of freshwater prawn by 75%. Compared to control ponds (C:N ratio 10 and no substrates), this higher yield concurred with reduced levels of toxic inorganic nitrogenous compounds, increased periphyton productivity and higher concentrations of total heterotrophic bacteria in the water column and sediment. In a further study, Asaduzzaman *et al.* (2010) investigated the effects of three C:N ratios (10, 15 and 20) along with substrate presence or absence on natural food communities in freshwater prawn culture ponds. Increasing the C:N ratio from 10 to 20 significantly increased the biovolume of phytoplankton, crustaceans and rotifers in the water column by 15%, 6% and 11%, respectively. The biovolume of periphytic plankton was 50% higher in treatment C/N20 compared to treatment C/N10. Higher C/N ratio raised the biovolume of total heterotrophic bacteria (THB) in the water column (70%), sediment (36%) and periphyton (40%). The addition of substrates decreased the biovolume of water column plankton by 14%, but the combined biovolume (plankton+periphytic plankton) was almost double in substrate-added ponds.

Evaluation of the effect of stocking density of freshwater prawn and addition of different levels of tilapia on production in C/N controlled periphyton based system was carried out by Asaduzzaman *et al*. (2009b). Increasing prawn density decreased periphyton biomass (dry matter, ash free dry matter, chlorophyll *a*) by 3–6%, while it increased the total heterotrophic bacterial load of water and sediment and gross and net prawn production. In another study, Asaduzzaman *et al*. (2009a) investigated the effect of addition of tilapia and substrates for periphyton development on pond ecology, production and economic performances in C/N controlled freshwater prawn farming system. Addition of tilapia and periphyton substrates in C/N controlled system benefited the freshwater prawn culture practices through (1) reducing toxic inorganic nitrogenous compounds in water (2) enhancing the availability of plankton, periphyton, microbial floc and benthic macroinvertebrates, thereby reducing the demand for supplemental feed (3) improving survival, production and economic returns. An intense exchange of inorganic and organic solutes takes place between autotrophic and heterotrophic components within the periphyton assemblage. In ponds with substrates, organic matter and nutrients derived from feed and carbohydrates are partly trapped by periphyton (van Dam *et al*., 2002) which has a fertilization effect on autotrophic periphyton in higher C:N ratio treatments.

BIOFILM IN FISH HEALTH

Attempts to understand the role of biofilm in improving the health status of cultivable species have also been made. A biofilm vaccine of *Aeromonas hydrophila*, a pathogen of freshwater carps, was evaluated for oral vaccination in Indian major carps (Azad *et al*., 1997). Higher antibody titre and immune protection were recorded in catla, rohu and common carp vaccinated with biofilm vaccine compared to those vaccinated with free cell vaccine. This was attributed to the antigen protection by the glycocalyx envelope, which prevented antigen destruction in the gut. Further, uptake, processing and retention of biofilm and free cell vaccines of *A. hydrophila* in Indian major carps and common carp following oral vaccination was evaluated by monoclonal antibody based antigen localization studies (Azad *et al*., 2000a,b). A larger quantity of biofilm vaccine was taken up by the lymphoid organs and was retained for a longer period compared to free cell vaccine. Joice *et al*. (2002) evaluated the resistance of common carp fry to *A. hydrophila* by rearing them in tanks in which biofilm growth was promoted by suspending SB. Significantly higher serum agglutination titre and protection against *A. hydrophila* was observed when compared to those from control tanks without substrate. The findings indicate that there is scope for improving the resistance of fish against ubiquitous secondary pathogens through biofilm promotion in aquaculture ponds.

The foregoing account on planktonic/periphytic natural food clearly brings out their multifarious benefits in aquaculture. In conclusion, farming of fish without the use of chemical fertilizers and drugs, depending largely on planktonic/ periphytic natural food, maupulating the pond environment suitably with C/N control can be considered equivalent to organic farming.

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