Tilapia culture without the use of fishmeal relieves pressures on natural fish stocks

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Tilapia hatcheries, as with most aquaculture ventures, have recently become highly productive and highly profitable. Approximately three million t of cultured product, worth nearly US$4 billion, were produced in 2008 (FAO 2010). The cultivation of Tilapia (*Oreochromis niloticus* and various associated species and hybrids) is being promoted rapidly and adopted by farmers in over 100 countries. One of the main benefits of fish farming, especially in developing countries, is to provide a cheap and abundant source of protein to local populations. In particular, tilapia are widely accepted across most cultural, traditional and religious factions. Farmed fish also provide a substitute to fish caught either by subsistence or commercial fishermen, relieving pressures on natural fish stocks normally generated as a result of overharvesting and poor fishery practices. The concern, however, is the utilization of fishmeal (ground dried fish) as a feed source for many species being cultured.

This article explores the extent to which tilapia can be farmed without the addition of protein sources to the diet and, alternatively, if plant protein and/or green-water systems can be used as complete substitutes to eliminate the reliance on fishmeal. This further promotes the benefits of tilapia as a more sustainable species for aquaculture, as well as highlighting the fact that aquaculture has the potential to fully realize its expectations of being an ecologically sound alternative to capture fisheries.

Nutritional Requirements of Tilapia During Their Life Cycle

Tilapia are omnivorous, with the potential to exist solely on a herbivorous diet. They can feed on phytoplankton, plants and particulates available in the water column inasmuch as they are filter feeders. Thus, if a pond system contains sufficient protein, carbohydrates, amino acids and lipids, the nutritional requirements of tilapia will be met (Watanabe *et al.* 2002).

Within fish aquaculture systems, the standardization of size during growout aids in production. This begins with fry selection. If fry are the same size and age, this ensures all individuals within a pond system will reach market size simultaneously so long as they do not become sexual mature. The application of sex reversal in tilapia has become increasingly popular since its inception. In a method developed at the Asian Institute of Technology (AIT) in Bangkok, Thailand, up to 99 percent of fry can become phenotypically male with treatment of 17α-methyltestosterone (MT). This has many benefits in that no new fry are introduced into the system, the fish expend no energy on breeding, growth is uniform, and males grow up to 25 percent faster than females (Watanabe *et al.* 2002, Stewart and Bhujel 2007). It has been determined that fry require around 13.5 kj/g of digestible energy per kg and 31 percent digestible protein (Furuya *et al.* 2004) as well as 6-8 percent lipid. These may be supplied by the algal component of green-water, however the application of the MT requires a substrate for application. It is insoluble in water, and, thus, needs to be treated with ethyl alcohol and mixed with feed to be distributed to the fry. Thus, the addition of fishmeal is unnecessary and may be readily replaced with an alternative protein source. Further technological advancements in sex-reversal technology involve the use of Rohu pituitary gland extracts as well as generating "supermales" (YY) to minimize the use of artificial hormones (Watanabe *et al.* 2002). This approach will also decrease the need for a feed-based application system.

Adult *O. niloticus* can be reared to market size (~500 g) within approximately 6-7 months in a green-water system alone. The standard percentage of crude protein in such systems is around 25-35 percent. This is considered sufficient to promote growth, as well as being cost effective. This protein level is also sufficient for broodstock to produce viable eggs at regular (one month) intervals. Broodstock should not be fed excessively to maximize their growth, inasmuch as they can grow too large to handle easily. Feeding at approximately one percent of biomass tends to result in the highest egg production, thus an optimal level of 0.8-1 percent is recommended (Bhujel 2002).

During growout, tilapia can be raised solely on green-water systems. Their protein requirements are similar to that of broodstock at about 25-27 percent. The limiting factor is normally space and the quality of the water system. Fertilizer should be applied, as with any green-water system, during the initial refilling and stocking of the pond to achieve an optimal secchi disk reading of 20-30 cm. The sex reversed individuals can then be stocked.

It is recommended that the tilapia be grown in monoculture at a density of approximately 20/m^2. Within a system such as this, tilapia can be farmed with very little effort or maintenance. The concern rests with more intensive systems where supplemental feed is required and feed levels are increased monthly.

Decreased Reliance on Fishmeal

Natural fish stocks have already declined and most fished species are expected to be depleted by 2048 if fishing practices continue at the current rate (FAO 2010). Approximately one billion people rely on fish as their primary animal protein source. Currently half of the total fish consumed worldwide is farmed. Aquaculture is now highly involved at a commercial level, from breeding to growout for consumption. Systems such those used to rear tilapia are now completely self sufficient in terms of not having to draw on broodstock or fry from the wild. Also, there exists the opportunity to develop more ecologically sound aquaculture approaches (Stewart and Bhujel 2007). Currently, many fish farms, such as those for salmon and trout, still heavily rely on wild stocks in some way, particularly with regard to incorporating fishmeal as a protein source in feeds. Therefore, sustainable aquaculture practices should be implemented as extensively as possible to decrease the pressures on the wild stocks.

Aquaculture techniques have for the most part become refined in developed nations, such as Norway, the United Kingdom and the United States. With this comes a certain level of education and awareness for the concept of sustainable fisheries. It is possible to obtain fishmeal from an organization with transparency as to the source and management of their fish stocks, such as those associated with the Sustainable Fisheries Partnership (SFP) and fishsource.org (Leadbitter 2010). As these aquaculture methods are increasingly adopted by rural populations in developing countries, such as in Africa and Asia, the access to those supplies becomes limited. Thus, while good aquaculture practices are being instilled they may have detrimental ecological consequences in drawing supply from unsustainable fisheries in the procurement of fishmeal.

Developing countries may, at least, try to promote sustainable fisheries in their oceans. However, it is often impossible to enforce any regulations resulting from a lack of management, manpower or other resources. Thus, considering the declining state of natural fish stocks, the explosion of aquaculture across the globe, as well as the technology and information available, can one justify promoting the utilization of fishmeal at all? Surely the option to utilize fish species such as tilapia, which can be reared organically, should become the foremost option and implemented as a generally accepted practice.

What Are the Alternatives?

Several alternatives have been posed as replacements for fishmeal (El-Sayed 1999). The most common is the utilization of other animal protein sources, such as the byproducts from poultry, swine and rabbits, as well as insects, their byproducts (e.g., silkworm pupae, fly larvae) or earthworms. More encouragingly current research indicates that plant proteins, with small additions of amino acids, is sufficient to totally replace the protein supplied by fishmeal in the diet of aquacultured species (Nguyen and Davis 2009). Products such as soybean meal or oils, sunflower meal, linseed meal and cottonseed meal, have been shown to contain high protein percentages and other nutrients essential for tilapia.

Animal protein sources have major drawbacks. There are environmental concerns associated with agriculture in terms of greenhouse gas emissions, land conversion and pollution. The widespread use of antibiotics and hormones in agriculture is also controversial. Relating specifically to aquaculture, an issue of concern is that the poultry and swine industries utilize the highest proportions of fishmeal (Naylor *et al.* 2000). While the overall contribution of fishmeal in livestock feed is considerably lower than that often used to feed fish (20-30 g/kg compared to 60 g kg), this reliance on fishmeal still exists (Naylor *et al.* 2000, Nguyen and Davis 2009). A further concern is the utilization of porcine byproducts, inasmuch as there are many religious factions who will not accept eating fish raised on those products, limiting their use in aquaculture feed.

The utilization of plant meal is still under debate. This is based on nutrient limiting factors and variance in availability and quality of products in different regions. Soybean meal is thought to be nutritious enough to supply protein to tilapia fry, and the most viable option (El-Sayed 1999). Yet, to replace fishmeal entirely, the addition of dicalcium phosphorous as well as several amino acids including lysine, threonine and methionine (Furuya *et al.* 2004, Nguyen and Davis 2009). Concern over lipid composition also suggests that soybean oil is more beneficial than oil from corn, coconuts or even anchovies (Watanabe *et al.* 2002). In particular, omnivorous and herbivorous fishes are able to assimilate plant proteins and oils efficiently (Naylor *et al.* 2000), further reducing the necessity for fishmeal in the diet. This also indicates that aquaculture feed with high levels of fishmeal are supplying excess nutrients that are not utilized by the fish for growth. Indications of variability of the quality of fishmeal because of the utilization of trash fish composites, means that specifically processed plant meal with a known nutrient composition may be more reliable.

Technology incorporating green-water systems is ultimately the most environmentally responsible alternative. Tilapia can be reared to harvest in these systems utilizing the particulates as a sufficient nutrient source without the addition of prepared feed. Green-water systems may contain protozoans, bacteria, macrophytes and zooplankton, as well as the phytoplankton component (Neori 2010). The ingestion of algal components in the diet is even suggested to increase tolerance to stress and disease, as well as increase survival rates (Olvera-Novoa *et al.* 1998). Needing only a small amount of fertilizer and maintenance, these systems are, in fact, carbon sinks and reduce greenhouse gas emissions. They can also be employed in tropical regions, such as southeast Asia and Africa.

Cost of Fish Feeds Versus Alternatives and Availability

In this rapidly developing field, the evaluation of cost/benefit analysis for any feed ingredient will have to be thoroughly scrutinized. Between 50 and 60 percent of the operating expense in a commercial culture venture can be associated with the feed (Furuya *et al.* 2004). Not only are plant products cheaper, they are often easier to obtain.

For small-scale farmers who rely on fingerlings bought from a hatchery, the expenses are minimal. If the farmers in such places as Thailand can be taught to efficiently utilize green-water systems, the need for feed is removed. Sex reversed fingerlings will need no additional feed and the system is completely self sustainable.

In terms of evaluating the cost of specific aquaculture ventures, it is no longer reasonable to simply evaluate cost as a linear estimate. Rather, life cycle analysis (LCA) should be utilized to completely understand the environmental and economic impacts. LCA evaluations incorporate the energy expenditure and material used from raw materials of each component part, through processing to its ultimate fate, as well as the environmental impacts of each input and output. While aquaculture ventures attempt to minimize ecological impacts and provide a substantially improved alternative to captured fish, there are concerns to be addressed. There is a distinct awareness of environmental concerns, such as ecosystem manipulation and waste discharge. However, the evaluation of materials and feed technology, as well as processing in a system also become relative. Without acknowledging the total process of aquaculture, the ultimate cost of a system may be underestimated. The future of aquaculture needs to be based on minimizing total costs, both monetary and environmental, to provide affordable protein alternative to capture fisheries.

This further supports the argument for fish feed replacements, specifically with the utilization of fishmeal being unnecessarily in feed for herbivorous and omnivorous fish species. Higher rates of algal ingestion increase the ecological efficiency of the fish because they are feeding at a lower trophic level (Neori 2010). Thus, the average feed conversion ratio of tilapia, for example, could be near zero, rather than at its current value of two (Naylor *et al.* 2000).

While it had been suggested that several feed types may replace 100 percent of dietary fishmeal, there does not appear to be one specific feed source that is being used exclusively in a semi-intensive or intensive system currently. However, El-Sayed (1999) concluded that even a lower biological performance of tilapia reared on fishmeal alternatives would be compensated for by cost reductions.

Conclusions and Recommendations

The intensive nature of commercial aquaculture means that farmed tilapia currently still need additional feed other than a green-water system to breed, rear and grow to market size. Relying on capture fisheries for fishmeal, however, is ultimately unsustainable and will deliver a large ecological cost to aquaculture. With further developments in fishmeal replacement technology, the application and accessibility of alternative products may soon be fully viable.

While commercial aquaculture initiatives are looking for the most cost effective options to maximize profits, the environment will also benefit. Subsistence farmers and small-scale units are extensively distributed in many developing countries, such as Thailand. Thus, they should also benefit from any reduction in reliance on fishmeal. If aquaculture projects encourage species such as tilapia utilizing green-water systems as a standard, they will require a lower investment of time and money. This will make them more appealing to farmers and encourage more environmentally friendly practices at the same time. Ultimately, the global market should strive to demand products that are 'green,' regardless of where they are produced. If aquaculture is to be the primary provider of cost effective, high-quality protein for the world, these alternatives must be more thoroughly implemented. Not only are they substantially more cost-effective, they can be generated from locally available resources and, ultimately, decrease any reliance on fishmeal without a compromise in farming efficiency.

Notes

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References

Bhujel, R. C. 2002. Nutrition and low-cost feeding management for tilapia. Panorama Acuícola Magazine.

El-Sayed, A. M. 1999. Alternative dietary protein sources for farmed tilapia, *Oreochromis* spp. Aquaculture 179:149-168.

FAO (Food Agricultural Organization of the United Nations). 2010. Fisheries and Aquaculture Information and Statistics Service. Total Tilapia Production. www.fao.org

Furuya, W. M., L. E. Pezzato, M. M. Barros, A. C. Pezzato, V. R. B. Furuya and E. C. Miranda. 2004. Use of ideal protein concept for precision formulation of amino acid levels in fish-meal-free diets for juvenile Nile tilapia (*Oreochromis niloticus* L.). Aquaculture Research 35:1110-1116.

Leadbitter, D. 2010. New Standards drive interest in fish used for fish meal. Aquaculture Asia Pacific 6(5): 40-41.

Naylor, R. L., R. J. Goldburg, J. H. Primavera, N. Kautsky, M. C. M. Beveridge, J. Clay, C. Folkes, J. Lubchenco, H. Mooney and M. Troell. 2000. Effect of

(Continued on page 69)

Microcystins

(Continued from page 57)

Ding, W. X., H. M. Shen, H. G. Zhu and C. N. Ong, 1998. Studies on oxidative damage induced by cyanobacteria extract in primary cultured rat hepatocytes. Environmental Research 78:12-18.

Ding, W. X., H. M. Shen, H.G. Zhu and B. L. Lee. 1999. Genotoxicity of microcystic cyanobacteria extract of a water source in China. Mutation Research 442:69-77.

Falconer, I R. 1991. Tumour promotion and liver injury caused by oral consumption of cyanobacteria. Environmental Toxicology 6:177-184.

Hernandez, M., M. Macia, C. Padilla and F. F. Del Campo. 2000. Modulation of human polymorphonuclear leukocyte adherence by cyanopeptide toxins. Environmental Research Sec. A 84:64-68.

Ibelings, B. W. and I. Chorus 2007. Accumulation of cyanobacterial toxins in freshwater "seafood" and its consequences for public health: A review. Environmental Pollution 150:177-192.

Jun, C., X. Ping, Z. Dawen and L. Hehua. 2007. *In situ* studies on the distribution patterns and dynamics of microcystins in a biomanipulation fish the bighead carp (*Aristichthys nobilis*). Environmental Pollution 147:150-157.

Lankoff, A., W. Wayne, K. Carmichael, A. Grasmanb and M. Yuan. 2004. The uptake kinetics and immunotoxic effects of microcystin-LR in human and chicken peripheral blood lymphocytes in vitro. Toxicology 204:23-40.

Lawton, L. A., C. Edwares and G. A. Codd. 1994. Extraction and HPLC method for the determination of microcystins in raw and treated waters. Analyst 119:1525-1530.

Liqiang, X., X. Ping , O. Kazuhiko, H. Takamitsu, Y. Atsushi and P. Ho-Dong. 2004. Dynamics of microcystins-LR and -RR in the phytoplanktivorous silver carp in a sub-chronic toxicity experiment. Environmental Pollution 127:431-439.

Li, L., P. Xie and J. Chen. 2007. Biochemical and ultrastructural changes of the liver and kidney of the phytoplanktivorous silver carp feeding naturally on toxic Microcystis blooms in Taihu Lake, China. Toxicon 49:1042-1053.

Liang, W., Q. F. Jia and Y. J. Hua. 2001. Influence of alga contamination on the quality of drinking water in the Tai Lake area. Jiangsu Prevention Medicine 12:1-2.

Mackintosh, C., K. A. Beattie, S. Klumpp, P. Cohen and G. A. Codd. 1990. Cyanobacterial microcystin LR is a potent and specific inhibitor of protein phosphatase 1 and 2A from both mammals and high plants. FEBS Letters 264:187-192.

McElhiney, J. and L. Lawton. 2005. Detection of the cyanobacterial hepatotoxins microcystins. Toxicology and Applied Pharmacology 203:219-230.

Ott, J. L. and W. W. Carmichael. 2006. LC/ESI/MS method development for the analysis of hepatotoxic cyclic peptide microcystins in animal tissues. Toxicon. 47:734-741.

Pelander, A., I. Ojanperä, K. Lahti, K. Niinivaara and E. Vuori. 2000. Visual detection of cyanobacterial hepatotoxins by thin-layer chromatography and application to water ananlysis, Water Research 34:2643-2652.

Roitt, I., 1993. The role of autoantigens in the driving of autoimmune diseases. Immunology Series 59:119-129.

Runnegar, M., S. Kong and N. Brandt. 1993. Protein phosphatase inhibition and *in vivo* hepatotoxicity of microcystins. American Journal of Physiology 265:224230.

Shen, P. P., S W Zhao, W J Zheng, Z C Hua, Q Shi and Z T Liu. 2003. Effects of cyanobacteria bloom extract on some parameters of immune function in mice. Toxicology Letters 143:27-36.

Sire´n, H., M. Jussila, H. Liu, S. Peltoniemi, K. Sivonene and M. Riekkol. 1999. Separation, purity testing and identification of cyanobacterial hepatotoxins with capillary electrophoresis and electrospray mass spectrometry. Journal of Chromatography A 839:203-215.

Smith, J. L. and J. F. Haney. 2006. Foodweb transfer, accumulation, and depuration of microcystins, a cyanobacterial toxin, in pumpkinseed sunfish (*Lepomis gibbosus*). Toxicon 48:580-589.

Soares, R. M., V. F. Magalhães and S. M.F.O. Azevedo, 2004. Accumulation and depuration of microcystins (cyanobacteria hepatotoxins) in *Tilapia rendalli* (Cichlidae) under laboratory conditions. Aquatic Toxicology 70:1-10.

Tillmanns, A. R., F. R. Pick and R. Aranda-Rodriguez. 2007. Sampling and analysis of microcystins: Implications for the development of standardized methods. Environ Toxicol, 22:132-143.

Yoshizawa, S., R. Matsushima, M. F. Watanabe, K. I. Harada, A. Ichihara, W. W. Carmichael and H. Fujiki. 1990. Inhibition of protein phosphatases by microcystins and nodularin associated with hepatoxicity. Journal of Cancer Research and Clinical Oncology 116:609-614.

Zakaria, A. M. and A. A. Hussein. 2006. Depuration of microcystins in tilapia fish exposed to natural populations of toxic cyanobacteria: A laboratory study. Ecotoxicology and Environmental Safety 63:424-429.

Zimba, P. A., A. Camus and J. A. Burkholder. 2006. Co-occurrence of white shrimp, *Litopenaeus vannamei*, mortalities and microcystin toxin in a southeastern USA shrimp facility. Aquaculture 261:1048-1055

Zurawell, R. W., H. Chen, J. M. Burke and E. E. Prepas. 2004. Hepatotoxic cyanobacteria: A review of the biological importance of microcystins in freshwater environments. Journal of Toxicology and Environmental Health Part B 8:1-37.

Zurawell, R, W., C. F. B. Holmes and E. E. Prepas, 2006. Elimination of the the cyanobacterial hepatotoxin microcystins from the freshwater pulmonate snail *Lymnaea stagnalis* Jugularis (SAY). Journal of Toxicology and Environmental Health Part A 69:303-318.

Tilapia Culture

(Continued from page 15)

aquaculture on world fish supplies. Nature 405:1017-1024.

Neori, A. 2010. "Green water" microalgae: The leading sector in world aquaculture. Journal of Applied Phycology DOI 10.1007/s10811-010-9531-9.

Nguyen, T. N. and D. A. Davis. 2009. Evaluation of alternative protein sources to replace fish meal in practical diets for juvenile tilapia, *Oreochromis* spp. Journal of the World Aquaculture Society 40:113-121.

Olvera-Novoa, M. A. , L. J. Domínguez-Cen and L. Olivera-Castillo. 1998. Effect of the use of the microalga *Spirulina máxima* as a fish meal replacement in diets for tilapia, *Oreachromis massambicus* (Peters), fry. Aquaculture Research 29:709-715.

Stewart, J. and R. C. Bhujel. 2007. Aquaculture and environmental sustainability in Thailand: Food or financial security? Aquaculture Asia 7(2):12-16.

Watanabe, W. O., T. M. Losordo, K. Fitzsimmons and F. Hanley. 2002. Tilapia production systems in the Americas: Technological advances, trends, and challenges. Reviews in Fisheries Science 10:465-498.