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Production of Genetically Improved Organic Nile Tilapia

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ABSTRACT

Demand for organic products for human consumption has been on the increase due to the belief that organic products are safer and healthier to the consumer and the environment. In developing countries, Nile tilapia (*Oreochromis niloticus*) is usually grown in low-input organically fed ponds with little or no high protein supplementary feeding, an environment suitable for production of organic fish. However, Nile tilapia from such production systems do not attain large sizes which leads to low pond yields. This paper presents results of an attempt to improve the performance of organically farmed tilapia through selection for growth in organically fertilised earthen ponds. The selection environment consisted of earthen ponds fertilized daily with 50 kg dry matter (dm)/ha chicken manure. Body weight increased with selection and substantial response was recorded. Gut length increased with selection for body weight. Moreover, gut length and body weight were genetically highly correlated indicating that tilapia selected for growth on a herbivorous diet may develop longer guts as a mechanism for increasing capacity and efficiency for nutrient absorption. Taken together, these results demonstrate the feasibility of selection for growth of organic Nile tilapia. Meanwhile, organic certifications for Nile tilapia should be instituted for better prices and increased profits of organic fish.

Keywords: body weight, gut length, low input, *Oreochromis niloticus*, pond, selection

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INTRODUCTION

Demand for organic products for human consumption has been on the increase due to the belief that organic products are safer and healthier to the consumer and the environment. Organic foods are grown on farms that adhere to certain government food safety and environmental standards such as avoiding the use of chemicals and synthetic fertilizers. The global market for organic food has been estimated to grow at about 18% per year (ITC 2002). Organic aquaculture is a relatively new concept which started with production of cold-water salmonids in Europe and Northern USA followed by warm-water organic aquaculture. The first certified organic warm-water fish farm in the world, Geva Fish Farm, was started in 2000 with blue tilapia (*Oreochromis aureus*) as the main species (Milstein and Lev 2004).

According to NOSB (2007), organic farming is an ecological production management system that promotes and enhances biodiversity, emphasizes the use of management practices that prefer the use of off-farm inputs, taking into account that regional conditions require locally adapted cultural, biological and mechanical systems as opposed to using synthetic materials to fulfill specific functions within the system. This definition also applies to organic aquaculture to a large extent. The basis for organic aquaculture production is the maintenance of the aquatic environment and surrounding aquatic and terrestrial ecosystem, achieved by encouraging the use of by-products and waste materials as a feed source, enhancing biological cycles in production, prohibiting synthetic fertilizers, avoiding chemotherapeutic agents, reducing environmental impact of effluents and wastes, and promoting polyculture when applicable (Milstein and Lev 2004).

CERTIFICATION OF ORGANIC FISH

Although it is broadly agreed that the organic label is not a necessity for primarily herbivorous fish like tilapia, carp and catfish, consumers have been confused on the meaning of organic fish. In developing countries where aquaculture production has mostly shunned the use of antibiotics or chemicals, no certified organic farms exist. This may be attributed to a lack of awareness about rules and regulations of organic production among farmers who are practicing or-

Received: 1 September, 2008. Accepted: 14 November, 2008.

Invited Mini-Review

ganic farming. In sub-Saharan Africa for example, fish farming is mainly extensive or semi-intensive which meets the most important criteria for organic fish production. Although it could be expected that fish and fish products coming from such farming systems would be sold with organic labeling to improve incomes of small scale farmers, labelling has not yet taken root in sub-Saharan Africa.

Lack of universally accepted regulations and specific standards has led to farmers not being able to access the benefits of better prices that are expected from organic aquaculture. In many countries, organic fish are produced using national or private standards for organic fish production. These standards are usually informed by environmental or consumer concerns. Organic aquaculture is seen by some as a means to mitigating the problems associated with highly intensive aquaculture. Such problems are associated with the use of fish meal and fish oil from wild fish for feeds, chemical and antibiotic usage and waste disposal, prevention of fish escapes which would contaminate wild stocks and disrupt biodiversity resulting to negative impact on the ecosystem through competition for food, hybridization, disease tranfer and habitat degradation.

Organic aquaculture should have its own specific standards different from those used for land raised livestock animals. A recent organic fish consumer survey report indicates that consumers have strong expectations of the organic fish they buy. Among the surveyed individuals, 91% indicated that organic fish should be produced without environmental pollution, and should be free-of or low-in contaminants like mercury and polychlorinated biphenyls (Rangan 2007). Therefore, the environment in which the fish grow and the feed they eat should be monitored from time to time to ensure fish are not contaminated.

Lack of specific standards for certification of organic fish will leave room for exploitation of consumers because farmers, individual certifiers, consumers and other stakeholders will not be able to agree on the interpretation of what organic aquaculture really means. It is important to note that without such standards, it is easier for the consumer to pay for fish that are in fact not organically produced. For example, tilapia produced from organic manure alone (e.g. Kang'ombe *et al*. 2006; Charo-Karisa *et al*. 2006b) or organic manure and bran (Mataka and Kang'ombe 2007) may be erroneously placed in the same category with tilapia receiving both organic and inorganic fertilizers with brans and fish meal (e.g. Eknath *et al*. 2007). The basis for organic aquaculture production is the maintenance of the aquatic environment and surrounding aquatic system (Milstein *et al*. 2008). Such a status can be achieved by the use of byproducts and organic waste materials as feed sources, enhancement of biological cycles in production, promotion of polyculture and mixed sex production, prohibition of genetically modified organisms (GMOs) and avoidance of chemicals and hormones and thus reducing the environmental impacts of effluents and wastes. Furthermore, the fish have to be reared under low densities with only certified organic feeds and natural fertilizers avoiding high intensity culture systems. Although the definition of low density is not yet defined, it should allow the fish to grow in conditions that are as much as possible similar to the natural (Milstein *et al*. 2008).

PRODUCTION OF ORGANIC TILAPIA

Nile tilapia is herbivorous by nature, consuming mainly phytoplankton (Moriarty 1973; Moriarty and Moriarty 1973), but can as well consume a variety of other natural food organisms found in ponds (Bowen 1982). Organic fertilizers may be applied to fishponds to stimulate natural food production because organic fertilizers enhance autotrophic and heterotrophic food webs. The use of manures and organic wastes in fish farming was developed long ago by Chinese fish farmers (Lin 1964; Tang 1970; Bardach *et al*. 1972). Due to the high cost of supplementary feeds, poor farmers either grow Nile tilapia with organic fertilization alone or with a variety of locally available farm resources and household wastes as supplementary feeds. As a result, a common characteristic of such systems is slow growth and poor pond yields.

Growth is one of the most important parameters in successful fish production ventures. Therefore, the breeding objective of most fish selective breeding programs is enhanced growth rate which leads to more efficient fish production (Gjedrem 1997). A number of selective breeding programs have been initiated to improve the growth of *O. niloticus* in ponds receiving high protein supplementary feed (Hulata *et al*. 1986; Eknath *et al*. 1993; Bentsen *et al*. 1998). Apart from taking up to 60% of fish production costs (Green 1992) due to high reliance on fish meal and oils, supplementary feeds are not considered environmentally friendly because they lead to further depletion of natural stocks (Tacon 2004; Marra 2005). A Nile tilapia selection experiment was carried out in ponds receiving chicken manure as the only external nutrient source with the objective of producing fast growing organically produced Nile tilapia (Charo-Karisa 2006). This study is used as a reference point in this paper.

PRODUCTION ENVIRONMENT

Farming of organic fish requires consideration of environmental criteria for it to qualify as organic farming. This is especially because consumers' concerns are not restricted only to the finished product as marketed but also the various inputs used during the production process (Aarset and Young 2004). In the case of Nile tilapia, it has been shown that the fish can thrive well through out its life stages in organicaly fertilized ponds at low densities. The production of Nile tilapia seed can be carried out in hapas suspended in fertilized ponds or directly in the ponds (Charo-Karisa *et al*. 2006a, 2006b). To boost natural pond productivity, ponds with hapas containing fry are fertilized daily with chicken manure at the rate of 50 kg dry matter ha^{-1} day^{-1}. This sub-optimal fertilization level allowed fry to grow to 2-5 g from 31 days at a stocking density of 15 fry m^{-2} (Charo-Karisa 2006). In the same study, it was shown that when stocked at low stocking densities (1 fish m^{-2}) tilapia in grow-out ponds receiving kg ha^{-1} day^{-1} dry chicken manure from layer and broiler farms can give yields of as much as 1250 kg ha^{-1} $year^{-1}$. This fertilization rate corresponds to 0.3 kg nitrogen ha^{-1} day^{-1} which is enough to support yields of 4.3 kg fish BW ha^{-1} day^{-1} (calculated from Knud-Hansen *et al*. 1991). At higher fertilization rates of between 500-1200 kg ha^{-1} $week^{-1}$, Kang'ombe *et al*. (2006) recorded similar results for tilapia in chicken manure (1255 kg ha^{-1} $year^{-1}$) but lower for pig manure (608 kg $ha^{-1}year^{-1}$) and cattle manure (583 kg ha^{-1} $year^{-1}$). At higher densities of 2 fish m^{-2} or higher, rates of fertilization may be increased to 100 kg dry matter ha^{-1} day^{-1} or fish may be given supplementary feed made from locally available organic materials. Green *et al*. (2002) working in organically fertilised ponds with or without supplementary feeding found Nile tilapia yields of between 1274 and 2929 kg ha^{-1} indicating substantial yield improvement with fertilization and supplemental feeding. Feed sour-

Table 1 Proximate composition of protein sources used for formulation of fish feeds (expressed as per cent dry matter).

Feed stuff	Dry matter	Crude protein	Crude fat	Ash
Fish Meal	92.1	65.2	15.1	11.5
Blood meal	90.9	71.9	1.7	6.4
Bean meal	99.5	23.1	7.1	3.5
Maize meal	91.4	6.2	3.1	1.4
Groundnut oil cake	89.4	47.6	30.9	2.7
Soybean oil cake	94.8	30.0	13.2	3.7
Sunflower oil cake	91.8	26.9	6.9	5.0
Sesame seed meal	97.2	24.4	5.7	11.1
Mustrard oil cake	86.0	35.9	7.0	8.4

Modified from **Nyina-wamwiza *et al*.** (2007) and **Mukhopadhyay and Ray** (1999).

ces vary according to local crops and factories in each region. These include fish meal, blood meal, wheat, maize and rice brans, cotton seed cake, sunflower, soybean, groundnut and mustard oil-cakes as well as leaves from local herbs. The proximate analysis of some of these ingredients (**Table 1**) indicate that they are useful protein sources. It should be noted that natural food production under conditions of high fish density in the presence of large amounts of added organic matter, is not a stable process but rather a delicate balance of various organisms becoming dominant (Schroeder 1978, 1980). Working with buffalo manure, Shevgoor *et al.* (1994) found higher water quality deterioration at higher manure loading rates of more than 100 kg dry matter ha^{-1} day^{-1}.

Table 2 Selection differentials (g) for organic Nile tilapia. Estimated by comparing estimated breeding values (EBVs) of selected brooders and of all fish in each generation before selection, and the observed (Obs.) and expected (Exp.) means of body weight at harvest (BW).

Generation	Obs. BW	Differential	Exp. BW
G_0	67.4	23.4	-
G_1	87.2	13.0	90.8
G_2	129.5	-	100.2

From: **Charo-Karisa H, Komen H, Rezk MA, Ponzoni RW, van Arendonk JAM, Bovenhuis H** (2006b) Heritability estimates and response to selection for growth of Nile tilapia (*Oreochromis niloticus*) in low-input earthen ponds. *Aquaculture* **261**, 479-486, with kind permission from Elsevier, ©2006.

FISH SURVIVAL IN ORGANICALLY FERTILISED PONDS

Widely varying survival rates (29-100%) have been recorded in Nile tilapia reared in fertilized ponds with or without supplementary feeds (e.g. Abdalla *et al.* 1996; Abdelghany and Ahmad 2002; Bolivar and Newkirk 2002), indicating that survival is an important trait to consider in pond experiments. Fertilized ponds are frequently affected by extended periods of low dissolved oxygen leading to hypoxia which may reduce growth (Chervinski 1982) and cause mortality (Coche 1982). Charo-Karisa *et al.* (2006a) found dissolved oxygen levels of as low as 0.6 mg/l in organically fertilised ponds. As suggested by Teichert-Coddington and Green (1993), it may be both the duration of hypoxic episodes and the level of dissolved oxygen rather than the level of dissolved oxygen alone that determine the effect of hypoxia on fish.

Natural food components in organic ponds

In a study of natural food components, Spataru *et al.* (1983) found that phytoplankton, zooplankton, detritus and, rarely, zoobenthos were found in the guts of tilapia. Kang'ombe *et al.* (2006), working with chicken, pig, cattle and no manure treatments, found significant differences in numbers among the classes of zooplankton such as copepods, cladocerans and rotifers. Furthermore, copepods, cladocerans (daphnia and moina) and rotifers (lecane and brachioni) densities differed significantly among the different treatments. Among the phytoplankton groups, Spataru *et al.* (1983) found Chlorophyta and Euglenophyta in most of the fish and in large numbers. Due to their small size the maximum weight of phytoplankton is usually much smaller than that of some zooplankton components, especially when Copepoda and Cladocera are involved. However the latter are present in much lower numbers. The largest bulk of natural food found in fish consists of detritus which can make up to 10 g per fish. To improve the supply of natural food, the amount of periphyton available to the fish in the rearing system may be increased since periphyton allows a more efficient absorption of energy than plankton derived from filter feeding, as evidenced by various studies (Dempster *et al.* 1993, 1995). This can be done through introduction of substrates such as bamboo sticks into the pond system.

SELECTION FOR GROWTH OF ORGANIC TILAPIA

Nile tilapia reared in fertilized ponds with no supplementary feeding have been found to have high heritability estimates for body weight and body measurements with low common environmental effects than those reared in recirculation systems. The reported h^2 estimates for body weight in organically fertilized ponds are between 0.2-0.6 (Eknath *et al.* 1995; Charo-Karisa *et al.* 2006b). Similar estimates have been reported in ponds receiving supplementary feeds (e.g. Velasco *et al.* 1995; Ponzoni *et al.* 2005). Velasco *et al.* (1995) found similarly high heritability estimates for body depth and body length. In contrast, Rutten *et al.* (2005) found lower estimates for body depth, body thickness and body length in recirculation systems. The high heritability and low common environmental effects recorded under the rearing conditions indicate sufficient additive genetic effects for selection in organically fertilized ponds. Substantially higher selection response for growth has been reported for fish reared under organically fed pond systems than in supplementary fed systems. The estimated selection response in organically fertilised non-fed ponds was 23.4 g (34.7%) between the first and second generation and 13.0 g (14.9%) between the second and third generations (**Table 2**, Charo-Karisa *et al.* 2006b). On the other hand, Eknath *et al.* (1998), Bolivar and Newkirk (2002) and Ponzoni *et al.* (2005) reported average genetic gains of between 8.4–17% per generation in ponds, cages and tanks receiving pelleted feeds.

A substantial amount of additive genetic variation and low common environmental effects exists for survival in organically fertilised fish ponds. Charo-Karisa *et al.* (2006b) found heritability (h^2) estimate of between 0.03 and 0.14 for survival of Nile tilapia in ponds receiving organic manure. These estimates are comparable with estimates for Nile tilapia and other species of fish farmed in high input conditions. For example, Standal and Gjerde (1987) and Rye *et al.* (1990) reported heritability estimates (0.04 to 0.21) for Atlantic salmon and Rainbow trout from the sire component and higher heritability (0.25 and 0.87) from the dam component of variance. Gjerde *et al.* (2004) found zero heritability and higher common environmental effects (0.12) for survival in Atlantic cod, suggesting non-additive genetic common environmental effects. In Nile tilapia reared in ponds receiving supplementary feeds, Eknath *et al.* (1998) reported lower heritability (0.08) than reported for organically fed ponds (Charo-Karisa *et al.* 2006b). Taken together, the h^2 estimates indicate prospects for improvement of survival in fertilized ponds by selection. Studies giving reliable estimates of correlations between survival and initial weight or between survival and BW have not yet been done.

Compared to recirculation systems, the Nile tilapia harvested in fertilized ponds are on average smaller and are usually not filleted. The fish farmer is therefore paid either for whole or gutted body weight; gutted weight being a direct measure of how much meat the consumer can get. Kronert *et al.* (1989) and Charo-Karisa *et al.* (2007) reported high phenotypic and genetic correlations between body weight and gonad weight, body weight, GSI, and maturity in *O. niloticus*. Similarly, Eknath *et al.* (1995) found heritability for maturity at spawning of 0.15. The low genetic correlation between maturity and body weight found in organically fertilised ponds is consistent with studies in other fish species (Gjerde 1986; Gjerde *et al.* 1994). Although excessive reproduction in culture ponds reduces the growth of fish, low fecundity of tilapia can hinder the production of adequate numbers of fingerlings for grow-out (Coward and Bromage 2000). Given the considerable heritability, the reproductive capacity of females and maturity at an earlier age can be improved by selection when necessary. Longalong *et al.* (1999) pointed out that selection for lower frequency of early maturing females in Nile tilapia may result in poorer growth and that selection for improved growth may increase the frequency of early maturing females. The low genetic correlation between maturity and body weight at harvest in organic ponds indicate that it is possible to simultaneously select for late maturity and fast growth. The fecundity and the number of eggs/kg body weight (10912 to 12138) in organic tilapia were consistent with earlier studies (Smitherman *et al*. 1988; Duponchelle *et al*. 1998) indicating that selection in low-input ponds did not reduce fecundity. Although no difficulties were reported in reproducing the selected individuals, it should be emphasized that because of high plasticity of reproductive traits in Nile tilapia (Pullin 1982; Kronert *et al*. 1989; Duponchelle *et al*. 1998; Duponchelle and Legendre 2001) routine monitoring of reproductive parameters should be done in tilapia breeding programs.

Herbivorous fishes are known to have longer intestines than carnivorous or omnivorous fishes because they live on food requiring greater digestive processing (Nagase 1964; Smith 1989). Therefore, it is expected that selection for growth would lead to tilapia with longer relative intestine lengths. Charo-Karisa *et al*. (2007) found that larger fish tended to have higher gut length to size ratios. In contrast, Abdel-Tawwab and El-Marakby (2004) found no differences in gut lengths of Nile tilapia between 25-125 g body weights.

It has been suggested that fish size may be genetically correlated with the efficiency for absorption of nutrients (Gjedrem and Thodesen (2005), and that growth rates of animals are fundamentally dependent upon the systems where digestive and absorptive processes occur (Zimmerman *et al*. 2005). Charo-Karisa *et al*. (2007) found substantial additive genetic variance for gut length and that gut length increased with selection for body weight. Gut length and body weight were also highly genetically correlated. According to Ferraris and Ahearn (1984), guts of herbivorous fish are long and appear structurally uniform from stomach to rectum. However, Sklan *et al*. (2004) found that tilapia fed fish meal diets did not have uniform structure and that the sites of nutrient absorption were altered. The intestine of hybrid tilapia *O. niloticus* X *O. aureus* comprises a series of nested loops, which are lined with villi on the luminal face, considerably enlarging the absorptive area (Sklan *et al*. 2004). This suggests that having longer guts may be a mechanism for increasing absorptive capacity through increase of surface area and hence more efficient nutrient absorption especially for tilapia fed on a diet of periphyton and phytoplankton.

The high correlated responses in body measurements and gut length indicate that fish selected for growth with natural organic food might become very different from fish selected for growth on a diet of high protein pellets. Because of the diversity of Nile tilapia fish farming systems it will be crucial to know how fish selected in high protein or low input organic environments will perform in these different farming systems.

CONCLUSIONS

Although organic fish are produced in conditions requiring special environmental considerations making them safer and healthier to the consumer, such environments lead to lower yields compared to highly intensive systems. Considering the consistent increase in body weight across generations and the high heritability estimates, we can conclude that there are good prospects for selection for growth of organic Nile tilapia. It is appropriate that Nile tilapia reared in developing countries be given it s rightful status as an organic fish. This should be done in recognition of the conditions and food type given to the Nile tilapia in ponds.

Lack of specific standards for certification of organic fish does not allow for profiteering from the poor small scale fish farmers. It is necessary that developing country government move with speed to institute standards for organic farming of Nile tilapia and other species to ensure that farmers receive organic certifications and make better profits.

ACKNOWLEDGEMENTS

This paper draws from a study funded by INREF-Pond, Wageningen University and the World Fish Center. We acknowledge the staff of The WorldFish Centre, Abbassa, Egypt for providing the necessary help and facilities during the experiments. We would like to thank Riccardo Russo for assistance with literature.

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