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REVIEW ARTICLE

Complete Replacement of Fish Meal in the Diet of Nile Tilapia (*Oreochromis niloticus* L.) Grow-out with Alternative Protein Sources. A review

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Abstract

Tilapia culture is widely practiced in tropical and subtropical regions with an annual growth rate of 12% thanks to their high growth rate, disease resistance, and low trophic feeding levels. The increase of aquaculture production has doubled the demand for fishmeal, which has been the most preferred protein ingredient for decades. The provisions of fishmeal are not adequate to sustain the current growth rate of aquaculture industry. Studies have demonstrated possibilities of substituting fishmeal with alternative sources without affecting fish performance. This paper argues the possibility of complete replacement of fishmeal with the alternative dietary protein sources such as terrestrial animal by-products, oilseed plants, single cell proteins and plant protein rich derivatives. The nutritive values of these sources are also discussed. Blood meal and meat and bone meal are perfect fishmeal replacers in tilapia feeds thanks to their high protein and essential amino acid profiles. Soybean meal and cottonseed meal are the best plant protein sources in terms of protein and amino acid contents. Plant proteins could be supplemented with cheap minerals instead of expensive amino acids to produce superior results. The use of aquatic plants and single cell proteins in tilapia feeds should be carefully evaluated because of the varying, and sometimes conflicting results. Both biological and economic evaluations of fishmeal replacers should be studied. More long-term evaluations should be conducted in practical culture systems rather than laboratories. In conclusion, tilapia producers should consider the unconventional dietary sources because complete replacement of fishmeal in tilapia diets is scientifically possible.

Introduction

The culture trend of tilapia

The exponential growth of the aquaculture sector during the past two decades is a result of the progressive intensification of production systems and use of quality feeds, which meet the nutritional requirements of cultured fish (FAO, 2006). Stimulated by higher global demand for fish, world fisheries and aquaculture production reached 157million tons in 2012 and is projected to reach about 172 million tons in 2021, with most of the growth coming from aquaculture (FAO, 2013). This increase of aquaculture production must be supported by a corresponding increase in the production of designed diets for the cultured aquatic animals (Rahman et al., 2013).

Tilapia is the common name given to three genera of fish in the family Cichlidae namely *Oreochromis*, *Sarotherodon* and Tilapia (Santiago and Laron, 2002). The genus *Oreochromis* includes Nile tilapia (*Oreochromis niloticus*), Mozambique tilapia, (*Oreochromis mossambicus*) and blue tilapia (*Oreochromis aureus*). Regionally, tilapia is the most preferred cultured fish in East Africa but are the second most important cultured fish in the world after carps (Dan and Little, 2000; El-Sayed, 2006). The culture of tilapia started as early as 2000 – 2500 BC (Chimits, 1957). Since then the growth trend of cultured O. niloticus has increased consistently (Figure 1). Today, more than 22 tilapia species are being cultured in many tropical and subtropical regions with an expanded penetration of a variety of tilapia products in markets (Avnimelech, 1999; Fitzsimmons, 2000; El-sayed, 2002). Indeed, there are not any reports of cultural or religious restrictions on tilapia consumption all over the world (Fitzsimmons, 2000). Tilapia growth is attributed to high resistance to diseases, ability to survive at low oxygen tensions and ability to feed on wide range of foods. Nile tilapias are relatively inexpensive fish to feed unlike other carnivorous finfish thanks to their low trophic feeding level. In addition, tilapia are similar to channel catfish (*Ictalutus punctatus*), in that they can tolerate higher dietary fibre and carbohydrate concentrations than most other cultured fish (El-Sayed and Teshima, 1992). However, to ensure high yield and fast growth at least cost, a well balanced prepared feed is essential to successful tilapia culture. Even though slight variations exist among tilapia species, nutrient requirements are primarily affected by the size of the fish (El-Sayed and Teshima, 1992).

Demand and cost of fish feed

The global fishmeal price has increased more than two fold in recent years (FAO, 2013). In Asia alone, the production of fish feed increased from 40% in 2000 to 60% in 2008 while the fishmeal consumption for tilapia increased from 0.8 million tons to 1.7 million tons during same period (Tacon and Metian, 2008). Despite the increase in fish feed prices, the farm gate prices of aquaculture products have remained static, literally impinging on the economic viability of thousands of small-scale producers that form the backbone of the aquaculture sector (Rana et al., 2009). Indeed, the increasing price of feed ingredients (fishmeal, fish oil and cereal), energy and transportation costs have complicated the availability of aqua-feeds to many fish farmers worldwide. This global phenomenon could influence small-scale producers to change businesses and/or result to poverty, vulnerability and loss of livelihood especially in developing countries (Rola and Hasan, 2007). Fish feeds account for the highest operational costs in aquaculture with protein being the most expensive diet (Munguti et al., 2012). Fish meal (FM) is the most expensive protein source in aquaculture feeds (Tacon, 1993). Fish require high proportion of protein in their diet because they metabolize protein as energy source (Aladetohun and Sogbesan, 2013). The development of commercial aqua-feeds has been traditionally based on FM as the main protein source thanks to its high protein content and balanced essential amino acid (EAA) profile (Tacon, 1993; Watanabe, 2002; El-sayed and Gaber, 2004). Compared to other animals, the percentage usage of fishmeal in aquaculture has increased significantly (Figure 2) with extruded diets being more expensive than pelleted ones (Figure 3). Despite the growth of aquaculture industry, the global production trend of both fishmeal and fish oil has remained fairly static over time and is currently declining (Figure 4). In addition to the introduction of precautionary quotas, human consumption and competition from other animal feed manufacturers has worsened the FM and oil production (Tacon and Metian, 2008).

The fishmeal dilema

Currently, up to 36% of the world's total fisheries catch each year is ground up into fishmeal and oil to feed farmed fish, chicken and pigs (Jacquet et al., 2010). The steady increase in FM consumption and declining fish catches in wild waters can only predict a gloomy future for aquaculture industry unless there is a paradigm shift to use of non-fish materials for fish feed production. Aquaculture is likely to grow over the next 20 years and the rising demand for FM and fish oil could place heavier fishing pressure on the already threatened stocks of wild fish (Aladetohun and Sogbesan, 2013). As the consumption rate of fish as human food increases, the use of fish materials for feed production also increases. This aggregate trend raise the perennial question: which came first, the supply push or the demand pull? While both may be at work in different proportions in different places, two elements suggest that demand is the primary motor of these changes especially in developing nations. The shortage in global FM production coupled with increased demand and competition with human and livestock has caused increase in FM prices, thus affecting aquaculture industry (Watanabe, 1988). Indeed, the fast declining status of world fisheries and corresponding increase in aquaculture production exposes great debate on whether it is sustainable to feed fish on FM. This is the great dilemma that all aquaculturists and environmental ecologists must urgently address.

Tilapia fishmeal alternatives

The development of sustainable aquaculture depends on the establishment of alternative feedstuffs to FM (Olukayode and Emmanuel, 2012). Since the success of fish farming depends on the provision of suitable and economical fish feeds, we need to use locally available feedstuff especially agricultural by-products to reduce the price of complete feeds (Fagbenro, 1999). Due to the rising cost of commercial tilapia feeds, farmers are looking for alternative feeds in order to make aquaculture a viable and attractive venture (El-sayed, 1998; Fasakin et al., 1999; Hossain et al., 2002). What therefore are the possible solutions to the FM dilemma in tilapia feed? Research has not only shown several alternative protein sources for FM in tilapia feeds but has also identified the essential nutrients in FM and a way of incorporating them into the alternatives (Tacon et al., 1983). During the last 3 decades, studies have revealed that warm water fishes require both n-6 and n-3 fatty acids while cold-water fishes require only n-3 fatty acids for optimum growth and development (Takeuchi, 2008). Whereas optimal use of the fish resources (trash fish) and exploiting underutilized ocean resources such as Antarctic krill have been proposed, the most significant option could be the use of terrestrial animal meals and plant protein-rich derivatives (Tacon and Metian, 2008). Experts have further proposed other protein source such as single cell proteins, earthworm, insects, snails, maggots, and frogs as potential fish meal replacers (Tacon et al., 1983). However, their sustainable production and effective use in aquaculture need further economic scrutiny.

Even though El-sayed and Tacon (1997) explained how animal products, plant protein derivatives and single cell proteins can be possible FM replacers in tilapia feeds, it is important to know whether these alternatives can completely replace FM without compromising production. This subject has been discussed by aquaculture nutritionists, fish biologists and fish farmers albeit with limited consensus. According to Jackson's (2009) Fish in-Fish out (FIFO) ratio concept, which technically considers how much forage (catch) fish needed to produce 1kg of cultured fed fish species, it would require only 0.3 kg of FM to produce 1kg of tilapia. This implies that complete FM replacement could be a scientific reality. Below we review the possibilities of complete FM replacers in Nile tilapia grow-out diets. The specific focus on their nutritive values, availability and economic feasibility has been also discussed.

Animal meals

The main terrestrial by-product meals, which have been tested as FM replacers for tilapia include poultry by-product meal (PBM), feather meal (FeM), blood meal (BM), and meat and bone meal (MBM). Despite their usually high crude protein content, they are usually deficient in one or more essential amino acids (EAA) whereby the limiting EAAs generally being lysine, methionine and isoleucine (Tacon and Jackson 1985). However, these imbalances can be overcome by mixing complementary protein by-product meals so as to obtain the desired EAA profile (Davies et al., 1989). The animal proteins are free of anti-nutritional factors, are palatable, cheaper and readily available than fishmeal thus making them perfect FM replacers for tilapia especially in developing nations (El-Sayed, 1999).

Blood Meal (BM)

BM is an animal waste product readily available in abattoirs and can be used as an alternative high quality and cheap protein source in fish feed formulation. BM products can effectively replace marine proteins in grow-out rations for shrimps (*Pannaeus vannamei*) when supplemented with methionine (Dominy and Ako, 1988). Davies et al. (1989) fed Mozambique tilapia (*O. mossambicus*) fry for seven weeks using BM and found that up to 75% of the FM in the diets could be effectively replaced. However, Otubisin (1987) conducted a 120 day experiment with caged O. niloticus fingerlings using BM and concluded that dietary BM inclusion levels above 50% of the FM protein significantly reduced fish performance. El-Sayed (1998) also found that BM used as a sole protein source in practical diets for Nile tilapia reared in outdoor concrete tanks for 150 days resulted to reduction in fish performance. It is important to realise that management factors such as feeding frequency, rearing condition and other environmental factors are equally important. Agbebi et al. (2009) reported that fish meal can be replaced completely by BM with no adverse effect on growth, survival and feed conversion of Nile tilapia and *Clarias gariepinus* juveniles. Hussain et al. (2011) found that nutrient digestibility values of FM and BM for dry matter and crude fat are significantly similar for most tilapia fish species hence BM can be a perfect FM replacer in the diets. The studies of Aladetohun and Sogbesan (2013) showed that inclusion of BM in the experimental diet improved the growth performance of Nile tilapia (Table 1). The summary of growth performance parameters of the experimental feeding using different BM inclusion levels are shown in Table 1 and Figure 5. Despite the difficulty in quantifying the amount of BM produced in Kenya or larger East Africa, BM is cheap, readily available and allowed by most governments of developing countries. The authors suggest that this could be the forgotten asset that can be used to formulate least cost fish feeds to lower production expenses and maximise profit in aquaculture. However, more studies are recommended for the BM feed formulation procedure to address issues of possible disease transfer from livestock to fish and human. Indeed, this is a lucrative opportunity for research collaborations in Kenyan aquaculture industry.

Meat and Bone Meal (MBM)

MBM is a by-product of the animal rendering industry, which is less expensive than FM but more expensive than BM. According to Kellems et al. (1998), MBM is an excellent source of supplemental protein, calcium, vitamin B-12 and phosphorus with a well-balanced amino acid profile and high protein digestibility to most fish (Table 2). However, MBM is somewhat lower in some amino acids content and higher in minerals as compared with FM and BM (Yang et al., 2004). Nevertheless, the frequently reported variations on composition of these protean meals could be largely due to variability in raw material composition and quality.

MBM has been used effectively in feeds for a variety of fish species, such as rainbow trout (Bureau et al., 2000), red drum (Kureshy et al., 2000), Australian snapper (Quartararo et al., 1998) and Nile tilapia (Fasakin et al., 2005). Even though the ash content may limit the use of MBM in fish feeds (Fasakin et al., 2005), research has demonstrated that MBM can partially or totally replace FM when used at levels of 5% to 15% in fish feeds (Kellems et al., 1998). Tacon et al. (1983) found that MBM supplemented with Methionine successfully replaced up to 50% FM protein within diets containing 45 % crude protein fed to *O. niloticus* fry over a six-week period. El Sayed and Tacon (1997) found that MBM could effectively replace up to 75% of the FM in diets fed to *O. mossambicus* fry over a seven-week period. In fact, El Sayed and Tacon (1997) reported that diets containing MBM or high MBM/BM ratios were superior to FM even at a 100% substitution level. Even though MBM is reported to be about 10% lower in protein and energy digestibility than FM (Table 2), this has insignificant impact on tilapia growth (Hanley, 1987) hence MBM could be a perfect complete FM replacer (Yang et al., 2004). However, due to fear of diseases transfer, some countries have restricted the feeding of MBM and some only allow MBM derived from monogastric animals to be fed only to ruminant animals and vice versa (European Community, 2002). In addition, the sustainability of MBM as fish feed ingredient could be threatened by the stiff competition from human. The use of MBM may need to be limited due to water quality considerations (Hanley, 1987; Smith et al., 1995; Hardy, 1996).

Poultry By-product Meal (PBM)

PBM is made of ground, rendered, or clean parts of the carcass of slaughtered poultry. PBM has been tested at varying success so far in salmon (Yang et al., 2004), tilapia (El-Sayed, 1998), sea bream (Nengas et al., 1999), channel catfish (Sadiku and Jauncey, 1995a) and common carp (Hasan et al., 1993). PBM is similar to FM in composition except being slightly lower in some amino acids (Table 2) (Yang et al., 2004). FM and PBM are generally highly digestible in protein (88%) and energy (82%) (Table 3). These digestibility values suggest that PBM could be used in aqua-feeds to a level similar to FM (Yang et al., 2004). Referring to proximate analysis (Table 2), the protein, fat, calcium and phosphorus contents in PBM are comparable to those of FM, suggesting possibility FM replacement by PBM. El-Sayed (1998) found that red tilapia and Nile tilapia can efficiently utilize PBM as single dietary protein sources. Belal et al. (1995) fed *O. niloticus* fingerlings with diets containing 0 – 20% chicken offal silage (COS) made from chicken viscera, as a replacement of FM. They found that the growth and body composition of fish fed COS were similar to that of fish fed with FM based diet. Similarly, Gaber (1996) found that the growth of Nile tilapia fingerlings fed with PBM as a protein source replacing FM up to 40% level was better than that of those fed 100% FM. It is therefore possible that PBM could totally replace FM in Nile tilapia diets.

Indeed, this is an interesting observation that should attract the attention of aquaculture nutritionists. However, more studies should be focused on the sustainable exploitation of PBM especially in developing countries.

Feather Meal (FeM)

Feather meal is a by-product from poultry production. FeM contains a complex protein (keratin), which can be hydrolysied to improve bio-availability (Munguti et al., 2014). FeM is an economical protein ingredient mostly used in aqua-feeds (Poppi et al., 2011). FeM is rich in amino acids such as cystine, threonine and arginine, and has high level of pepsin digestible protein (Fowler, 1990). The amino acid profile of FeM is similar to those of FM and soybean meal (Fowler, 1990). FeM has been used to feed many fish species including shrimps (Fowler, 1990; Steffens, 1994; Bureau, 2000), salmon and African catfish (Fowler, 1990). However, the utilization of FeM in fish diets is limited due to a complex protein called keration (Steffens, 1994). The utilization of hydrolyzed FeM protein in tilapia feeds could be economically feasible. However, studies conducted to evaluate the use of hydrolysed FeM in fish diets recommend low substitution levels due to poor digestibility and sub-optimal levels of essential amino acids (Steffens, 1994; Mendoza et al., 2001). Due to this, studies show that combination of hydrolysed FeM and papaya leaf meal (PLM) may promote the feeding value of FeM and by extension promote its use in Nile tilapia feeds and that complete replacement of FM with hydrolysed FeM dietary levels and PLM cannot significantly affect growth of Nile tilapia reared in cages (Munguti et al., 2014). Arunlertaree and Moolthongnoi (2008) concluded that fermented FeM could be used at 25 % up to 50 % as the replacement of FM for 30 % CP Nile tilapia diet.

Plant protein-rich derivatives

Plant proteins are almost similar to FM in terms of the protein content and protein and amino acid digestibility (Hardy, 1996). However, their amino acid profile does not match the amino acid requirement of some fish species as FM does (see figure 6) (Hardy, 1996). For example Methionine is the limiting amino acid in soybean meal (SBM), while corn gluten meal is deficient in lysine (Gallagher, 1994). Wheat gluten meal is limited in lysine and arginine (Gallagher, 1994). So far, nutrition research has concentrated on the replacement of animal protein by plant proteins (Liti et al., 2006) but the palatability of many plant materials is hindered by presence of anti-nutritional factors and low bioavailability (Francis et al., 2001). Some plant proteins contain phosphorus phytate, which binds phosphorus, reduces palatability and interferes with the bioavailability of divalent trace elements (Gallagher, 1994). Nevertheless plant based feeds containing soybean meal protein, canola meal, extruded pea seed meal, wheat and corn meal supplemented with lysine and methionine has been used in the formulation feeds for catfish, tilapia and carps without affecting their growth performance (Tacon and Metian, 2008).

Soy Bean Meal (SBM)

So far, SBM is the best plant protein source in terms of protein content (Table 4) and EAA profile (Figure 6). Scientists have considered SBM as a partial or total FM alternative for tilapia, with varying results. SBM could replace between 67 and 100% of FM, depending on fish species, dietary protein level, source, processing methods and culture system used (El Sayed, 1999). With or without Methionine supplementation, SBM successfully replaced up to 75% of FM in test diets fed to Nile tilapia fry (Shiau et al., 1989) suggesting that supplementing SBM with the limiting EAA could be insignificant. Studies of Viola and Zohar (1984) also reported that supplementing tilapia diets with crystalline EAA did not improve Nile tilapia performance. This implies that minerals, rather than limiting EAA, may be the limiting factors in the efficient utilization of SBM for tilapia (El Sayed, 1999). Viola et al. (1988) found that the growth of tilapia hybrids (*O. niloticus x O. aureus*) fed 100% SBM diet supplemented with Lysine, Methionine, oil and di-calcium phosphate was similar to that of fish fed 100% FM diet. Also, the non-inclusion of the limiting EAA to SBM diet did not affect growth and SBM supplemented with 3% di-calcium phosphate and oil completely replaced FM without any adverse effects on tilapia growth (Viola et al., 1988). Davis and Stickney (1978) found that the inclusion of SBM at 15% dietary protein level impaired growth of blue tilapia, while at 36% protein; SBM could totally replace FM in the diets without significant growth retardation. The contradiction among researchers regarding the use of SBM as a protein source for fish may be related to the quality and processing of SBM, fish species, size and culture systems. Even though SBM contain some anti-nutritional factors (trypsin) (El Sayed, 1999), thermal processing can be used to make quality feeds out of SBM (Tacon, 1993). Wassef et al. (1988) found that the germination and defattening of SBM reduces the activity of protease inhibitors. Similarly, heating

SBM destroys the anti-nutritional factors and improves nutrient bio-availability (Tacon and Jackson, 1985). The authors recommend blending SBM with grain protein concentrates to adjust the amino acid profile to overcome limitations of individual plant proteins. Sadiku and Jauncey (1995a) recommended mixing SBM with animal protein sources to improve its quality for Nile tilapia.

The safety and use of genetically modified soybean meal (GM SBM) as fish feed protein source has been demonstrated (Suharman et al., 2009). Studies have shown that there are no differences in fish growth, survival, feed conversion, and fillet composition between the fish fed GM soybean and non GM SBM for Nile tilapia (Suharman et al., 2009). According to Watanabe (2002), defatted soybean meal is universally accepted, both qualitatively and quantitatively, has favourable amino acid profile compared with other plant protein sources. Soybean meal is consistently available, cost-effective, and reported to be palatable to most fish species (Watanabe, 2002). Based on these benefits, several aquaculture nutritionists should aim at totally replacement of FM with SBM as a protein source because many results have indicated that SBM is one of the most promising FM replacements (Watanabe, 2002).

Cotton Seed Meal (CSM)

CSM contains good protein contents and amino acid profile (Table 4) depending on processing methods (El sayed, 1999). However, CSM is limited in Cystein, Lysine and Methionine and has high content of gossypol, an anti-nutrient compound, which may limit the use of CSM in animal feeds (El Sayed, 1999). The use of CSM as protein sources for tilapia has registered mixed results. El-Sayed (1990) successfully used prepressed solvent extracted CSM as a single dietary protein source for Nile tilapia and they performed better than FM fed fish. However, El-Sayed (1990) found that O. niloticus and O. aureus fed on CSM-based diets grew at slower rates compared to fish fed FM-based diets, probably due to the gossypol and cyclopropionic acids contained in CSM. The studies of Viola and Zohar (1984) reported that about 50% CSM successfully replaced SBM in diets fed to tilapia hybrids reared in floating cages. El-Sayed (1987) found that Tilapia zillii grew best on diets containing 80% CSM protein. El-Sayed and Kawanna (2008) found that CSC (42% CP) used as the only feed input for Nile tilapia reared in earthen ponds, fertilized with cattle manure for 100 days, resulted in a sharp increase in fish weight. In addition to the use of CSC as a protein source in commercial pelleted feeds for tilapia, it can be used as a source of fertilizer in semi-intensive tilapia culture to increase natural food production within fish ponds (El Sayed, 1999). CSM is readily available and cheap plant protein source in most parts of the world.

Other oilseed plant by-products

There are many oilseed by-products such as groundnut, sunflower, rapeseeds, sesame seeds, macadamia and palm kernel, which can be utilized as alternative protein sources for tilapia. Despite their good protein contents and EAA profiles (Figure 6), not much literature is available on their use as complete FM replacers. Jackson et al. (1982) found that 25, 75, 75 and 50% of groundnut cake, sunflower meal, rapeseed meal and copra meal respectively could replace FM protein without significant effect on *O. mossambicus* growth. However, Davies et al. (1989) reported that only 15% rapeseed meal could effectively replace FM in *O. mossambicus* diets, while higher levels resulted in poor growth due to the high content of glucosinolate (anti-nutrient) in rapeseed. When Nile tilapia fingerlings were fed up to 60% palm kernel meal, the performance was similar to those fed 100% FM diet (Omoregie and Ogbemudia, 1993). Macadamia press cake was successfully used as a protein source for Nile tilapia by Fagbenro (1999) who found that the growth of tilapia fed 33.4% CP Macadamia cake in concrete tanks for 180 days was similar to those offered a commercial 35.5% CP FM diet. The low price of MC favours it as a promising alternative plant protein source for tilapia.

Aquatic plants

Several species of aquatic plants could be potential sources of FM replacers in aquaculture. However, studies conducted on the use of aquatic plants in tilapia feeds have produced varying, and sometimes, conflicting results. When fish feed made of *Azolla pinnata* was used as a FM replacer for Nile tilapia fingerlings and adults respectively, at 0 –100% substitution levels, fish fed with *Azolla pinnata* showed extremely poor performance even at the lowest inclusion level of 25% (El-Sayed et al., 2000). Similar results were reported for *T. rendalli* fed *Azola* microphylla (Micha et al. 1988). However, Naegel (1997) found that up to 30% of FM diet fed could be successfully replaced with dried *Azolla* meal for Nile tilapia. Moreover, Santiago et al. (1988a) reported that a diet containing up to 42% of Azola pinnata produced better growth rates of Nile tilapia fry than did the control FM diet. Fresh duckweed (family: Lemnaceae) is a good food source for tilapia, as it contains about 35 – 45% CP with good AA and mineral profiles (Mbagwu et al., 1990). Production of Nile tilapia using duckweed (Lemna and Wolffia) feed as a single nutritional input in earthen ponds was very successful in Bangladesh, netting up to 7.5 metric ton ha^{-1} $year^{-1}$ (Skillicorn et al., 1993). The EAA index value of 81 for raw Spirulina is scientific evidence that it is an adequately nutritious food source for larval tilapia (Takeuchi et al., 2002). It can be concluded that the availability of adequate supply of Spirulina during the early stages is important for the normal growth and development of larval tilapia (Takeuchi et al., 2002). Nevertheless, complete replacement of FM using aquatic plants needs further scientific investigations including in and outdoor trials.

Single Cell Proteins (SCP)

In the recent past, biosynthesis and utilization of SCP, which are a group of microorganisms including unicellular algae, fungi, bacteria, cyanobacteria and yeast by tilapia within culture systems has attracted the attention of aquaculture nutritionists (El-Sayed, 1999; Avnimelech, 2007). The concept of heterotrophic food web indicates that fish can be fed directly or indirectly on primary producers and also have a chance to feed on bacteria degrading residues present in the pond (Avnimelech, 2007). The main principle of SCP is to recycle nutrient by maintaining a high carbon / nitrogen (C: N) ratio in the water in order to stimulate heterotrophic bacterial growth that converts ammonia into microbial proteins, also known as biofloc technology (Avnimelech et al., 1989; Azim and Little, 2008). As a by-product, bacteria produce between 60-600 kg ha^{-1} day^{-1} of protein for fish (Avnimelech, 1999). Indeed authors agree that SCP produced using cheap carbon and nitrogen sources can partially or completely replace expensive commercial protein sources in *O. niloticus* feeds (Dempster et al., 1995).

SCP contains more than 38% protein, 3% lipid, 6% fibre, 12% ash and 19 K J g^{-1} energy, which is just sufficient for tilapia production (Azim and Little, 2008). Proximate analysis of biofloc sample collected from tilapia SCP fed system revealed promising nutrient contents (Figure 7) (Widanarni et al., 2012). The biofloc contains up to 10–25% lipid content, which is the optimum dietary lipid requirement for tilapia (Widanarni et al., 2012). Indeed these values are far much better than most commercial pellet feeds used in aquaculture farms today (Ogello et al., 2014). Fish fed with 20% CP of SCP based diet significantly performed better than those fed commercial 30% FM diet (Table 5). The active recirculation of proteins by microorganisms is credited for the increased protein utilization in fish reared in SCP fed systems (Ogello et al., 2014). This is definitely positive information to farm managers who may even aim at increasing further recycling of proteins. However, more studies are needed to ascertain the sustainability and the nature of bacteria contained in the SCP production systems. Several authors have performed studies on many other potential FM replacers for Nile tilapia production (see table 6).

Economic feasibility of FM alternatives

Evaluation of FM replacers in tilapia feeds has mainly taken biological and nutritional points of view with limited economic studies. Despite mixed results obtained from the FM replacers, cost benefit analyses indicated that they are economically better. For example, economic evaluation of cotton seed meal (El-Sayed, 1990), corn gluten feed (Wu et al., 1995) and animal by-product meal (El Sayed, 1998) as protein sources for Nile tilapia indicated that cost and profit indices of these protein sources were better than for FM-based diets. An analysis of the cost implication of replacing FM with BM revealed that 100% BM inclusion was significantly cheaper compared to 100% FM diet (Aladetohun and Sogbesan, 2013). It cost 0.62 USD to produce 64g of tilapia within 3 months using 100% BM while 0.79 USD was spent to produce 30g of tilapia using 100% FM diet over the same period (Aladetohun and Sogbesan, 2013). Economically, significant reduction of feed price have been noticed in SCP fed ponds compared to conventional pond (Table 5) hence lowering cost of production.

Conclusions and recommendations

So far, the data accrued shows that FM is technically replaceable by other protein sources. However, an optimal essential amino acid balance must be maintained. Also, improving nutrient availability and optimizing the digestible protein to energy balance of the alternative diets must be prioritized. Through this approach, the diets become effective in good health maintenance and disease resistance through enhancement of immune responses is improved. Aquaculture nutritionists should consider using unconventional dietary sources, which are cheap and readily available in the producing regions. Numerous studies have shown the potential of many alternative protein ingredients in tilapia diets with success. However, the authors uphold the suitability of BM and SBM due to high efficacy, low cost and availability especially in almost all developing countries. More long-term evaluations should be conducted in practical culture systems such as ponds, outdoor tanks and cages rather than laboratory based analyses. This will authenticate the practicability of FM replacers. The authors therefore conclude that it is possible to completely replace FM in tilapia diets. However, best aquaculture management practices must be involved.

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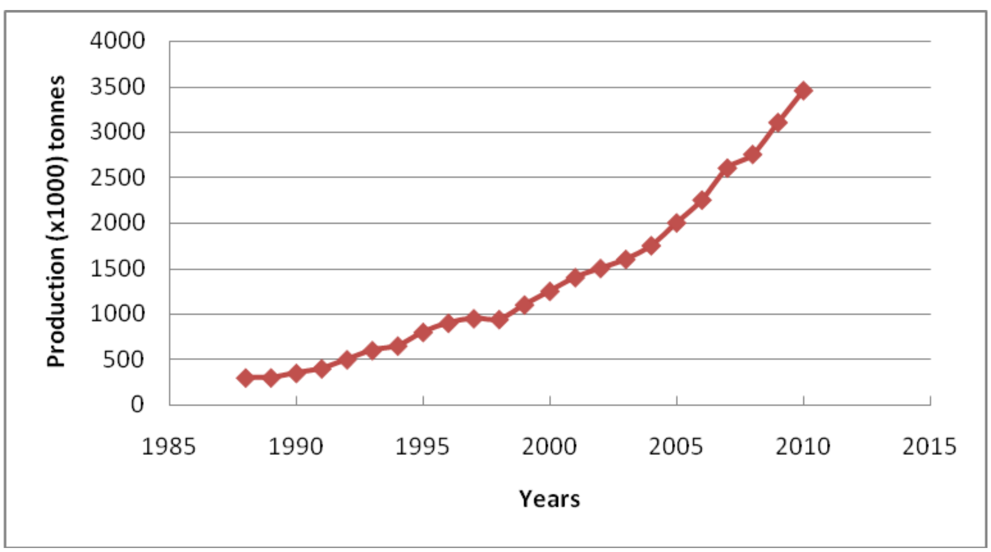

Figure 1: Current global aquaculture production trends for Nile tilapia (O. niloticus). Adapted from FAO (2006)

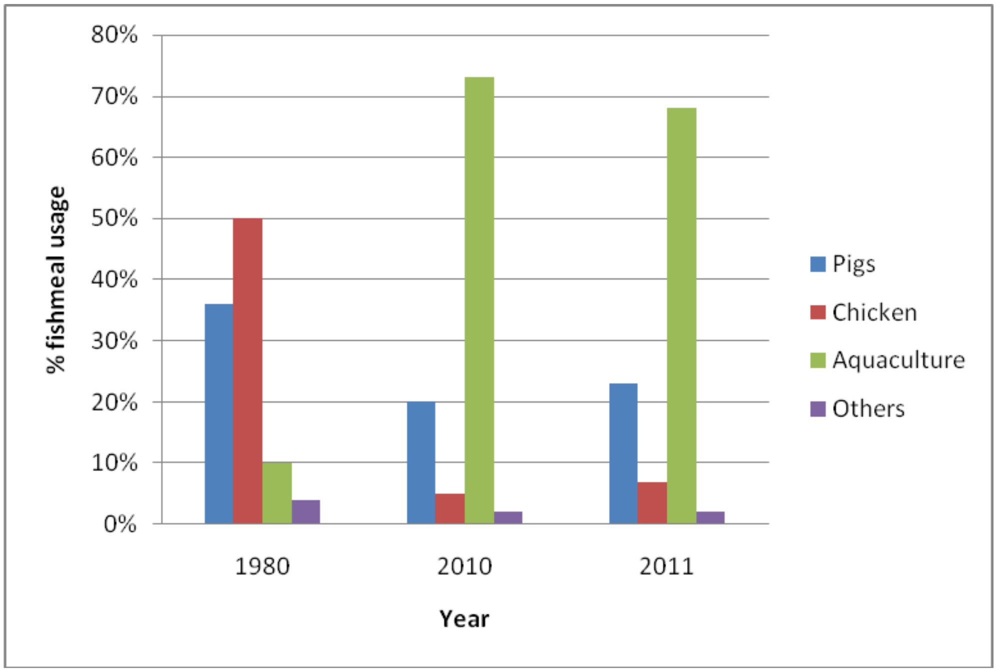

Figure 2: Percentage of fishmeal usage among diets for pigs, chicken, aquaculture and other animals between 1980 and 2011. (Adapted from FAO 2006)

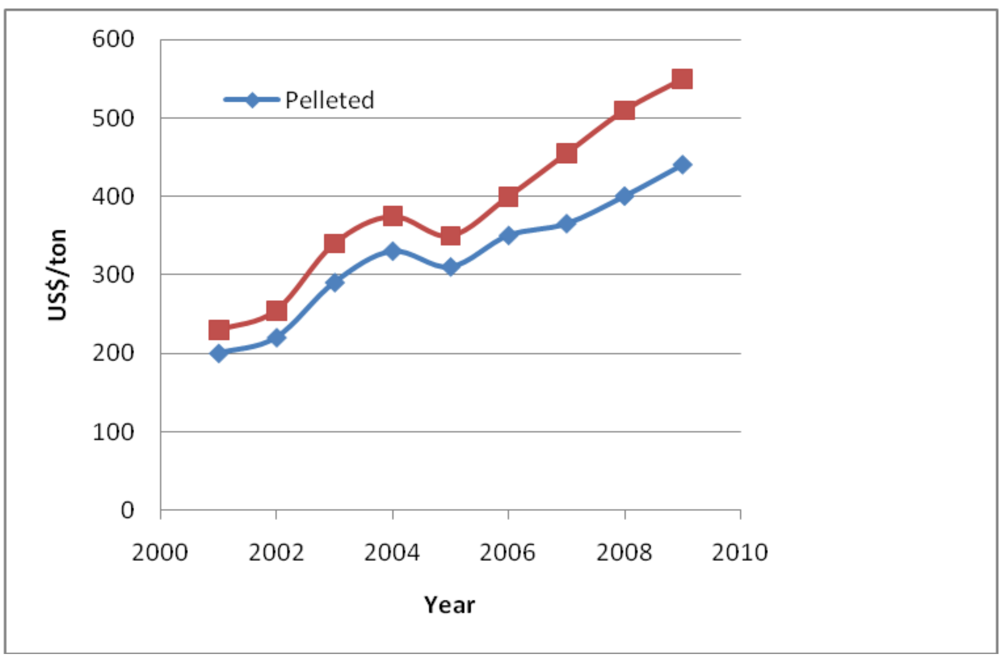

Figure 3: Price of extruded and pelleted tilapia feeds (25% CP) between 2001 and 2009. (Adapted from El-Sayed 2013)

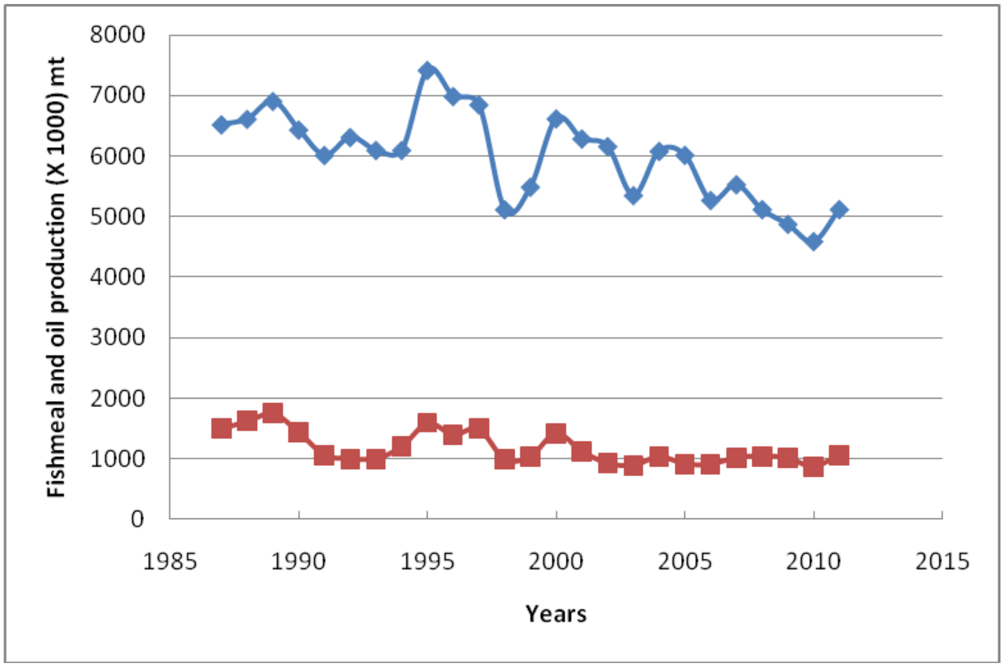

Figure 4: Global trend (stagnation and decline) of fish meal and fish oil production since 1986 to 2011 (Source: Adapted from FAO 2006)

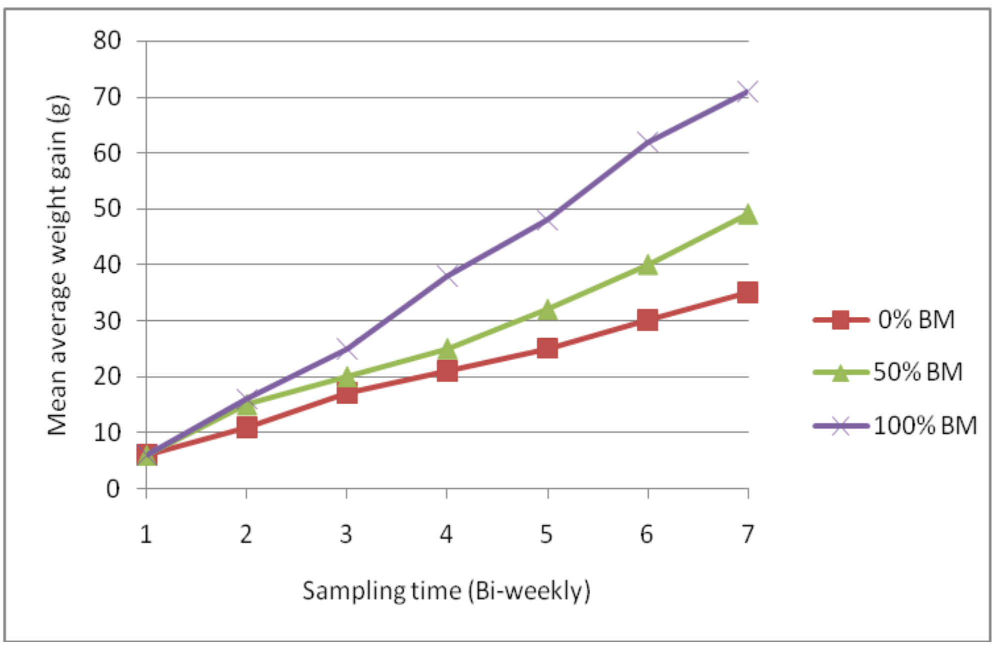

Figure 5: Bi-Weekly growth pattern of Oreochromis niloticus fed with different blood meal inclusion diets (Adapted from Aladetohun and Sogbesan 2013).

Table 1: Growth and feed utilization of Nile tilapia (O. niloticus) fed with different level inclusions of blood meal (BM) courtesy of Aladetohun and Sogbesan (2013)

Parameter	0% BM	50% BM	100% BM
Experimental days	84	84	84
No of fish stocked	20	20	20
Initial average weight (g)	6.20	6.26	6.15
Final average weight (g)	36.60	48.00	69.00
Average weight gain (g)	24.20	41.74	62.85
Mean weight gain/day (g)	0.29	0.50	0.75
Average weight gain/weekly	2.02	3.48	5.24
Mean weight gain/biweekly	4.40	6.96	10.47
Specific growth rate (SGR)	0.93	1.06	1.27
Total feed intake (g)	8.30	10.14	13.96
Feed conversion ratio (FCR)	0.34	0.24	0.22
Protein intake	2.92	3.49	5.20
Protein efficiency ratio (PER)	56.76	58.38	53.4
Survival (%)	100	100	100

Table 2: Proximate and amino acids composition of meat and bone meal (MBM), poultry by-product meal (PBM) and fish meal (FM) courtesy of Yang et al., (2004)

	MBM	**PBM**	**FM**
Crude protein %	50.0	58-65	64.6
Crude fat%	10.0	12.0	7.9
Calcium%	8.8	4.0	3.93
Phosprus%	4.0	2.0	2.55
Ash	25-35	10-18	16.0
Gross Energy(Kcal/kg)	3850	4900	4500
Arginine	3.25	3.94	3.68
Histidine	0.84	1.25	1.56
Isoleucine	1.55	2.01	3.06
Leucine	2.99	3.89	5.00
Lycine	2.6	3.32	5.11
Methionine	0.63	1.11	1.95
Phenylalanine	1.63	2.26	2.66
Threonine	1.75	2.18	2.82
Tryptophan	0.28	0.48	0.76
Valine	2.16	2.51	3.51
Crystine	0.41	0.66	0.61
Tyrosine	1.34	1.56	2.15

Table 3: Apparent protein and energy digestibility of meat and bone meal, poultry by-product meal and fish meal by tilapia courtesy of Yang et al., (2004)

	MBM	PBM	FM
Protein Digestibility (%)	83	88	90
Energy digestibility (%)	73	82	86

Table 4: Proximate composition of selected terrestrial plant products. Source: FAO (2006)

	Average composition (% by weight)					
Cereal by-products	Water	Crude Protein	Crude Fibre	Ash	Calcium	Phosphorus
Brewers grains	8.4	25.9	14.3	4.3	0.36	0.44
Distillers dried grains	8.2	27.1	11.2	3.8	0.13	0.57
Corn gluten meal	8.6	56.1	2.9	2.1	0.15	0.44
Wheat gluten meal	8.7	80.3	0.3	0.9	0.22	0.10
Rice protein meal	7.5	52.0	1.5	2.6	-	-
Oil seed by-products						
Canola meal	10.0	35.0	12.0	6.1	0.63	1.08
Mustard meal	10.1	42.4	9.1	6.3	-	-
Rapeseed meal	8.5	37.4	4.7	7.0	0.62	1.0
Coconut oil meal	8.7	21.5	14.8	7.1	0.18	0.6
Cotton seed meal	10.0	32.9	21.8	6.0	-	-
Palm kenel meal	9.9	17.5	19.6	3.9	0.38	0.82
Sesame meal	7.6	45.0	6.7	13.0	2.33	1.29
Soybean meal	10.3	44.7	6.0	6.7	0.29	0.65
Sunflower meal	10.0	23.3	31.6	5.6	0.21	0.93
Legume meal						
Lentils	10.9	24.4	3.3	2.5	0.06	0.31
Pea meal	11.3	23.1	6.2	3.2	0.17	0.4

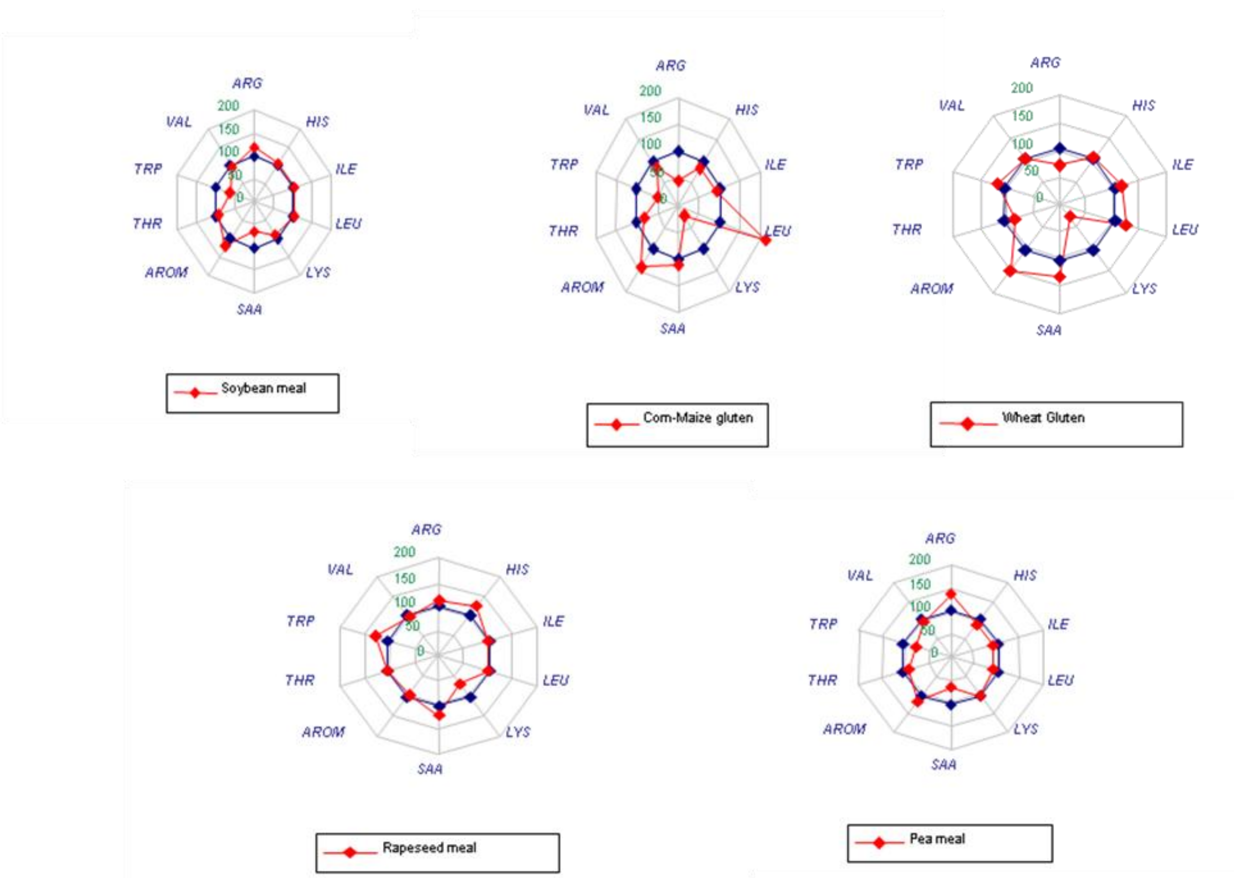

Figure 6: The EAA profile of plant protein rich derivatives, often deficient relative to FM (blue line). ARG: Arginine, HIS: Histidine, ILE: Isoleucine, LEU: Leucine, LYS: Lysine, SAA: Unknown amino acid, AROM: Aromatic THR: Threonine, TRP: Tryptophan, VAL: Valine (Source: FAO 2006)

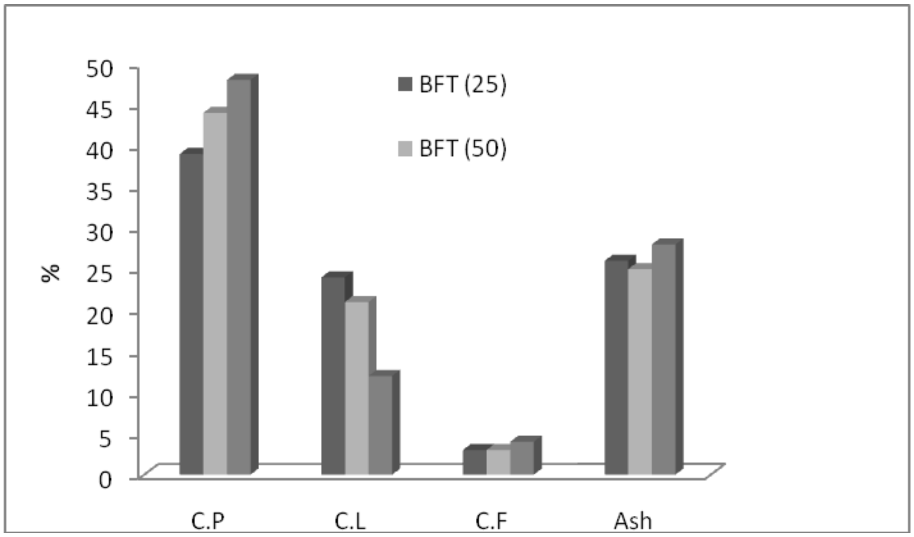

Figure 7: Proximate parameters of bioflocs collected from Biofloc technology treatment at different fish density; BFT (25) = 25 fish/m2, BFT (50) = 50 fish/m2, BFT (100) = 100 fish /m2 CP= crude protein; CL=Crude lipid; CF=crude fat. (Adapted from Widanarni et al. 2012)

Table 5: Fish grown and yield coefficients of tilapia fed with conventional pellets in 2 pond experiments for 51 days in courtesy of Avnimelech et al. (1989)

	Treatments	
	Conventional control (30%) protein)	BFT Carbon enriched (20% protein)
Feed C:N ratio	11.1	16.6
Fish weight g/fish		
Initial weight	112	112
Final weight	193	218
Daily gain	1.59	2.0
Mortality (%)	14.6	10.3
Feed conversion coefficient	2.62	2.17
Protein conversion coefficient	4.38	2.42
Feed cost coefficient (US$/kg fish)	0.848	0.583

Table 6: Crude protein contents of some non conventional potential feedstuffs for Nile tilapia

Ingredients	CP (%)	References
Maggot	43.8	Ugwumba et al., (2001)
Cotton seed cake	38.9	El-Sayed and Kawanna (2008)
Mucuna seed meal	32.1	Siddhuraju and Becker (2001)
Mango kernel meal	7.5 – 13.0	Joseph and Abolaji (1997)
Cassava peel	12.1	Oresegun and Alegbeleye (2001)
Pawpaw leaf meal	23.0	Reyes and Fermin (2003)
Dock weed	45.5	Mbagwu et al. (1990)
Earthworm meal	56.4	Tacon (1994)
Garden Snail	66.7	Sogbesan et al., (2006)