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The Effects of Substituting Fishmeal Based-Diet With Plant Based-Diet on Nile Tilapia (*Oreochromis niloticus*) Fish Growth, Feed Efficiency and Production Cost-Effectiveness

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Abstract

Aquaculture started in The Gambia in 1979 but is still at a rudimentary stage. Many government and private interventions conducted on fish farming failed due to the high cost of feed. Fishmeal based diets are expensive thus using them makes many fish farming in the developing countries unprofitable businesses. There is a need to use locally available plant ingredients to develop fish feeds. This study was conducted to compare the growth, feed efficiency and production cost-effectiveness of the Nile tilapia (*Oreochromis niloticus*) fish fed on fishmeal-based diet (control diet) to that of the same fish fed on plant-based diet (test diet). The two isonitrogenous (30 % CP) experimental diets were tested on 0.81g Nile tilapia (*Oreochromis niloticus*) fry for a period of six (6) weeks. The control diet composed of fishmeal, soybean meal, cassava flour, and a blend of palm oil and fish oil premixed with mineral and vitamin supplements. The plant-based diet consisted of groundnut cake, wheat flour, brewery waste and rice bran supplemented with mineral and vitamin premixes. Regarding growth performance parameters, there were significant differences between the final mean weight, mean weight gain, percentage mean weight gain and the specific growth rate of Nile tilapia (*Oreochromis niloticus*) fish fed on the control diet and the plant-based diet. For feed efficiency parameters, there was significant difference between feed conversion ratio for fish fed the control diet and the plant-based diet. However, there was no difference between the fish fed the two diets with regards to the protein efficiency ratio or survival rate. The plant-based diet was inferior to the fishmeal-based diet in terms of growth and feed efficiency parameters of 0.81g Nile tilapia (*Oreochromis niloticus*) fry. When compared to the fish-meal based diet, the plant based-diet was more cost-effective in producing a kilogram of feed but less cost-effective in producing of a kilogram of fish. Therefore, a plant based-diet cannot replace a fishmeal based-diet without compromising Nile tilapia (*Oreochromis niloticus*) fish growth performance and production cost-effectiveness.

Keywords: fishmeal-based diet, plant-based diet, least cost feed, tilapia

1. Introduction

Aquaculture, the current fastest growing animal production sectors in the world, significantly contributes to global food security (FAO, 2013). In the year 2016, aquaculture's global production was 110.2 million tons; a contribution that surpassed the 90.9 million tons produced by capture fisheries the same year (FAO, 2018). Aquaculture is considered a sustainable solution to overcome the dwindling harvests from wild stocks. In the past, the global fish consumption was initially dependent on capture fisheries. However, from 2014, aquaculture began contributing more to the global fish consumption than the capture fisheries (FAO, 2016) due to overfishing of some fish stock. Sustaining this momentum will undoubtedly require high demands for aqua feeds to scale-up aquaculture production (Rahman *et al.*, 2013).

Although aquaculture started in The Gambia in 1979, it is still at a rudimentary stage. High costs of aqua feeds prohibited the operations of many government and private interventions running fish farms. Furthermore, aqua feeds imported into the country were not accessible to many farmers. Feed, one of the most crucial components of fish farming, accounts for more than 50% of the running costs in intensive and semi-intensive systems (Sharma *et al.*, 2001; Oliveira-Cavalheiro *et al.*, 2007). The price increase in fish feeds was not commensurate with the farm gate price of fish obtained from aquaculture especially for low value fish like the Nile tilapia (*Oreochromis niloticus*). Thus many small-scale aquaculture ventures were not economically viable since they had to incur high costs when procuring the protein component of aqua feeds; especially those obtained from animal protein sources, (Munguti *et al.*, 2012). Initially, fish feeds contained a high concentration of fishmeal. But with increasing demands for feeds, it became the most expensive animal protein component in aqua feeds (Tacon, 1993). Recently, the price of aqua feeds increased more than two-fold (FAO, 2013).

Therefore, fish farmers may have to resort to fishmeal-free diets. Successful replacement of fishmeal based-diet with plant based-diet will make aqua-feeds more accessible to small-scale Gambian fish farmers. The replacement of fishmeal with plant materials is essential for sustainable aquaculture (Naylor *et al.*, 2009).There was a significant reduction of fishmeal in the diets of carnivorous and omnivorous fish (Hardy, 2010). However, finding of a suitable plant-based substitute for fishmeal-based diet is a daunting task because plant proteins have anti-nutritional factors that hinder their potentials for high inclusion in fish diets. Although some authors do not recommend the replacement of fishmeal in fish diets (Engin *et al*., 2005; Bonaldo *et al*., 2011), Twibell and Brown achieved satisfactory growth using a plant-based diet (1998).

The Nile tilapia (*Oreochromis niloticus*) is an economically important fish farmed in both tropical and sub-tropical regions. It was earmarked in many developing countries as a species with huge potentials in aquaculture that could also immensely contribute to food security. The Nile tilapia (*Oreochromis niloticus*) has high yield potentials, rapid growth, a high resistance to diseases, an ability to survive at low oxygen levels, an ability to feed on wide range of foods, is easy to reproduce in captivity, and accepts manufactured feed immediately after yolk sac stage. It also tolerates high dietary fiber and carbohydrate levels in its diet (El-Sayed and Teshima, 1992). These qualities make the Nile tilapia (*Oreochromis niloticus*) fish a good candidate for small and large-scale production particularly in the third world countries. The hypothesis of this research was plant based-diet will replace fishmeal based-diet without any significant effects on Nile tilapia (*Oreochromis niloticus*) fish growth, feed efficiency and production cost-effectiveness. The main research question was: can plant based-diets replace fishmeal based-diets without significant impact on Nile tilapia (*Oreochromis niloticus*) fish growth performance, feed efficiency and production cost-effectiveness?

The objectives of these trials were: (a) to evaluate whether a plant-based diet could substitute fishmeal-based diet in Nile tilapia (*Oreochromis niloticus*) fry culture without an impact on growth and feed utilization parameters; (b) and to evaluate whether the substitution of plant-based diet for fishmeal-based diet would be more cost-effective in Nile tilapia (*Oreochromis niloticus*) fry culture.

2. Materials and Methods

2.1 Preparation of the Plant-Based and Fishmeal-Based Diets

Two practical diets containing the same protein level (30%) with varying levels of lipid levels (7.2-8.6 %) were prepared from locally available ingredients. Prior to formulating the diets, the ingredients were analyzed to determine the proximate chemical composition of each ingredient (see **Table 1**). In the **Table 2,** the Diet 1 and Diet 2 and their proximate compositions are described based on the chemical compositions of their ingredients. Diet 1 (the fishmeal-based diet/also known as the control diet), is composed of fishmeal, soybean meal, cassava flour and a mixture of corn and fish oils and mineral and vitamin premixes. Diet 2 (a plant-based diet/also known as the test diet), is composed of groundnut cake, brewery waste, wheat flour, rice bran and mineral and vitamin premixes. The ingredients of both diets were separately grounded using a hammer mill and sieved with a 1 mm mesh-size sieve to obtain a fine powder. During diet preparation, an electronic scale with a precision of 0.1 g was used to weigh ingredients. The weighed ingredients of each diet were placed in a container and mixed by hand. When the ingredients were thoroughly mixed, oil was added depending on the diet and further mixed. Then tap water equivalent to 30% of the weight of each diet was added and further mixed to obtain a moist dough. The dough was then made into spaghetti-like filaments using a meat grinder. The feeds were then dried for two hours in an oven at 60 °C for gelatinization of starch followed by a 2-day sun-drying period to ensure proper drying. The diets were separately grounded using local mortar and pestle into powder, sieved with a 1 mm mesh-size sieve to remove fine powder. The feeds, in the form of crumbs, were kept in air-tight containers at room temperature. At different time points, the required amounts of each diet were periodically removed for feeding during the trial.

Table 1. Proximate composition (%) of the feed ingredients

Ingredients	DM	CP	CL	CF	Ash	NFE
Fishmeal	93.60	64.30	8.5	0.0	10.24	16.96
Soybean meal	95.68	53.70	4.23	8.32	6.36	27.39
Groundnut cake	93.00	46.00	8.92	4.0	5.36	35.72
Brewery waste	90.10	15.50	7.28	12.8	3.72	60.70
Cassava flour	90.30	3.5	3.25	2.00	2.56	88.69
Rice bran	90.00	10.00	9.65	7.51	6.49	66.35
Wheat flour	87.90	14.00	1.70	1.90	2.10	80.30

DM = dry matter; CP = crude protein; CL = crude lipid; CF = crude fiber, NFE = nitrogen free extract.

Table 2. Formulations and proximate composition of experimental diets (% dry matter)

Ingredient (%)	Diet1	Diet2
Brown FM	21.5	
Soybean meal	28	
Groundnut Cake		54
Brewery waste		10.3
Cassava	40.5	
Rice Bran		14
Wheat Flour		16
Oil Mixture [a)]	4.3	
Vitamins [b)]	2.7	2.7
Minerals [c)]	3.0	3.0
Total	100	100.7
Proximate composition (%)		
DM	85.4	88.59
CP	30.82	30.46
CL	7.68	8.24
CF	5.77	12.66
Ash	11.08	12.39
NFE	44.65	36.12

a) Lipid source: Palm oil and fish oil (3:1); **b)** Vitamin (mg/kg premix):Vit A 250000 UI; Vit D3 250000 UI; Vit E 5000;Vit B1100; Vit B2400; Niacine 1000; Pantothenate Ca 2000; Vit B6300; Vit K31000; Vit C 5000; Biotine 15; Choline 100; BHT 1000; **c)** Phosphorus 7%; Calcium 17%; Sodium 1.5%; Potassium 4.6%; Magnesium 7.5%; Manganese 738 mg/kg premix; Zinc 3000 mg/kg premix; Iron 4000 mg/kg premix; Copper 750 mg/kg premix; Iodine 5 mg/kg premix; Cobalt 208 mg/kg premix; Calcium and ground attapulgite q.s. 1000 mg/kg premix; Fluoride 1.5%. DM = dry matter; CP = crude protein; CL = crude lipid; CF = crude fibre, NFE = nitrogen free extract.

2.2 Growth Trial

The experiments were conducted at the aquaculture station of the University Institute of Fisheries and Aquaculture at the University of Cheikh Anta Diop, Dakar, Senegal. The Nile tilapia fry were obtained from the same location. For this trial, mixed-sex Nile tilapia (*Oreochromis niloticus)* fry of 0.81g were used. Prior to the start of the experiment, the fry were acclimatized for two weeks and fed with plant-based diet (Diet 2). At the start of the experiment, the individual weight of the fish for each tank was measured. The acclimatized fish were randomly distributed into a stocking density of 15 individuals of fish per tank; in six 50 L isolated plastic containers. Fish in three tanks received a plant-based diet while fish in the remaining three tanks received a fishmeal-based diet. Water temperature, dissolved oxygen and pH were recorded during all feeding times (9 AM and 5 PM). Fish were fed at 10%, 8% and 6 % of their body weight during the first, second and third fortnight, respectively, during a six (6) weeks' period. Every fortnight, fish were pooled weighed to determine their growth rate for adjustments to the feed allocation. At the end of the experiment, all the fish in each tank were counted and weighed.

2.3 The Sampling

At the beginning of the experiment, 90 fish were individually weighed and distributed to 6 tanks. At the end of the experiment, all the remaining fish for each treatment were individually weighed to determine their final mean weight (FMW), mean weight gain MWG), relative growth rate (RGR), specific growth rate (SGR), feed conversion ratio (FCR), protein efficiency ratio (PER) and survival rate (SR).

2.4 The Sample Analysis

The proximate composition of the feed ingredients (**Table 1**) and experimental diets (**Table 2**) was evaluated following AOAC (1995) procedures. The samples were dried to a constant weight at 105^0 C to determine their moisture levels. Ash content was determined by burning the samples at 540^0 C in a muffle furnace. The crude protein was determined by measuring feed nitrogen (N x 6.25) constitution using a micro-Kjeldahl method (Kjeltec System 1002 Distilling Unit, Tecator, Hoeganaes, Sweden). Crude lipid was extracted using the Soxhlet method (Soxtec system, Foss, Model HT, Sweden). Crude fiber composition was determined by acid and alkaline digestion using a Fibertec M 1020 system (FOSS Tecator).

2.5 Calculations of Parameters

The mean body weight, relative growth rate, specific growth rate, feed conversion ratio, protein efficiency ratio and survival rate were calculated as shown below.

Mean body weight (g/fish) = total fish body weight/number of fish

Relative growth rate (RGR) = 100 x (final mean weight – initial mean weight) / initial mean weight

Specific Growth Rate (SGR) = ((ln Wt - ln Wi) /T) x 100; where Wt is the weight of the fish at time t, Wi is the weight of the fish at time 0, and T is the rearing period in days

Feed conversion ratio (FCR) = total dry feed fed (g) / total wet weight gain (g)

Protein Efficiency Ratio (PER) = wet weight gain (g)/ total protein intake (g)

Survival Rate (S %) = final number of fish / initial number of fish x 100.

2.6 Statistical Analysis

Significant differences between treatments were analyzed using analysis of variance (ANOVA) after confirming the homogeneity of variance using the Levene's test. A one-way analysis of variance (ANOVA) was performed to test for differences in IW, FMW, RGR, SGR, FCR, PER and survival rate among fish fed with the two treatment diets. When the significance level was $p < 0.05$, a Turkey's HSD test was used to compare the relevant mean differences between groups. All statistical analyzes were performed using the SAS software program for windows (V. 9.4, SAS Institute).

3. The Results

In this experiment, both fishmeal and plant-based diets were accepted by the fish, but the fish preferred the control diet to the test diet. Throughout the experimental period, no pathological signs and symptoms were detected among the fish. The fishes' culture environment was conducive during the entire experimental period because the average temperature, dissolved oxygen concentration and pH of the water were within optimum ranges for the Nile tilapia (*Oreochromis niloticus*). The survival rate, which was good, did not differ between the fishes fed the two diets.

The growth performance and feed efficiency parameters are shown in the **Table 3**. There were significant differences between the control diet and the tested diet regarding the final mean weight, mean weight gain, relative growth rate and specific growth rate. There was a significant difference between the two diets for feed conversion ratio (FCR) but not for protein efficiency ratio (PER).

The estimated cost of ingredients used to produce a kilogram of the experimental feeds and the cost of feeds for producing a kilogram of fish are shown in the **Table 4**. The cost per kilogram of the control diet was higher ($1.08/Kg) than the cost per kilogram of plant-based diet ($0.71/Kg). The cost of feed for producing a kilogram of fish with Diet 1 was $2.18 and with Diet 2 was $2.36.

Table 3. Growth and feed utilization parameters of Nile tilapia fry fed on different experimental diets at the end of 6 weeks. (N=3)

TREATMENT	Diet 1	Diet 2
IW	0.81±01[a]	0.81±0.01[a]
FMW	3.33±0.80[a]	1.92±0.28[b]
MWG	2.52±0.80[a]	1.11±0.27[b]
(RGR, %)	309.67±97.23[a]	137.72±31.10[b]
SGR	3.31±0.61[a]	2.05±0.30[b]
FCR	2.02±0.62[b]	3.33±0.54[a]
PER	1.75±0.46[a]	1.02±0.18[a]
Survival Rate	93.33±5.77[a]	83.33±20.82[a]

Values are means of the triplicates ± SD; values within the same row without a common superscript are significantly different ($p < 0.05$). IW = initial weight; FMW = final mean weight; MWG = mean weight gain; RGR (%) = relative growth rate; SGR = specific growth rate; FCR = feed conversion ratio; PER = Protein efficiency ratio.

Table 4. Estimated cost per Kg of experimental feeds and cost of feed per Kg fish produced

Ingredient	**(Cent/Kg)**	**Diet1**	**Diet2**
Brown FM	74.55	17.12	
Soybean meal	72.73	21.28	
Groundnut Cake	45.46		26.41
Brewery waste	36.36		4.15
Cassava	90.91	40.77	
Rice Bran	29.09		4.54
Wheat Flour	72.73		13.24
Fish oil	74.55	0.80	
Palm oil	163.64	5.28	
Vitamins	404.6	10.92	10.92
Minerals	129.2	3.88	3.88
Other charges*)	8.30	8.30	8.30
Total cost(USD/Kg)		**1.08**	**0.71**
FCR		2.02	3.33
Feed cost/Kg fish		**2.18**	**2.36**

*) Labor cost, transport fee, machine wear cost and cost of electricity

4. Discussion

The Nile tilapia (*Oreochromis niloticus*) species are herbivorous/omnivorous fish which eat both plant and animal matter, but prefer animal ingredients to plant materials. Of the animal ingredients also, Nile tilapia have high preference for fishmeal because it optimally meets their nutritional requirements. Fishmeal has high quantity and quality protein, a good amino acid profile and high digestibility and palatability; reasons why fish feeds usually contain a high concentration of fishmeal. However, the current rise in prices of fishmeal obliged nutritionists to look for cheaper plant-based diets as alternatives to fishmeal-based diet for low-value species like tilapia. Soybean meal, a potential impressive substitute for fishmeal (Shiau *et al.*, 1989; Furuya *et al.*, 2004), has recently become expensive (Brown, 2008; FAO, 2014) especially in regions where it is not commonly farmed. In this experiment, fish final mean weight, mean weight gain, relative growth rate, specific growth rate and feed conversion ratio was higher for fish fed on fishmeal-based diet (control) compared to the fish fed on a plant-based diet (Diet 2). These results are consistent with the findings of Hansen *et al.*, (2007) and Soltan *et al.*, (2008). The suboptimal results obtained from the fish fed on plant-based diet could be attributed to factors such as the high fiber content, low digestibility, nutrient availability and anti-nutritional factors in plant ingredients. The nutritional value of a feed largely depends on the degree of digestibility of the feed and the bioavailability of digested nutrients and energy. A high dietary fiber content reduces the digestibility of the feed whereas anti-nutritional factors lower the palatability of the diet. In this study, the plant-based diet had a high fiber content (12.66) whereas the fishmeal-based diet had a low fiber content (5.77). According to Altan and Korkut (2011), a dietary fiber content more than 8% decrease feed digestibility which consequently reduces nutrient bioavailability. Similarly, for the *Tilapia rendalli*, when diets were exclusively formulated from plant ingredients, less nutrients and energy were available for growth due to low digestibility (Mzengereza *et al.*, 2016). The negative influence of anti-nutritional factors in plant ingredients on palatability was also reported by Francis *et al*. (2001).

The current results contradict the findings by El- Saidy and Gaber (2003) who found no significant differences in growth performance and feed efficiencies with Nile tilapia fingerlings fed on fishmeal-based diets and plant-based diets. Tacon and Metian (2008) also observed no change in the growth performance of catfish, tilapia and carps given plant-based diets containing soybean meal protein, canola meal, extruded pea seed meal, wheat and corn meal supplemented with lysine and methionine. The differences seen in the current study and those mentioned above could be attributed to the ingredient composition of the experimental diets. The plant-based diets in previous studies used plant ingredients constituted of mainly protein sources; a condition not replicated in this study. In the literature, an experiment evaluating growth rate of Nile tilapia fish fed 'simple' and 'complex' plant protein mixtures, fish fed with the complex plant protein mixture diet had significantly better growth, protein efficiency ratio and feed/gain ratio than those fed with the simple plant protein mixture diet (Borgeson *et al.*, 2006). Additionally, the same studies used methionine and lysine supplements in their experiments whereas the present study did not.

Plant proteins could not comprehensively replace the fishmeal proteins in feeds due to the presence of plant anti-nutritional factors, an incomplete amino acid profile, phosphorus deficiencies, reduced digestibility and low utilization of nutrients by the fish. Therefore, a host of authors recommend only partial substitution of fishmeal protein sources by plant protein sources (El-Saidy and Gaber 2004; Garcia-Abiado *et al.*, 2004; Yue and Zhou 2008; Zhao *et al.*, 2010).

From the economic point of view, Diet 2 is not cost-effective or economically viable to use in place of the fishmeal-based diet in the Nile tilapia (*Oreochromis niloticus*) culture. When comparing the cost of production of a kilogram of fish using the two diets, an additional $0.14 would be required to produce Diet 2. On the contrary, El- Saidy and Gaber's (2003) cost-benefit analysis showed that a whole plant protein mixture diet was more cost effective than fishmeal-based diet.

5. Conclusion

Substituting fishmeal based-diet with plant based-diet significantly reduced the growth and feed efficiency parameters for Nile Tilapia. Thus, it is not cost effective to replace fishmeal based-diet with plant based-diet in the current formulation for Nile tilapia (*Oreochromis niloticus*) fry culture.

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