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Original Article

Evaluation of diets with sunflower cake as a replacement for fish meal in feeds for Nile tilapia (*Oreochromis niloticus*) production

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ABSTRACT

Sunflower cake (SFC) was evaluated as a partial replacement for conventional protein sources including fishmeal, soybean meal, and mustard oilcake in tilapia feed. Four isonitrogenous (26% crude protein) and isocaloric (354–376 kcal) diets were formulated. Diet-1 (control), Diet-2, Diet-3, and Diet-4 had 0, 30, 40, and 50% SFC inclusion, respectively, replacing fish meal, soybean meal, and mustard oilcake. In Diets 2, 3, and 4, 15% yellow maize was also included as a replacement for rice bran. Average 11.54 g tilapia fingerlings were stocked at density 3.5/m^2 in an earthen pond's compartments. After 100 days, diets with SFC showed uncompromised growth ($P > 0.05$) and favorable economics compared to the control diet. Production parameters (feed conversion ratio, specific growth rate, and protein efficiency ratio) were unaffected by SFC diets ($P > 0.05$). Proximate analysis of harvested tilapia showed that crude protein and crude lipid content were unaffected by the experimental diets. Income, gross margin, and benefit-cost ratio were not affected by experimental diets. Encouraging growth performance and product quality were accompanied by production costs savings with diets that contained SFC. Improved economics with 40% SFC replacement suggest its potential for commercial tilapia cultivation. Continued efforts to optimize SFC-based diet formulation are recommended.

Keywords: Benefit-cost ratio, feed conversion ratio, fishmeal, protein efficiency ratio, specific growth rate, sunflower cake

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INTRODUCTION

Bangladesh ranks highly among world food fish producer countries,[3] and tilapia contributes approximately 10% of total national inland fish production.[1] Tilapias are a widely-cultured family of fishes, with the Nile tilapia (*Oreochromis niloticus*) currently comprising about 75% of world tilapia production.[3] Tilapia farming continues to spread rapidly because of favorable production and market parameters.[2] The omnivorous Nile tilapia is well-suited to semi-intensive culture, polyculture operations, and integrated rice-fish farming, and thriving on a variety of foods including benthic and attached macroalgae, plankton, and detritus.[4] Nile tilapia has responded exceptionally well to genetic selection[5] and is suited to emerging technology such as small-scale aquaponics,[7] production using biofloc,[8] and intensive cultivation in low-discharge recirculating aquaculture systems.[9]

A majority of fish consumed in Bangladesh is produced by aquaculture, about 78% of which are cultured in ponds, and the tilapia industry has a large and steadily-growing market share in Bangladesh.[10] Tilapia production in fiscal year 2013–2014 reached 2,98,062 MT, with more than 92% cultured in ponds.[1] A critically important facet of growth in the aquaculture industry in Bangladesh has been the increased domestic production of commercial feeds, with an estimated 1 million tons and an additional 0.3 and 0.4 million tons of feeds produced by micro, small, and family enterprises at the village level.[11] A widely-connected supply chain has developed, but small-scale and rural farmers still have inadequate access to acceptable feeds. Although Nile tilapia is omnivorous, commercial tilapia feeds in Bangladesh usually rely on fishmeal as a primary protein source, using either imported fishmeal or producing it locally at high environmental costs.[12] Dependence on fishmeal has imposed price volatility, variation in quality, and considerable economic risk to the aquaculture industry.[13] Feed is the major

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operating expense in semi-intensive and intensive aquaculture systems, and protein is the most expensive macro-nutrient. In intensive tilapia culture, feed accounts for 60–80% of the variable costs, whereas, in semi-intensive systems, feed and fertilizer expenditures account for 30–60% of the variable costs.[14,15] Costly ingredients, especially fishmeal, hold profit margins at a dangerously low level for Bangladeshi tilapia farmers.

Sunflower cake (SFC) is a byproduct of sunflower oil production - it is the protein-rich residue that remains in the form of seeds after the oil has been extracted. The sunflower oil industry produces millions of tons of this material, and it has attracted some attention as a possible substitute for fishmeal in aquaculture feeds. Comparison of the biochemical makeup of SFC with fishmeal suggests some potential as a plant-based substitute for declining supplies of increasingly expensive and environmentally unsustainable fishmeal.[16] Total protein content and specific amino acid profiles of the two are comparable, although SFC has relatively lower levels of lysine and threonine than fishmeal.[17] Trials of the palatability, digestibility, and nutrient utilization of SFC-based aquaculture diets have produced generally encouraging results.[18]

SFC contains a high level of crude protein - 27.8–37.4%, which varies with seed quality and processing.[19] The potential of SFC for replacement of animal and plant protein sources such as fishmeal and soybean meal is based in part on competitive nutritional value and relatively lower prices. Determination of the optimal inclusion level of oil-extracted SFC and maize in fish diets requires attention to nutritive balance and practical testing of performance in farm production settings. In recent years, in Bangladesh, the cultivation of sunflower (*Helianthus annuus*) and hybrid maize (*Zea mays*) has been promoted with the traditional rice farming system by public and private agencies, and both have been adopted as cash crops.

Although plant ingredients contain some anti-nutritional substances including protease inhibitors,[20] evaluations of the use of SFC and soybean meal as substitutes for fish meal in aquaculture diets have shown effectiveness.[18,21,22] Limited amounts of sunflower meal have been tested with positive outcomes for rainbow trout,[23] tilapia,[24,25] and other fishes. It is possible that mixtures of anti-nutrients detected in SFC could have disruptive actions on aquaculture subjects in higher concentrations, but these compounds as used in feed formulations are unlikely to affect fish growth performance.[20] Because an acute loss of interest in food has been ascribed to trypsin-inhibitor precursors identified in SFC fed to fishes,[26] monitoring feeding behavior and appetite carefully are considered advisable in experimentation with sunflower-based protein sources.

Plant oilseeds and their byproducts are often used as a major source of dietary protein in feeds for warm water omnivorous and herbivorous fishes and invertebrates.[27] The present study was designed to evaluate production and economics of inclusion of variable quantities of SFC as a replacement for fishmeal and soybean meal in the diet of Nile Tilapia (*O. niloticus*). SFC has also been tested recently and successfully as an experimental replacement for fishmeal in the farming of the prawn, *Macrobrachium rosenbergii*, leading to the conclusion that feeds with the highest concentration of SFC produced the maximal cost-benefit ratio, without negative effects. Many of the nutritional formulations and laboratory analytical methods used in that investigation[28] were adapted for use in the present study on Nile tilapia.

MATERIALS AND METHODS

A controlled 100 days feeding trial was conducted in farmer's earthen pond locally called "Gher" of Dighalia village under Abhaynagar Upazila of Jessore district, Bangladesh from July 18 to October 27, 2014. The pond exemplifies environmental and chemical conditions used commercially for tilapia production in Jessore, southern Bangladesh. The pond used in these studies were guarded throughout the study to prevent poaching and animal predation. The pond was divided into 12 compartments (156 m^2–187 m^2 area) with bamboo fencing and polyethylene netting for the management of experimental groups used in the feeding trials. Quantifications of fry and inputs were based on actual water area of each compartment, but for growth and other performance analyses, we considered average compartment size to be 175 m^2. Compartments were used for three replicates (R1, R2, and R3) for each of the specific feeds (F1 [control], F2, F3, and F4). The feeds and experimental replicates were distributed randomly among the compartments.

The pond was repaired, cleaned and enclosed with nylon net to prevent entrance of snakes and frogs and then treated with rotenone (9.1% strength) at the rate of 2.03 g/m^2 (20.34 kg/ha) per each meter of water depth to eliminate unwanted fish and/or predators. After 5 days of rotenone treatment, agriculture lime ($CaCO_3$) was applied at the rate of 25 g/m^2 (250 kg/ha); ponds were later filled by rainwater and irrigation from an adjoining canal by the pump. Due to low rainfall, regular irrigation was provided to maintain the optimum water depth between 70 and 90 cm. Genetically improved farmed tilapia (GIFT) *O. niloticus* strain fingerlings (average weight 11.54 g) were stocked on July 18, 2014. All male GIFT tilapia fingerlings were obtained from a local nursery, reared for approximately 35 days, and stocked at the rate of 3.5 fry per square meter of water area.

Four different isonitrogenous and isocaloric diets were formulated, maintaining approximately 26% crude protein and calorie level [354–376 kcal; Tables 1 and 2]. Using the "Pearson square" method we developed and used a MS Excel-based feed formulation spreadsheet. The feed ingredients were chosen as

Table 1: Proximate composition of feed ingredients and experimental diets

Ingredients	% Crude protein	% Crude lipid	% Fiber	% Ash	% Moisture	NFE*
Fish meal	52.94	6.65	0.60	22.91	16.43	0.47
Mustard oil cake	29.81	10.83	4.25	6.60	16.90	31.61
Soybean oil cake	43.24	8.40	6.41	5.35	15.58	21.02
SFC	29.48	14.63	3.20	5.65	11.53	35.51
Rice bran (auto)	13.10	10.60	6.40	7.42	18.15	44.33
Maize (yellow)	14.19	5.60	3.35	1.48	14.75	60.63
Wheat flour (atta)	10.81	2.80	0.50	0.67	15.93	69.29
Experimental Diets						
Diet 1 - control	25.98	11.39	5.60	16.64	16.35	24.04
Diet 2–30% SFC	26.06	8.94	4.80	11.98	15.59	32.63
Diet 3–40% SFC	26.44	9.15	4.00	8.24	18.46	33.71
Diet 4–50% SFC	26.18	8.77	5.60	11.96	16.28	31.21

*NFE: Nitrogen-free extract, 100 - (% protein+% lipid+% ash+% moisture+% crude fiber). SFC: Sunflower cake

Table 2: Experimental diets for Nile tilapia listing ingredients by %. SFC; prices are given in BDT*/kg

Type of diet, cost, BDT*/kg ingredient (%)	Diet-1, control	Diet-2, 30% SFC	Diet 3, 40% SFC	Diet-4, 50% SFC
	38.59	**33.24**	**32.00**	**30.50**
Fish meal (chewa)	16.00	11.00	9.50	8.00
Mustard oil cake	15.00	9.00	7.00	5.00
Soybean meal	15.00	8.00	7.00	5.00
Sunflower oil cake	0.00	30.00	40.00	50.00
Rice bran	41.00	20.30	14.80	10.30
Maize (yellow)	6.30	15.00	15.00	15.00
Vegetable oil	1.00	1.00	1.00	1.00
Wheat flour	5.00	5.00	5.00	5.00
Salt	0.50	0.50	0.50	0.50
Vitamin supplement**	0.20	0.20	0.20	0.20
Total	100.00	100.00	100.00	100.00

*BDT: Bangladesh taka, 78 BDT: $1 USD** composed of Vitamins A, D3, E, K3, B1, B2, B6, B12, folic acid, biotin, nicotinic acid, pantothenic acid, selenium, iron, copper, zinc, iodine, cobalt, and manganese. SFC: Sunflower cake

per the formula including SFC and maize on the basis of their nutritional content, local availability, and price profiles.[27] For the experimental diets, oil extracted SFC was substituted for fish meal and plant-based protein sources such as soybean meal and mustard oil cake. Maize was also chosen as an option to replace the rice bran in Diet-2, Diet-3, and Diet-4. The major source of protein in the control diet (Diet-1) was fish meal and conventionally used plant-based proteins in soybean meal and mustard oil cake. These proteinaceous materials were partially replaced by SFC at the rates of 30%, 40%, and 50% in Diet-2, Diet-3, and Diet-4, respectively. Approximately 30% of rice bran from Diet-1 was also replaced by 15% yellow maize in those three diets, in place of 6.3% in Diet-1 [Table 2].

Whole dried chewa fish (*Pseudapocryptes elongatus*) were collected from Dublar char, Sarankhola Upazila of Bagerhat district, and mustard oil cake, soybean meal, sunflower oil cake, maize, rice bran, vitamin premix, vegetable oil, and salt were obtained from a local retail source. Dried Chewa fish were used to produce fishmeal; this is the favored source of fishmeal for aqua feed in Bangladesh. Experimental feeds were prepared as sinking pellets by a local miller. The ingredients were milled and bagged accordingly. Feed ingredients were measured and mixed, then homogenized with vegetable oil and water at approximately 500 ml/100 kg of mixed ingredients to prepare sinking pellet diets, making pellets of different sizes (2-4 mm) for different stages of fishes. The pelleted feeds were air-dried and stored until used.

Fish were fed to satiation twice daily (at 08:00–09:00 and 16:00–17:00). Feed amount was initially set at 10% and finally at 2% of body weight of stocked tilapia. Feeds were broadcast over the compartments and consumption was monitored for 15–20 min after application. The quantity of feed was adjusted fortnightly after measuring growth in sampled specimens. Feeding was withheld or reduced to a single feeding per day during abnormal weather (heavy rain, extreme hot, and excessively cloudy), per customary commercial practices.

Water depth was maintained in the pond between 70 and 90 cm by irrigating with pumped groundwater. Liming of the pond water was conducted at the rate of 5 g/m^2 1 month after stocking. We treated with agricultural lime ($CaCO_3$) at about 10-day intervals at the rate of 5-6 g/m^2 to help maintain water quality by stabilizing pH.[29] Tilapia health and water quality remained satisfactory, with pond water showing a light green color after applications of lime. Racking was done to remove accumulated gas from the pond bottom once a month. Water quality parameters temperature (°C), transparency (cm), pH, dissolved oxygen (DO) (ppm), alkalinity (ppm), hardness (ppm), and ammonia-nitrogen (ppm) were recorded in each compartment at fortnightly intervals. Water temperature was measured with a digital thermometer (Brand: Conrad Electronic, model: K102, capacity: 200°C, readability: 0.1°C, and made in Germany) and water pH was measured (Hanna instruments model-HI 98107 pH meter). Water transparency was measured using a locally made Secchi disc. DO° was measured by a Hanna instruments model-PDO 520 DO°m. Ammonia-nitrogen (NH_3-N) concentration was quantified with a test kit (Hanna instruments Model-HI 3824). Total alkalinity (Hanna instruments Model-HI 3811) and hardness (Hanna instruments Model-HI 3812) were also measured and recorded. These protocols followed procedures reported earlier.[28]

Tilapia was sampled (20–30 fish) fortnightly from each compartment by cast net. Total length to the nearest cm and weights in g of individual tilapia was measured and recorded using a scale and digital balances. Feeding was stopped 24 h before harvesting. Fish were harvested by seine net and weighed by electronic balance. Proximate composition analysis of feed ingredients formulated diets and of experimental tilapia (fingerlings initially and later samples of the harvested adults) were carried out as described in detail previously.[28] The proximate composition of experimental feed ingredients, prepared diets, tilapia fry, and grown tilapia samples is presented in Table 1. These analyses followed the methods of the Association of Official Analytical Chemists[30] as explained in detail previously, and performance parameters followed techniques and calculation methods reported earlier.[28]

An economic performance analysis was based on variable input costs including fingerlings, feed, lime, irrigation, and hired labor for repairs excluding the costs of pond lease and family labor. Cost of production was estimated based on the local market price during 2014 and is expressed in Bangladesh currency (Taka; $1 US = 78 BDT at the time of the study). Harvested fishes were marketed or consumed locally. Total return from tilapia produced was estimated by the price of fish sold in the market and consumed by the family. Gross margins, benefit-cost ratios (undiscounted benefit cost ratio [BCR]), the cost of experimental feeds, and statistical analyses (ANOVA and Duncan's Multiple Range Tests) were calculated using SPSS as described elsewhere.[28] Statistical significance of apparent differences was assessed at the 5% probability level ($P < 0.05$).

The experiment was conducted under the guidelines of the "Animal Welfare and Ethical Committee" of Bangladesh Agricultural University.

RESULTS

All experimental diets were accepted readily by the stocked tilapias. Tilapia fed aggressively in all experimental groups, and within approximately 15–20 min, all feeds had been consumed from the feeding tray. No abnormal tilapia or disease symptoms were observed during the feeding trial. No behavioral or health-related issues were observed in response to any of the experimental diets. Survival rates were similar in all treatment groups.

Mean water quality values varied within recommended ranges for tilapia cultivation. The mean transparency and temperature of the water ranged from 20.07 ± 4.02 to 20.45 ± 4.18 cm and 26.31 ± 3.34 to 26.60 ± 3.30°C, respectively, and did not show any treatment-related significant differences throughout the study. The mean DO level ranged from 5.36 ± 1.08 to 5.43 ± 1.07 ppm and pH value was within 8.27 ± 0.65 to 8.37 ± 0.40. Mean total alkalinity values were in the 144.00 ± 12.01 ppm range, and mean hardness was 126.00 ± 12.01 ppm among all treatments. Ammonia nitrogen was undetectable throughout the study.

Growth performance and efficiency of the four formulated diets are compiled in Table 3. The survival rates of tilapia did not vary significantly among treatments, ranging from 71.27 ± 14.21 to 78.58 ± 4.52%; ($P > 0.05$). Similarly, differences in total weight gain [production, shown in Figure 1] and percent of weight gain did not vary significantly among treatments ($P > 0.05$). Feed conversion ratio (FCR) values of the experimental diets varied from 1.37 ± 0.05 to 1.68 ± 0.4. And protein efficiency ratios (PER) of the diets ranged from 2.00 ± 0.47 to 2.25 ± 0.08 ($P > 0.05$). Similarly, specific growth rate (SGRs) ranged from 1.00 to 1.04% per day among the treatment groups, and did not differ significantly [Table 3]. Proximate carcass composition analyses of the whole tilapia were similar among all four treatment groups. No significant differences ($P > 0.05$) were observed in whole body crude protein, crude lipid, crude ash, moisture, and dry matter contents among dietary treatments.

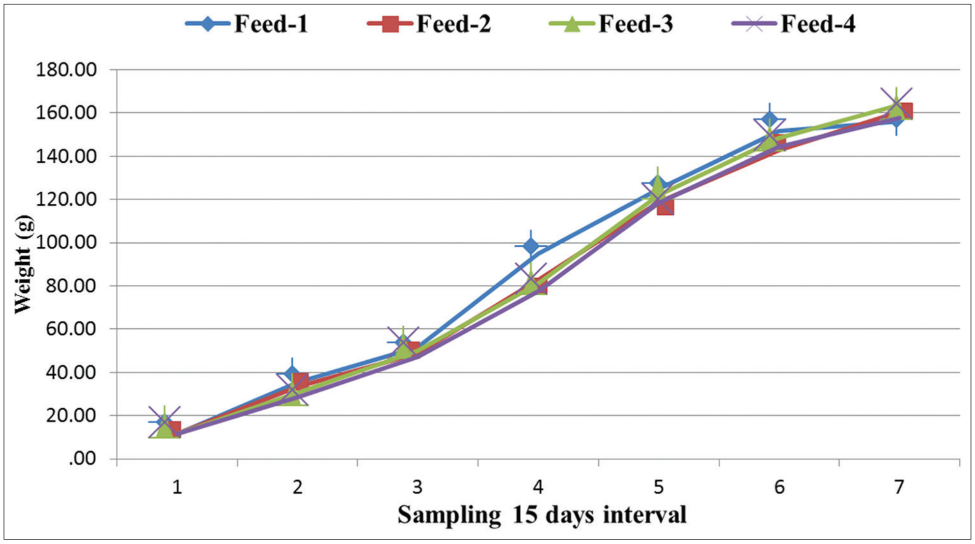

Figure 1: Growth of tilapia fed 4 experimental diets over the course of the 100-days grow-out study

Table 3: Economic efficiency for 1 kg gain with feeds containing variable levels of SFC for tilapia, *O. niloticus* (mean±SD)

Parameter	Diet-1 control	Diet-2 30% SFC	Diet-3 40% SFC	Diet-4 50% SFC
Cost of feed (BDT/kg)	38.59	33.24	32.00	30.50
FCR*	1.68	1.47	1.37	1.49
Cost of feed/kg tilapia gain	64.83	48.86	43.84	45.45
Cost** reduction/kg weight gain	0.0	15.97	20.99	19.38
% cost reduction/kg gain***	0.0	24.63	32.38	29.89

*P>0.05, no significant differences, **cost reduction per kg tilapia gain=feed cost in BDT/kg gain for control Diet-1 - feed cost per kg of gain for formulated diets, ***% cost reduction per kg gain=100×(cost reduction per kg gain in Diet 2–4/feed cost per kg gain of control Diet-1). SFC: Sunflower cake, *O. niloticus: Oreochromis niloticus*, SD: Standard deviation, BDT: Bangladesh taka, FCR: Feed conversion ratio

Partial analyses of productivity and economic performance of tilapia fed with different experimental diets for 100 days grow-out revealed no treatment-related differences. No significant differences ($P > 0.05$) were observed in productivity, income, gross margin, and BCR among the diets. The absence of any detectable treatment-related impairments of performance was accompanied by reductions in the costs of the experimental diets, ranging from BDT 38.59 to BDT 30.50/kg, with operating cost decreasing in proportion to the amount of SFC used [Table 4]. Corresponding FCR and feed cost per kg produced are displayed in Table 3; cost of feed per kg tilapia gain was lowest for Diet-3 (BDT 43.84) followed by Diet-4, Diet-2, and Diet-1. Estimated cost reduction to produce one kg tilapia was highest (BDT 20.99) for Diet-3 **(**40% SFC), 32.38% lower than the cost of production using the control Diet-1 [Table 3]. The percent of feed cost for the total operational expenditure varied from 64% to 72%, with Diet-3 costs lowest and Diet-1 highest.

DISCUSSION

Various cereal grains, oilseed, and other agro byproducts have been reported to be suitable for use as ingredients in fish and prawn diets.[31-33] SFC is among the most promising of readily available alternatives of plant protein sources to replace fish meal for tilapia farming in Bangladesh. Although plant ingredients can contain phytohormones and a variety of anti-nutritional substances like protease inhibitors,[19] the use of SFC along with soybean meal as a substitute for fish meal has been reported for many fish and shrimp species.[18,21,22,34] Results with moderate concentrations of SFC as a protein source in aquaculture feeds have been generally positive. In Bangladesh, practical knowledge of SFC as a farm-scale tilapia feed is scarce. All four diets in this study were well accepted by the stocked tilapia, and no abnormal symptoms or reactions were observed in response to any of the treatments. Positive trends on growth and economic performance of tilapia grow-out were observed with all three diets containing variable levels of SFC in this study, as compared to the control diet, with no losses in product nutritional quality. These positive trends were not accompanied by any detrimental effects of the experimental diets or negative impacts on water quality. The potential nutritional effects of available planktonic food organisms on the growth of tilapias were presumed to be similar for all treatments of the feeding trial.

Table 4: Nile tilapia production and economic performance of diets containing variable levels of SFC (mean±SD)

Parameters	Diet-1 control	Diet-2 30% SFC	Diet-3 40% SFC	Diet-4 50% SFC
Production (kg/ha)*	4,022.50±553	4,352.36±203	4,437.55±62	4,112.20±422
Total income (BDT**/ha)*	442,474.61±60,810.02	478,760.08±22,299.96	488,130.70±6,830.17	452,342.00±46,412.45
Total expenditure (BDT/ha)	362,483.76±29,265.82	316,787.78±6,812.74	306,205.45±5,309.37	288,293.45±5,671.25
Gross margin (BDT/ha)*	79,990.86±87,744.10	161,972.30±16,141.37	181,925.25±10,890.22	164,048.55±40,748.90
BCR*	1.23±0.25	1.51±0.04	1.59±0.04	1.56±0.13

*Not significant (P>0.05), **BDT: Bangladesh taka, 78 BDT: $1 USD. SFC: Sunflower cake, SD: Standard deviation, BCR: Benefit cost ratio

Performance of Nile tilapia in terms of health, production, and survival is contingent on factors that include the size of the fry at stocking,[35] age at the time of first feeding,[36] stocking density, genetic quality of the stocked fish, nutrition and feeding strategy,[37] water quality, and grow-out management including the exclusion of external predators. The total final weight of tilapia was not significantly diminished by the inclusion of SFC in any of the diets ($P > 0.05$). Encouraging but statistically insignificant trends appeared in FCR (1.37 ± 0.05), SGR (1.04 ± 0.01), and PER (2.25 ± 0.08) with Diet-3, although no significant difference was detected ($P > 0.05$) among those nutritional indices when comparing responses to the experimental diets. There were no indications of any detrimental effects of the more affordable SFC-based experimental diets. Differences in FCR (1.37–1.68) in the current study from those reported in other studies[38,39] may have resulted from lower stocking densities, more optimally-sized fry, and variable productivity of the earthen experimental pond. Different sources, qualities, and concentrations of dietary plant and animal proteins may also result in significantly variable FCR and SGR reported in some investigations, but that did be not the case within our study.

Significant changes ($P < 0.05$) were seen in whole carcass protein, lipid, and moisture found in harvested tilapia from all the treatments as compared to fingerlings as initially stocked for the feeding trial. Different dietary protein sources including SFC, fish meal, soybean meal, mustard oil cake, and maize did not affect the carcass protein content of harvested tilapia significantly ($P > 0.05$), which is in agreement with the findings of Abdel-Hakim *et al*.[39]

The highest production trend (4,438 kg/ha) was seen in response to Diet-3, but positive production trends were apparent with other diets containing SFC as compared to control, ranging from 4023 to 4438 kg/ha the 100-day grow-out trial. Similar[5] and higher production have been reported, possibly in response to stocking densities,[36] or perhaps reflecting other differences such as the use of floating or sinking feeds, or brackish as opposed to fresh water. Much lower production (421.94–516.69 kg/ha) was reported from rice fields using lower stocking density and tilapia as a second crop, with only fertilization without supplemental feeding.[5] Productivity depends on a spectrum of grow-out management parameters including length of the grow-out period, stocking density, size of the fry, survival rate, type and quality of feed, and water quality management.

The cost of experimental diets was reduced in parallel with the increased inclusion rate of SFC, resulting in economic benefits from Diet 3. Total income, gross margin and BCR per hectare per 100 days achieved from marketing tilapia were US$ 6258, US$ 2332, and 1.59, respectively, with Diet-3. 40% inclusion of SFC in Diet-3 resulted in a 32.38% feed cost reduction per kg of tilapia production over Diet-1 (control), clearly underscoring the economic potential of reducing fish meal, soybean meal, mustard oil cake, and rice bran based protein, and energy sources by replacement with SFC and maize, with no losses in grow-out performance. Fish meal inclusion ranged from 9.5% in Diet-3 up to 16% in the control diet (Diet-1), which may or may not reflect the minimal percent of animal protein required with such plant-based protein sources for cost-effective grow-out feed for tilapia. Omnivorous species like tilapia utilize carbohydrate efficiently as a source of energy, typically requiring 25–35% crude protein.[41] Dietary crude protein requirements met by feeds can be even lower in earthen grow-out systems that support planktonic production since phytoplankton and zooplankton supply some macro- and micro-nutrition essential for the cultured fish growth.[42] Tilapia protein requirements vary according to the protein and energy ratio, and balanced dietary protein and energy are essential in fish feed formulation. Earlier reports[43,44] recommended the same proportion of crude protein (25–35%) and carbohydrate (25–30%) along with 8–10% crude lipid for tilapia grow-out diets. The experimental diets of the present study met or exceeded the standard, for example, Diet-3 had crude protein, carbohydrate, and lipid content at 26.44%, 33.71%, and 9.14%, respectively, within the recommended range, or slightly higher for carbohydrates [Table 3].

Traditionally, fish feed formulations contain 5–50% of fish meal as the main dietary protein source, but for shrimp and carnivorous fish species replacement of fishmeal by plant protein sources has achieved limited success.[45] Feedstuffs containing at least 20% crude protein are used as protein supplements, and SFC with around 30% crude protein is rich in methionine and arginine[46] but with low levels of lysine and threonine.[47] Both lysine and threonine are essential amino acids in *O. niloticus* and are, therefore, required in the diet. Lysine appears to have some rate-limiting effects on growth in juvenile[48] and finishing[49] Nile tilapia. Either deficiencies or excessive quantities of threonine can negatively impact weight gain in juvenile tilapia.[50] For these reasons, some fishmeal or alternative and balanced supplies of lysine and threonine may be necessary to meet requirements for optimal growth and farm production of *O. niloticus*. Considering its high palatability and low anti-nutritional factor content (a polyphenolic compound around 1–3%) SFC has been used up to 30% inclusion in fish feed as an alternative plant protein source to fish meal with good results.[47] A feeding trial with tilapia fingerlings replacing fish meal with SFC meal at 10, 20, 30, 40, and 50% level of a 40% crude protein diet and revealed the best growth and feeding efficiency with 10% and 20% replacement by sunflower seed meal, with values statistically similar to those of the control fish meal based diet.[24] Zero to 100% replacement of fishmeal with sunflower seed meal resulted in optimal *O. niloticus* performance at the 25% level.[25] Reasonable growth and feed conversion were observed in 30% crude protein diets with up to 50% of fish meal protein replaced by sunflower seed meal in *Sarotherodon mossambicus* (now classified as *O. mossambicus*) over a seven to 9-week rearing period.[51] In addition, up to 33% replacement with SFC in Atlantic salmon feed[52] and 42% inclusion in rainbow trout feed produced no adverse effects.[23] The fish meal used in this study was obtained from a locally available dried fish, the chewa (*P. elongatus*). Varying quality of crude protein in fish meal has been ascribed to problems with species composition, storage condition, and insect infestation during storage.[45]

CONCLUSION

The results of the current experiment demonstrated that Nile tilapia (*O. niloticus*) diets formulated with variable levels of SFC as a replacement for a more expensive fish meal and soybean meal protein had no discernable negative effects on productivity and some positive impacts on profitability under authentic farm conditions. There was no significant loss or compromise performance in response to any of the experimental diets**.** Inclusion of SFC between 30 and 50% and 15% yellow maize did not negatively impact grow-out performance, weight gain, survival, SGR, PER, and FCR. Due to the low price of SFC and uncompromised growth performance trends, Diet-3 generated the most commercially appealing pattern of income, gross margin, and BCR in this study. Acceptance by the fish, their health and survival, and their nutritional quality at harvest were excellent. Diminishing the demand for fishmeal could result in positive economic and conservation consequences. Further research is justified to seek the optimal balance of SFC, maize, fishmeal, and other plant protein sources for sustainable and economically viable feed formulation. Additional attention may be required to the adequacy of lysine and threonine in diets with the extensive substitution of SFC for fish meal, especially for production in which plankton-derived essential amino acids are unavailable.

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REFERENCES

1. DoF. Fisheries Statistical Report of Bangladesh 2013-14. Bangladesh, Dhaka: Department of Fisheries (DoF), Ministry of Fisheries and Livestock; 2015.
2. FAO, Food and Agriculture Organization of the United Nations. 2007 FAO Year Book, Fishery and Aquaculture Statistics. Rome: FAO; 2009. p. 72.
3. FAO, Food and Agriculture Organization of the United Nations. The State of World Fisheries and Aquaculture 2016. Rome: Contributing to Food Security and Nutrition for All; 2016. p. 200.
4. Mjoun K, Rosentrater KA, Brown ML. Tilapia: Environmental Biology and Nutritional Requirements. FS963-02. South Dakota: Cooperative Extension Service, South Dakota State University, USDA; 2010.
5. Hossain M, Mridha MA, Shah AK, Nahiduzzaman M, Uddin MS. Performance of mono-sex tilapia (*Oreochromis niloticus*) in rice field with different ditch size. Aquacul Res 2015; 46(8):1891-1901.
6. Khan S, Hossain MS, Hossain MM. Production and economics of GIFT strain of tilapia (*Oreochromis niloticus*) in small seasonal ponds. Prog Agricul 2008;19:97-104
7. Somerville C, Cohen M, Pantanella E, Stankus A, Lovatelli A. Small-scale Aquaponic food Production. Integrated Fish and Plant Farming. Rome: FAO Fisheries and Aquaculture Technical Paper No**.** 589. FAO; 2014. p. 262.
8. Nahar A, Siddik MA, Chaklader MR, Sharker MR, Rahman MM. Biofloc technology in aquaculture systems generates higher income in mono-sex tilapia farming in Bangladesh. Adv Biol Res 2015;9:236-41.
9. López-Luna J, Ibáñez MA, Villarroel M. Using multivariate analysis of water quality in RAS with Nile tilapia (*Oreochromis niloticus*) to model the evolution of macronutrients. Aquacul Eng 2013;54:22-8.
10. Shamsuzzaman MM, Islam MM, Tania NJ, Al-Mamun MA, Barman PP, Xu X. Fisheries resources of Bangladesh: Present status and future direction. Aquacul Fish 2017;2:145-56.

11. Mamun-Ur-Rashid M, Belton B, Phillips M, Rosentrater KA. Improving Aquaculture Feed in Bangladesh: From Feed Ingredients to Farmer Profit to Safe Consumption. World Fish, Penang, Malaysia. Working Paper; 2013. p. 2013-34.
12. Funge-Smith S, Lindebo E, Staples D. Asian fisheries today: The Production and use of Low Value/Trash Fish from Marine Fisheries in the Asia-Pacific Region. Bangkok: FAO; 2005. Available from: http://www.fao.org/docrep/008/ae934e/ae934e00.htm.
13. Asche F, Oglend A, Tveteras S. Regime shifts in the fish meal/soybean meal price ratio. J Agric Econ 2013;64:97-111.
14. Bolivar RB, Jimenez EB, Brown CL. Alternate-day feeding strategy for Nile tilapia grow out in the Philippines: Marginal cost-revenue analyses. North Am J Aquacul 2006;68:192-7.
15. World Fish Center. Producing Tilapia Feed Locally: A Low-cost Option for Small-Scale Farmers. Flyer 1956; 2009. Available from: http://www.pubs.iclarm.net/resource_centre/WF_2462.pdf.
16. Brown CL, Yang TB, Fitzsimmons K, Bolivar R. The value of pig manure as a source of nutrients for mass culture of Nile tilapia in ponds (a review). Agricul Sci 2014;5:1182-93.
17. Maina JG, Beames RM, Higgs D, Mbugua PM, Iwama G, Kisia SM. The feeding value and protein quality in high-fibre and fibre-reduced sunflower cakes and Kenya's "omena" fishmeal for tilapia (*Oreochromis niloticus*). Livestock Res Rural Dev 2007;19. Available from: http://www.lrrd.org/lrrd19/11/main19164.htm. [Last retrieved on 2016 Aug 03].
18. Dayal JS, Rajaram V, Ambasankar K, Ali SA. Sunflower oil cake as a replacement for fish meal in feeds of Tiger shrimp, *Penaeus monodon* reared in tank and in net cages. Indian J Geo-Mar Sci 2011;40:460-70.
19. Munguti JM, Liti DM, Waidbacher H, Straif M, Zollitsch W. Proximate composition of selected potential feedstuffs for Nile tilapia (*Oreochromis niloticus* Linnaeus) production in Kenya. Die Bodenkultur 2006;57:131-41.
20. Francis G, Makkar HP, Beeker K. Antinutritional factors present in plant-derived alternate fish feed ingredients and their effects in fish. Aquaculture 2001;199:197-227.
21. Hasanuzzaman AF, Siddiqui MN, Chisty MA. Optimum replacement of fish meal with soybean meal in diet for *Macrobrachium rosenbergii* (De Man 1879) cultured in low saline water. Turk J Fish Aquatic Sci 2009;9:17-22.
22. Meriç İ, Demir N. Assessment of growth, fatty acids and protein profiles of carp (*Cyprinus carpio* L. 1758) fed diets including incremental levels of sunflower seed meal. Israeli J Aquac Bamidgeh 2012;64:759-8.
23. Sanz A, Morales AE, de la Higuera M, Cardenete G. Sunflower meal compared with soybean meal as partial substitutes for fish meal in rainbow trout (*Oncorhynchus mykiss*) diets: Protein and energy utilization. Aquaculture 1994;128:287-300.
24. Olvera-Novoa MG, Olivera-Castillo L, Martínez-Palacios CL. Sunflower seed meal as a protein source in diets for *Tilapia rendalli* (Boulanger, 1896) fingerlings. Aquacul Res 2002;33:223-9.
25. Ogello EO, Kembenya EM, Githukia CM, Aera CN, Munguty JM, Nyamweya CS. Substitution of fish meal with sunflower seed meal in diets for Nile Tilapia (*Oreochromis niloticus* L.) reared in earthen ponds. J Appl Aquac 2017;1:81-99.
26. Kumar V, Barman D, Kumar K, Kumar V, Mandal SC, Clercq ED. Anti-nutritional factors in plant feedstuffs used in aquafeeds. World Aquacul 2102;43:64-8.
27. Lim CW, Dominy T. Utilization of plant proteins by warm water fish. In: Akiyama DM, Tan RK, editors. Proceedings of the Aquaculture Feed Processing and Nutrition Workshop. Singapore: American Soybean Association; 1991. p. 163-72.
28. Hossain MM, Chakraborty SC. Growth and economic analysis of freshwater prawn, *Macrobrachium rosenbergii* (de Man), produced with feeds substituting sunflower cake for fish meal, soya bean meal and mustard oil cake. Aquac Res 2017;48:5418-29.
29. Boyd CE. Water quality in ponds for aquaculture. Alabama: Alabama Agriculture Experiment Station, Auburn University; 1990. p. 482.
30. AOAC (Association of Official Analytical Chemists). In: Horwitz W, editor. Official Methods of Analysis of AOAC. 13th ed. Washington, DC: AOAC; 1980. p. 1038.
31. Mitra G, Mukhopadhyay PK, Chattopadhyay DN. Nutrition and feeding in freshwater prawn (*Macrobrachium rosenbergii*) farming. Aqua Feeds 2005;2:17-9.
32. Bhavan PS, Ruby SA, Poongodi R, Seenivasan C, Radhakrishnan S. Efficacy of cereals and pulses as feeds for the post-larvae of the freshwater prawn *Macrobrachium rosenbergii*. J Eco-Biotechnol 2010;2:9-19.
33. Beaven U, Bere T, Dzikiti B. Comparative study on maize bran and chicken manure as fish feed supplement: Effects on growth rate of *Oreochromis niloticus* in pond culture system. Int J Aquac 2013;3:23-9.
34. Davis DA, Arnold CR. Replacement of fish meal in practical diets for the pacific white shrimp, *Litopenaeus vannamei*. Aquaculture 2000;185:291-8.
35. Bolivar RB, Jimenez EB, Sugue JR, Brown CL. Effect of stocking sizes on the yield and survival of Nile tilapia (*Oreochromis niloticus* L.) on-grown in ponds. Int Soc Tilapia Aquac Proc 2004;2:574-83.
36. Brown CL, Bolivar RB, Jimenez EB, Szyper JP. Timing of the onset of supplemental feeding of Nile tilapia (*Oreochromis niloticus*) in ponds. In: Fitzsimmons K, Filho JC, editors. Tilapia Aquaculture in the 21st Century. Proceedings from the 5th Int'l Symposium on Tilapia Aquaculture. Brazil: Rio de Janeiro; 2000. p. 682, 237-240.
37. Brown CL, Bolivar RB, Jimenez EB. Philippine studies support moderate feeding in tilapia. Glob Aquac Alliance Advocate 2004;7:4-70.
38. Saha SB, Khatun MS. Production performances of monosex nile tilapia, *Oreochromis niloticus* in brackishwater ponds. Bangladesh J Zool 2014;42:261-9.
39. Abdel-Tawwab M, Fayza EA, Medhat EA. Partial and total replacement of fishmeal with cheese processing by-product meal in practical diets for nile tilapia, *Oreochromis niloticus* (L.): A preliminary study. 2016. Available from: http://www.ag.arizona.edu/azaqua/ista/ISTA9/FullPapers/Mohsendiet.doc.
40. Abdel-Hakim NF, Lashin ME, Al-Azab AA, Nazmi HM. Effects of Replacing Soybean Meal with other Plant Protein Sources on Protein and Energy Utilization and Carcass Composition of Nile tilapia (*Oreochromis niloticus*). 8th International Symposium on Tilapia in Aquaculture; 2008. p. 979-95.
41. Gatlin DM IIIrd. Principles of Fish Nutrition. In: Southern Regional Aquaculture Center (SRAC). Publication No. 5003. College Station TX, USA: Department of Wildlife and Fisheries Sciences, Texas A and M University; 2010. p. 8.
42. Solomon IO, Stella OO. Moisture, protein, and amino acid

contents of three freshwater zooplankton used as feed for aquacultured larvae and postlarvae. Israeli J Aquacul Bamidgeh 2006;58:29-33.
43. El-Dahhar AA. Review article on protein and energy requirements of tilapia and mullet. J Arab Aquac Soc 2007;2:1-28.
44. Bhujel RC. Recent advances: Tilapia nutrition, feeds, and feed management. Advocate Glob Aquacul Alliance 2001:44-47.
45. Dersjant-Li Y. The use of soy protein in aquafeeds. In: Cruz-Suarez LE, Ricque-Marie D, Tapia-Salazar M, Gaxiola-Cortes MG, Simoes N, editors. Advances on Nutrieion Acuicola VI. Memorias del VI Symposium International de Nutrieion Acuicola. 3 al 6 de Septembre del 2002. Mexico: Cancin Quintana Roo; 2002. p. 541-58.
46. Ramachandran S, Singh SK, Larroche CC, Soccol CR, Pandey A. Oil cakes and their biotechnological applications–a review. Bioresour Technol 2007;98:2000-9.
47. Merida SN, Tomas-Vidal A, Martinez-Llorens S, Cerda MJ. Sunflower meal as a partial substitute in juvenile sharpsnout sea bream (*Diplodus puntazzo*) diets: Amino acid retention, gut and liver histology. Aquaculture 2010;298:275-81.
48. Furuya WM, Michelato M, Graciano TS, Vitor L, Vidal O, Xavier O, *et al*. Digestible lysine requirement of Nile tilapia from 86 to 227 g fed arginine to lysine balanced diets. Ciências Agrárias 2013;34:1945-54.
49. Michelato M, Vidal LV, Xavier TO, de Moura LB, de Almeida FL, Pedrosa VB, *et al.* Dietary lysine requirement to enhance muscle development and fillet yield of finishing Nile tilapia. Aquaculture 2016;457:124-30.
50. Yue Y, Zou Z, Zhu J, Li D, Xiao W, Han J. Dietary threonine requirement of juvenile Nile tilapia, *Oreochromis niloticus*. Aquacul Int 2014;22:1457-67.
51. Jackson AJ, Capper BS, Mathy AJ. Evaluation of some plant proteins in complete diets for the tilapia *Sarotherodon mossambicus*. Aquaculture 1982;27:97-109.
52. Gill N, Higgs DA, Skura BJ, Rowshandeli M, Dosanjh S, Mann J, Gannam AI. Nutritive value of partially dehulled and extruded sunflower meal for post-smolt Atlantic Salmon (*Salmo salar* l.) in sea water. Aquacul Res 2006;37:1348-59.