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Potentials of Dietary Betaine Additives in Reduction of the Cost of Production and Improving Nutrient Content of *Oreochromis niloticus* (Linnaeus, 1788)

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ABSTRACT

This study investigated the effects of graded levels of dietary betaine supplementation (0.0, 0.25, 0.50, 0.75 and 1.0 g/100g feed) on growth performance, nutrient utilisation, carcass composition, and feed cost-effectiveness of Nile tilapia (Oreochromis niloticus) fingerlings over a 12-week feeding trial. Three hundred fingerlings with a mean initial weight of 8.00±0.00g were randomly distributed into five treatment groups (BT0-BT4) in triplicate at 20 fish per 300-litre tank. Fish were fed isonitrogenous and isocaloric diets containing 40% crude protein, twice daily at 5% body weight. Results showed that betaine supplementation at 0.50 g/100g (BT2) significantly (P<0.05) improved mean weight gain (44.63g), specific growth rate (2.91%/day), feed conversion ratio (1.72 g/g), protein efficiency ratio (2.31 g/g), and apparent net protein utilisation (55.8%). Fish fed BT2 also exhibited the highest carcass crude protein (19.1%) and lowest carcass lipid (4.2%), indicating enhanced protein deposition. Water quality parameters remained within acceptable ranges across all treatments. Cost analysis revealed that BT2 yielded the most economically favourable production cost per kilogram of fish gain. These findings confirm that betaine at 0.50 g/100g is the optimal inclusion level for cost-effective and nutritionally superior production of Nile tilapia, with significant implications for food security in Nigeria.

Key words: Betaine, *Oreochromis niloticus*, Growth Performance, Feed Conversion Ratio, Protein Efficiency.

INTRODUCTION

Aquaculture in Nigeria represents one of the most critical sectors in addressing the growing protein deficit facing the country's rapidly expanding population (Abdullahi et al., 2025; Ogunji & Wuertz, 2023). Among cultured fish species, Nile tilapia (*Oreochromis niloticus*) stands out as particularly significant due to its economic importance, consumer acceptability, adaptability to captivity, and favourable response to artificial feeding (Idodo-Umeh, 2003). Despite its prominence, the high cost of fish production, driven primarily by the expense of conventional feed ingredients, remains the most formidable barrier to the sector's growth.

Betaine (trimethylglycine; TMG), a naturally occurring compound derived from sugar beets (*Beta vulgaris*), has attracted growing attention as a multifunctional dietary additive. As both an osmoprotectant and methyl group donor, betaine participates in a broad range of cytoprotective and metabolic pathways (Eklund et al., 2005). Its water-soluble nature enables it to effectively stimulate the olfactory sensory system of fish, thereby enhancing feed intake and palatability. Previous studies in common carp (Cyprinus carpio) have demonstrated significant improvements in weight gain, feed conversion ratio, specific growth rate, survival rate, and protein efficiency ratio following betaine supplementation (Abed Ali and Al-Faragi, 2017; Murthy et al., 2016). However, data on its efficacy in *Oreochromis niloticus* under Nigerian aquaculture conditions remain scarce, necessitating this study. This study therefore evaluated the effects of graded dietary betaine levels on growth performance, nutrient utilisation, carcass composition, and the cost-effectiveness of Nile tilapia production over 12 weeks, aiming to identify the optimal betaine inclusion rate that promotes food security by reducing fish production costs.

MATERIALS AND METHODS

Study Area and Experimental Fish

The feeding trial was conducted at the Hydrobiology Research Unit, Biology Department, College of

Education, Zing, Zing Local Government Area, Taraba State, Nigeria. A total of 300 *O. niloticus* fingerlings (mean initial weight: 8.00±0.00g; mean total length: 6.0cm) were procured from a reputable fish farm in Jalingo, Taraba State. Fish were acclimatised for one week in aerated flow-through freshwater before the commencement of the trial.

Experimental Diets and Design

Five isonitrogenous (40% crude protein) and isocaloric experimental diets were formulated using Pearson's square method, incorporating betaine (sourced from Bon Amour Pharmacy, Lagos, imported from Piping Rock Health Products, USA) at levels of 0.0, 0.25, 0.50, 0.75, and 1.0 g/100g, designated BT0 (control), BT1, BT2, BT3, and BT4, respectively. Feed ingredients included fish meal, soybean meal, groundnut cake meal, yellow maize, fish oil, vegetable oil, starch, lysine, methionine, vitamin/mineral premix, salt, and chromic oxide (Cr2O3) as an inert digestibility marker at 0.5% inclusion. Fifteen 1,000-litre rectangular plastic tanks (300-litre water volume each) were stocked at 20 fingerlings per tank in a completely randomised design with three replicates per treatment. Fish were fed twice daily (08:00–09:00 and 16:00–17:00) at 5% body weight for 12 weeks. Biweekly sampling determined weight gain and feed ration adjustments.

Measurements and Analytical Methods

- Growth performance indices including mean weight gain (MWG), daily weight gain (DWG), specific growth rate (SGR), relative growth rate (RGR), survival rate (SR), and condition factor (K) were computed using standard equations (Stickney et al., 2006).
- Nutrient utilisation was assessed through feed conversion ratio (FCR), protein efficiency ratio (PER), apparent net protein utilisation (ANPU), and nitrogen metabolism (NM).
- Apparent digestibility coefficients (ADC) of protein and lipid were estimated by the indirect method using chromic oxide as an inert marker.
- Proximate composition of diets and fish carcasses was determined using AOAC (2005) standard methods.
- Water quality parameters (temperature, pH, dissolved oxygen, and ammonia) were measured fortnightly using a Horiba U-22 XD multi-parameter checker.
- One-way ANOVA analysed the data, and treatment means were separated using Fisher's LSD at $P<0.05$ (SAS, 2010).

RESULTS

Proximate Composition of Experimental Diets

Table 1 presents the proximate composition of the five experimental diets. All diets were comparable in crude protein content (39.8–40.4%), confirming the isonitrogenous nature of the formulations. Gross energy values ranged from 17.42 to 17.73 KJ/g across treatments, with BT2 recording the highest value. No significant differences were observed in moisture, ash, or crude fibre across treatments, indicating consistent diet quality.

Table 1. Proximate Composition of Experimental Diets with Graded Betaine Levels

Parameter (%)	BT0 (0.0 g/100g)	BT1 (0.25 g/100g)	BT2 (0.5 g/100g)	BT3 (0.75 g/100g)	BT4 (1.0 g/100g)
Crude Protein	39.8	40.1	40.4	40.2	40.0
Crude Lipid	6.1	6.3	6.5	6.4	6.2
Crude Fibre	4.8	4.7	4.6	4.7	4.8
Moisture	9.2	9.1	9.0	9.1	9.2
Ash	7.9	7.8	7.7	7.8	7.9
NFE	32.2	32.0	31.8	31.8	31.9
Gross Energy (KJ/g)	17.42	17.59	17.73	17.66	17.51

Values are means of triplicate determinations. NFE = Nitrogen-Free Extract.

Growth Performance

Table 2 presents the growth performance indices of *O. niloticus* fed the experimental diets. Fish fed BT2 (0.50 g/100g betaine) recorded significantly ($P<0.05$) higher final weight (52.63g), mean weight gain (44.63g), daily weight gain (0.531 g/day), specific growth rate (2.91%/day), relative growth rate

(557.9%), and survival rate (95.0%) compared to the control group (BT0). The condition factor was highest in BT2 (K=2.39), indicating superior physiological well-being. Growth performance declined at higher betaine levels (BT3 and BT4), suggesting that inclusion beyond 0.50 g/100g does not confer additional benefit and may be inhibitory at 1.0 g/100g.

Table 2. Growth Performance Indices of *O. niloticus* Fed Graded Dietary Betaine Levels

Parameter	BT0	BT1	BT2	BT3	BT4
Initial Weight (g)	8.00	8.00	8.00	8.00	8.00
Final Weight (g)	38.42^{c}	44.17^{b}	52.63^{a}	48.91^{ab}	42.38^{bc}
MWG (g)	30.42^{c}	36.17^{b}	44.63^{a}	40.91^{ab}	34.38^{bc}
DWG (g/day)	0.362^{c}	0.430^{b}	0.531^{a}	0.487^{ab}	0.409^{bc}
SGR (%/day)	2.14^{c}	2.46^{b}	2.91^{a}	2.72^{ab}	2.31^{bc}
RGR (%)	380.3^{c}	452.1^{b}	557.9^{a}	511.4^{ab}	429.8^{bc}
Survival Rate (%)	85.0^{b}	88.3^{ab}	95.0^{a}	91.7^{ab}	86.7^{b}
Condition Factor (K)	1.83^{c}	2.04^{bc}	2.39^{a}	2.21^{ab}	1.97^{bc}

Means with different superscripts in the same row differ significantly (P<0.05). MWG = Mean Weight Gain; DWG = Daily Weight Gain; SGR = Specific Growth Rate; RGR = Relative Growth Rate.

Nutrient Utilisation and Feed Conversion

Betaine supplementation significantly influenced nutrient utilisation parameters (Table 3). The lowest FCR (1.72 g/g) and highest PER (2.31 g/g) were recorded for fish fed BT2, indicating superior feed efficiency and protein utilisation at this inclusion level. Apparent digestibility coefficients for both protein and lipid were significantly higher in BT2-fed fish (82.3% and 79.1%, respectively) compared to the control (71.4% and 68.2%). ANPU was highest in BT2 (55.8%), confirming greater retention of ingested dietary protein in fish tissues. Nitrogen metabolism values followed the same trend, with BT2 recording the highest metabolic efficiency (0.303 g/day).

Table 3. Nutrient Utilization Parameters of *O. niloticus* Fed Graded Dietary Betaine Levels

Parameter	BT0	BT1	BT2	BT3	BT4
FCR (g/g)	2.41^{a}	2.13^{b}	1.72^{c}	1.91^{bc}	2.24^{ab}
PER (g/g)	1.63^{c}	1.89^{bc}	2.31^{a}	2.11^{ab}	1.74^{bc}
ANPU (%)	42.3^{c}	47.6^{bc}	55.8^{a}	52.1^{ab}	45.2^{bc}
ADC – Protein (%)	71.4^{c}	75.9^{bc}	82.3^{a}	79.6^{ab}	74.1^{bc}
ADC – Lipid (%)	68.2^{c}	72.4^{bc}	79.1^{a}	76.3^{ab}	70.8^{bc}
NM (g/day)	0.214^{c}	0.248^{b}	0.303^{a}	0.281^{ab}	0.236^{bc}

Means with different superscripts in the same row differ significantly (P<0.05). FCR = Feed Conversion Ratio; PER = Protein Efficiency Ratio; ANPU = Apparent Net Protein Utilization; ADC = Apparent Digestibility Coefficient; NM = Nitrogen Metabolism.

Carcass Composition of *O. niloticus*

The proximate carcass composition of fish at the end of the feeding trial is shown in Table 4. Fish in the BT2 group exhibited significantly higher carcass crude protein (19.1%) and lower carcass lipid (4.2%) compared to all other groups. Ash content was also highest in BT2-fed fish (4.1%), indicating enhanced mineral deposition. Moisture content did not differ significantly across treatments. These results suggest that dietary betaine at 0.50 g/100g promotes lean muscle deposition and reduces fat accumulation in fish tissues.

Table 4. Carcass Proximate Composition of *O. niloticus* Fed Graded Dietary Betaine Levels

Parameter (%)	BT0	BT1	BT2	BT3	BT4
Crude Protein	16.2^{c}	17.4^{bc}	19.1^{a}	18.3^{ab}	16.9^{bc}
Crude Lipid	5.3^{a}	4.9^{ab}	4.2^{c}	4.5^{bc}	5.0^{ab}
Moisture	72.1	72.3	72.4	72.2	72.1
Ash	3.6^{b}	3.8^{ab}	4.1^{a}	4.0^{a}	3.7^{ab}

Means with different superscripts in the same row differ significantly (P<0.05).
Parameters confirm that the variation in growth and nutrient utilization observed across treatment groups was attributable to dietary betaine levels and not water quality differences.

Water Quality Parameters

Mean water quality parameters measured across all treatment groups throughout the 12-week trial are presented in Table 5. Temperature, pH, dissolved oxygen, and ammonia levels were comparable across all treatments and remained within ranges considered acceptable for optimal Nile tilapia production. The stability of these parameters confirms that variation in growth and nutrient utilisation across treatment groups was attributable to dietary betaine levels, not water quality differences.

Table 5. Mean Water Quality Parameters Across Treatment Groups

Parameter	BT0	BT1	BT2	BT3	BT4
Temperature (°C)	26.4±0.3	26.5±0.2	26.6±0.3	26.5±0.2	26.4±0.3
pH	7.1±0.2	7.2±0.1	7.2±0.2	7.1±0.1	7.1±0.2
DO (mg/L)	6.8±0.4	6.9±0.3	7.0±0.3	6.9±0.4	6.8±0.3
Ammonia (mg/L)	0.031±0.004	0.029±0.003	0.026±0.003	0.028±0.004	0.030±0.004

Values are means ± standard deviation. DO = Dissolved Oxygen.

Cost-Effectiveness of Betaine Supplementation

A feed cost analysis compared production cost per kilogram of fish weight gain across all treatment groups. Although betaine supplementation marginally increased feed cost per kilogram, the significantly improved FCR in BT2 reduced the total feed required per unit of growth. Consequently, the overall production cost per kilogram of fish gain was lowest in the BT2 group. This demonstrates that betaine inclusion at 0.50 g/100g is economically advantageous, as gains in feed efficiency more than offset the additional cost of betaine supplementation.

DISCUSSION

Growth Performance

The significant improvement in growth performance observed in *O. niloticus* fed BT2 (0.50 g/100g betaine) is consistent with the findings of Abed Ali and Al-Faragi (2017), who reported enhanced specific growth rate, survival rate, and protein efficiency ratio in common carp supplemented with 0.25% betaine. Similarly, Murthy et al. (2016) demonstrated that betaine supplementation enhanced growth and feed utilisation in common carp. The superior performance observed in BT2 compared to BT0 (control) may be attributed to betaine's role as a potent feed attractant and palatability enhancer. As a highly water-soluble compound, betaine diffuses rapidly in the aquatic environment and stimulates the olfactory bulb of fish, thereby increasing voluntary feed intake (Leong-Seng et al., 2019). This enhanced feed intake, combined with improved digestibility, translates to greater nutrient availability for growth.

The diminished performance observed in BT3 and BT4 relative to BT2 suggests a dose-dependent response with an optimum threshold. Excess betaine supplementation beyond the optimal level may interfere with normal amino acid metabolism or competitively inhibit other methyl donors, resulting in suboptimal growth responses. This dose-dependent response to feed additives is well established in fish nutrition literature and underscores the importance of precisely quantifying optimal inclusion rates. The higher condition factor (K) recorded in BT2-fed fish further confirms the positive effect of betaine on overall body condition and physiological fitness. A higher K-value reflects better energy storage and body reserves, which are important for disease resistance and reproductive success.

Feed Conversion and Nutrient Utilization

The significantly improved FCR in BT2 (1.72 g/g) compared to the control BT0 (2.41 g/g) demonstrates that dietary betaine at the optimal inclusion level substantially enhances the efficiency with which ingested feed is converted to growth. This reduction in FCR has important economic implications, as feed constitutes approximately 60–70% of total fish production costs in Nigeria. A lower FCR directly translates to reduced feed wastage and lower production costs, which addresses a central challenge in Nigerian aquaculture.

The higher apparent digestibility coefficients for protein and lipid in BT2 indicate that betaine supplementation improves the bioavailability of these key macronutrients. This may be related to betaine's role as a methyl donor in regulating liver function and lipid metabolism, which enhances nutrient absorption efficiency in the gastrointestinal tract. The higher ANPU values observed in betaine-supplemented groups further confirm that a greater proportion of ingested dietary protein was

retained in fish carcass tissue rather than being excreted, which is nutritionally and economically advantageous.

Carcass Composition and Nutritional Quality

The significantly elevated carcass crude protein and reduced lipid content observed in BT2-fed fish are particularly noteworthy from a human nutrition and food security perspective. Betaine acts as a lipotropic agent; it mobilises fat from the liver and redirects metabolic energy toward protein synthesis and lean tissue deposition rather than fat accumulation. This mechanism is supported by betaine's methyl-transfer function in hepatic fat metabolism. Fish with higher carcass protein content and lower fat content represent a higher-quality, more nutritious product for consumers.

These findings carry significant implications for food security in Nigeria, where protein malnutrition remains a public health challenge. Producing fish with enhanced protein content and reduced fat through simple dietary additive inclusion represents a cost-effective, practical strategy for improving the nutritional quality of animal protein available to the Nigerian public.

Water Quality Parameters

The absence of significant differences in water quality parameters across treatment groups confirms that betaine supplementation at the levels tested does not adversely affect aquatic environmental conditions. The lower ammonia levels observed in betaine-supplemented groups (particularly BT2) may reflect improved nitrogen retention and reduced excretion, consistent with the higher ANPU and nitrogen metabolism values recorded. This has positive environmental implications, as reduced nitrogen loading into aquaculture effluents can mitigate the risk of eutrophication and ammonia toxicity in receiving water bodies.

Cost-Effectiveness

The economic analysis affirms that the enhanced feed efficiency realised through betaine supplementation at 0.50 g/100g generates net production savings that justify the additional cost of betaine as a feed additive. In a production environment where feed costs are a dominant constraint on profitability, the ability to reduce FCR from 2.41 to 1.72 g/g represents a substantial reduction in feed expenditure per kilogram of fish produced. This finding aligns with the broader goal of developing cost-effective, naturally derived feed additives that reduce the overall cost of fish production while simultaneously improving fish quality.

CONCLUSION

This study has demonstrated that dietary betaine supplementation significantly enhances growth performance, feed utilisation, carcass protein deposition, and cost-effectiveness of Nile tilapia (*O. niloticus*) production in a controlled tank culture system. The optimal betaine inclusion rate was established at 0.50 g/100g feed (BT2), which produced the best outcomes across all measured parameters, including the highest mean weight gain (44.63g), the lowest feed conversion ratio (1.72 g/g), the greatest carcass crude protein (19.1%), and the most favourable production cost per kilogram of fish gain. Beyond 0.50 g/100g, betaine showed diminishing returns, indicating a clear dose-response threshold. The stability of water quality parameters across all treatments confirms the environmental safety of betaine as a feed additive at the inclusion levels tested.

Betaine, a naturally derived, low-cost supplement sourced from sugar beet processing by-products, presents a practical, accessible, and scientifically validated solution to two of the most pressing challenges in Nigerian aquaculture: the high cost of fish production and the nutritional quality of farmed fish. The findings of this study make a compelling case for adopting betaine supplementation in commercial *O. niloticus* production systems as a meaningful contribution to national food security goals.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are advanced: Dietary betaine should be incorporated at 0.50 g/100g of feed in Nile tilapia (*O. niloticus*) production diets as the optimal inclusion level for maximizing growth performance, nutrient utilization, and cost-effectiveness; Fish feed manufacturers and commercial tilapia farmers in Nigeria should consider integrating betaine supplementation into their feed formulations as a strategy to reduce feed wastage, lower production costs, and improve the nutritional value of farmed fish for consumers.

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