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An Evaluation of Iso-Nitrogenous Floating and Sinking Diets on Growth, Feed Utilization and Apparent Digestibility of the Redbreast Tilapia (*Coptodon rendalli* Boulenger, 1897)

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ABSTRACT

One of the main challenges in the tilapia culture in Malawi is the low growth rates and yields. This study aimed to compare iso-nitrogenous fish feeds concerning growth, feed utilization, and apparent digestibility of the redbreast tilapia (*Coptodon rendalli*) raised in pond-hapas and tanks. *Coptodon rendalli* fingerlings were stocked in hapas (1m² each) at 10 fish per hapa, each measuring 6.81± 0.33g, and reared for 70 days. The fish were fed on floating, sinking, and maize bran (control) feeds. In a parallel digestibility experiment, six aquarium glass tanks were stocked with 10 *Coptodon rendalli* fingerlings, each for 21 days. Fecal material was collected and transferred into conical flasks after one hour of feeding for storage at -20°C. Results showed significant differences in specific growth rate, weight gain, relative condition factor, final weight, and survival rate, with floating feeds yielding the highest values ($P< 0.001$). The fish displayed negative allometric growth, with a growth coefficient of b=1.84. Apparent feed conversion ratio and protein efficiency ratio varied significantly across treatments ($P< 0.001$). In the digestibility experiment, differences in protein digestibility were also significant ($P< 0.001$), while no significant differences were observed in fat ($P = 0.22$), ash ($P = 0.53$), and energy ($P = 0.34$) across treatments. Fish fed on floating feeds exhibited better growth, feed utilization, and digestibility, highlighting the need to enhance the use of floating feeds in aquaculture

INTRODUCTION

Aquaculture remains one of the most important sources of proteins, moreover it is considered an income generation for millions of people in Malawi and the world **(FAO, 2018)**. The lack of international consistent, coherent and effective cooperation among countries and institutions worsens the availability of these proteins **(FAO, 2020)**. Aqua feed formulated at desirable nutrient levels according to the dietary nutrient requirements of the fish minimizes wastage, leading to increased growth, utilization and digestibility **(Tomás-Vidal *et al.*, 2019)**. In aquaculture, feed usually accounts for 40-60% of the operational costs depending on the level of culture and fish species **(Scott *et al.*, 2005; Hasan & Michael, 2013)**. The provision of high-quality and cost-effective aqua feeds that satisfy the nutritional requirements of cultured fish species and optimize growth is thus, a prerequisite **(FAO, 2018)**. *Coptodon rendalli* (the redbreast tilapia, Boulenger, 1897) according to **Makwinja *et al.* (2013)**, is one of the common raised fish species by farmers in Malawi. Its major attributes for culture include: acceptance of artificial feeds after yolk sac absorption, resistance to handling stress, a voracious plant feeder thus efficiently utilizes locally formulated feeds and consumer acceptance. Several authors attribute *Coptodon rendalli* to be an important food commodity and a fast-growing species **(Fitzsimmons, 2000; Alceste & Jory, 2002; Hlophe & Moyo, 2013)**. In aquaculture, the use of floating and sinking fish feeds on fish growth; nutrient utilization and yield have generated inconsistent results **(Ajani *et al.*, 2011)**. Quality ingredients for their use as aqua-feeds are assessed by a series of indicators, such as growth performance, biochemical composition, as well as effects on disease and histopathology **(Poleksic *et al.*, 2010)**. **El-Gendy (2017)** reported the highest ranges of body weight, body length, condition factor, daily weight gain and specific growth rate for the Nile tilapia fed on floating feeds. Similar observations on higher growth rates of *Coptodon rendalli* fed on floating feed were made by other authors **(Zidana *et al.*, 2015)**. Contradictions however, were reported by **Abiodun and Boboye (2014)**, whose feed conversion ratios recorded for commercial floating feeds were higher than two locally formulated sinking feeds compounded with fish and feather meal. Inconsistent results on the same observation were also reported by **Wu *et al.* (2015)** showing low growth of *Trachinotus ovatus* fed on formulated floating feed in net pens.

Conversely, poor feed nutrient digestibility leads to minimal utilization of feed nutrients by the fish. The presence of anti-nutritional factors such as histamine and phytic acid in plant materials used in feeds reduces the bioavailability of zinc and depresses on protein digestion in fish **(Abdoulaye *et al.*, 2011; Kemigabo *et al.*, 2017)**. Maintenance energy requirements are dependent on the dietary micronutrient composition and fish meal replacement with other ingredients associates well with different nutrient composition **(Schrama *et al.*, 2012; Koch *et al.*, 2016)**.

This study assessed the growth and feed utilization of *Coptodon rendalli* fed on three diets. These included two iso-proteinaceous (floating and sinking) diets with maize bran as a control for growth and utilization and two iso-proteinaceous (floating and sinking) diets for the apparent digestibility.

MATERIALS AND METHODS

Study area

The study was conducted at the Mzuzu Fish Farming Center facilities in Mzuzu City, Malawi (11. 45456^{0} S and 034.03233^{0} E) (Fig. 1). The digestibility experiment was carried out in the Mzuzu University Fisheries and Aquatic Science Laboratory.

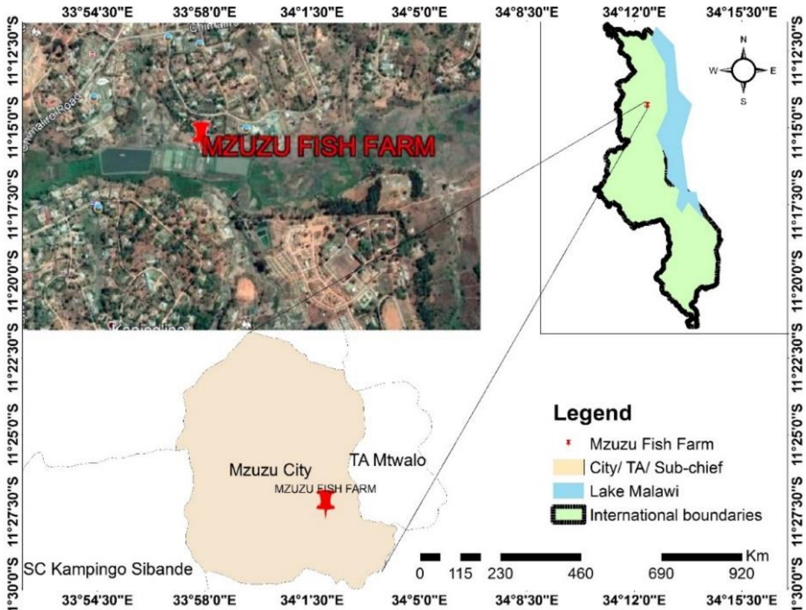

Fig. 1. Location of study area

Research design

Fish growth and feed utilization experiment

The experiment was laid out in a completely randomized design (CRD) with three treatments (feeds); T_1 (floating), T_2 (sinking) and T_3 (maize bran) in nine (9) 1m^3 hapas (i.e. 3 hapas per treatment) with a mesh size of 0.8cm in triplicate. The hapas were set out in a 50m x 100m x 2m pond. The hapas (0.75m) were submerged in water with a free board of 0.25m on the water surface and 0.25m from the pond bottom. The hapas were positioned at a distance of 5 meters away from the pond dyke and 1 meter between hapas to control sedimentation from the pond bottom and also allow for easy nutrient dilution. The water level in the pond was maintained by replenishing with water after every 3 days. Ten *Coptodon rendalli* fingerlings, whose average initial weight is 6.81± 0.33g, were stocked into each hapa and raised for 70 days. During the experiment, weekly cleaning of hapa nets with a gentle brush was done to minimize on biofouling by bryozoans and other organisms. The fingerlings were fed twice daily till apparent satiation was achieved between 09:00 and 15:00.

Apparent digestibility experiment

The experiment was laid out in a completely randomized design (CRD) where two treatments (feeds); T_1 (floating) and T_2 (sinking) were used. Six glass aquarium tanks with a capacity of $0.0315m^3$ were used. Tanks were cleaned and disinfected using chlorinated water and sodium chloride (Common salt) to remove potential pathogens. Tanks were sun dried for one hour and later set for the experiment. Tap water used in the experiment was left for 48 hours to allow for chlorine evaporation before using the glass tanks. Each experimental tank was filled with $0.02364m^3$ of water (3/4 full). Moreover, each aquarium tank was stocked with ten *C. rendalli* fingerlings with an initial average weight of 8.42± 0.33g and length 72.52± 0.91mm. The tanks were covered with a meshed net to stop the fish from jumping out of the fish tank. The fish were fed twice a day until satiation between 09:00 and 15:00. Additionally, air to the experimental tanks was supplied using an aeration pump (Model: AP-115RN, 100 Volts, REI-SEA CO. LTD, China).

Experimental diets

A 32% of crude protein in 1mm pellet size floating fish feed was procured whose major animal and plant protein sources were fish meal and soya bean, respectively. Another 32% crude protein sinking fish feed was locally made from available ingredients purchased from Mzuzu market, Malawi and formulated using Pearson’s Square method (Table 1).

Table 1. Ingredients used in formulation of the fish diet

Ingredient	Inclusion rate (%)
Fish meal	10.0
Soya bean	50.0
Wheat flour	13.4
Maize	25.5
Fish oil	0.4
Vitamins	0.2
Minerals	0.3
Common salt	0.2
Total	**100**

Amino acid micros; Lysine 20,000mg, Methionine 25,000mg.

The protein components for the formulation were chosen according to their cost, availability and suitability for use in aquafeeds. Principal animal and plant protein sources consisted of fish meal and soya bean, respectively. Other ingredients included maize, wheat flour, common salt, vitamin, mineral premixes and cooking oil.

Preparation of the sinking diet

Soya bean grains were roasted in a frying pan to remove anti-nutritional factors like trypsin inhibitor. Temperature was monitored using a thermometer at 105°C. Maize and wheat bran were prepared by pulverizing whole grains into bran (125μm) using a hammer mill (Model: Y2-160M-4, Dongxiang Hongxiang, China). The soya bean and fish meal were milled into powder and the milled ingredients were manually mixed using a spade to form a homogenized mixture. Water, salt, vitamin premix and cooking oil were added to the homogenized mixture. The mixture was steam pelleted at 90-120°C using an electric powered pelletizer (Model: Y2-160M-4, Dongxiang Hongxiang, China) to form 1mm fish feed pellets. Formulated pellets were spread on a clean synthetic tarpaulin and dried under the shade for three days to reduce moisture content.

Proximate analysis of feed ingredients

One gram of each ingredient in triplicate was subjected to proximate analysis (Table 2) for essential nutrients using standard procedures **(AOAC, 2003)** at the Lilongwe University of Agriculture and Natural Resources' nutritional laboratory.

Table 2. Proximate composition (%) of the main ingredients for diet formulation (Mean ± SD)

Ingredient	% Dry Matter	% Crude protein	% Crude fat	% Crude fiber	% Ash
Fish meal	88.86±0.08	63.15±0.17	20.56±0.11	0.36±0.01	12.02±0.04
Soya bean	92.59±0.09	41.06±0.42	22.27±0.60	3.57±0.09	5.86±0.02
Wheat bran	93.52±0.22	17.99±0.57	0.97±0.01	1.17±0.05	3.22±0.01
Maize bran	93.57±0.09	11.35±0.08	1.11±0.01	1.06±0.08	2.54±0.01

Nutrients included dry matter, crude protein, crude lipid, crude fibre and ash. Dry matter was calculated by weighing after drying to a constant weight in an oven at 100-105°C. Crude protein was determined by the Kjedahl method. Percentage protein was calculated by multiplying apparent nitrogen by 6.25. Lipid extraction was done using Soxhlet apparatus. Crude fiber was determined by transferring the residue into a crucible and placed in a muffle furnace at 400-600°C for 4 hours. This was cooled in a desiccator and weighed. Ash was determined by weighing the sample in a pre-heated crucible, which was further put in a muffle furnace at 400-600°C for 4 hours until a white-grey ash was obtained. The crucible was placed in a desiccator and weighed. The experimental diets for the digestibility experiment were formulated with an addition of 1% of an inert indigestible indicator, chromic oxide (Cr_2O_3) prior to feeding.

Data collection

Fish growth and feed utilization

Growth parameters - total length (mm) and weight (g) were collected using a measuring board and digital scale (Model: ATY224, Shimadzu, Philippines), respectively, every 14 days. A total of seven *C. rendalli* fingerlings were sampled per hapa. The data collected were further calculated as follows:

a) Specific growth rate (% / day) was calculated using the following formula by **Chiu (1989)**

$$\mathbf{SGR}(\%/\mathbf{day}) = \frac{(\mathbf{LnWf} - \mathbf{LnW}i)}{\mathbf{t}} * \mathbf{100}$$

Where, $\mathbf{LnW_f}$ is the natural log of final body weight (g), $\mathbf{LnW_i}$ is the natural log of initial body weight (g) and **"t"** is the time or number of the days for the trial.

b) Weight gain was analyzed using the formula described by **Chiu (1989)**

$$\mathbf{Weight\ gain\ (g)} = \mathbf{Wt_2} - \mathbf{Wt_1}$$

Where, $\mathbf{Wt_2}$ is final mean weight of fish at time $\mathbf{t_2}$ and $\mathbf{Wt_1}$ is initial mean weight fish at time $\mathbf{t_1}$.

c) Length-weight relationship was analyzed using the following formula:

$$\mathbf{W} = \mathbf{aL^b}$$

Where, **W** is weight in grams; ***a*** is the intercept; ***L*** is the length in millimeters, and ***b*** is the exponent of the length-weight regression but transformed using logs.

d) Relative condition factor (Kn) was analyzed using the following formula **(Le Cren, 1951)**

$$\mathbf{K} = \frac{\mathbf{W}}{\mathbf{aL^b}}$$

Where, **W** is weight (g); ***a*** is the intercept; ***L*** is the length (mm), and ***b*** is the exponent of the length-weight regression but transformed using logs.

e) Apparent feed conversion ratio was analyzed using the following formula **(Byerly, 1967)**:

$$\mathbf{Apparent\ feed\ conversion\ ratio} = \frac{\mathbf{Total\ dry\ feed\ fed(g)}}{\mathbf{Wet\ weight\ gain\ (g)}}$$

f) Protein efficiency ratio was analyzed using the formula **(AOAC, 1996)**:

$$\mathbf{PER} = \frac{\mathbf{Total\ weight\ gain\ (g)}}{\mathbf{Total\ protein\ fed\ (g)}}$$

g) Survival rate was analyzed using the following formula **(Fleiss, 1973)**:

$$\mathbf{Survival\ rate}(\%) = \frac{\mathbf{Nf}}{\mathbf{Ni}} \times \mathbf{100}$$

Where, $\mathbf{N_f}$ is final number of fish at the end of experiment, and $\mathbf{N_i}$ is initial number of fish at the beginning of the experiment.

Apparent digestibility

Fecal materials were collected one hour before decomposition of fecal material after feeding. This was done in the experimental units using a siphon horse pipe of length 1.8 meters and 1- inch diameter (Model: Vecligt, M8617, China) connected to an electric pump (Model: AP-115RN, 100 Volts, REI-SEA CO.LTD, China). The overnight accumulated fecal materials were collected the following morning at 06:00 a.m. The siphoned fecal materials were delivered onto a filter mounted with a glass microfiber filter paper (Model: Chalice, GFI grade, 47 mm Ø). The filtered fecal materials were then placed in conical borosilicate conical flasks of 250ml (Model: Sammach, 250 ml, China) using a spatula. The flasks were covered with aluminum foil and stored at -20^{o}C awaiting further chemical analysis for crude protein, crude lipid, energy and ash.

Apparent nutrient digestibility coefficients were analyzed using the following formula **(Weiss, 2009)**:

$$\mathbf{ADCN(diet)} = \mathbf{100} - \left\{\mathbf{100}\left[\left({}^{\mathbf{Crd}}/_{\mathbf{Crf}}\right) \times \left({}^{\mathbf{Fn}}/_{\mathbf{Dn}}\right)\right]\right\}$$

Where, $\mathbf{Cr_d}$: % Chromium oxide in diet; $\mathbf{Cr_f}$: % Chromium oxide in feaces; $\mathbf{F_n}$: % Nutrient in feaces, and $\mathbf{D_n}$: % Nutrient in diet.

Water quality parameters

The various *in-situ* physico-chemical water quality parameters - pH, dissolved oxygen (mg/L), temperature (^{o}C) and conductivity (µS/cm) were measured three times a day (09:00, 12:00, and 15:00). A multi-parameter water quality probe (Model: HACH, 44600 Conductivity / TDS meter, USA and Model: H198130 Hannah probe) was used.

Data analysis

Data were subjected to normality and homogeneity of variances using Shapiro-Wilk's and Bartlett's tests, respectively. A one-way analysis of variance (ANOVA) was used to test for significance in treatment means at 5 % significance level for growth and utilization parameters. Statistically significant treatment means were separated using

Tukey's *Honest Significant Difference post hoc*. Non-linear data were log transformed. The log transformed data for the length-weight relationship (LWR) were analyzed by the cube law **(Le Cren, 1951)**. A linear regression was used to establish the relationship between length and weight. A one sample t-test was used to test for significant differences in the growth exponent coefficient in relation to the isometric exponent coefficient (b = 3) at 5 % significance level. A T-test for independent samples was used to test for significant differences between treatment means for the apparent digestibility coefficients of feed nutrients of floating and sinking diets at 5% significance. A multiple linear regression model using unstandardized values was run to establish the relationship between water quality parameters and growth parameters of length and weight. All statistical analysis were carried out in Python Statistical Package Version 3.12.1 using Jupiter Notebook version 6.5.4 and Spyder Version 5.5.1 application environments.

RESULTS

Growth of fish

The results for fish growth are presented in Table (3). Significant differences were higher for the floating diet in the parameters of specific growth rate (SGR), weight gain (WG), relative condition factor (RCF), final weight (FW) and survival rate (SR) (*P*<0.001) than other treatments. Significant differences for SGR, final weight and survival were observed between sinking and maize bran diets (*P* < 0.05).

Table 3. Growth parameters of *Coptodon rendalli* fed on floating, sinking and maize bran feeds (Mean ± S.E)

Feed (Diet)	Growth parameter					
	Initial weight (g)	**Final weight (g)**	**Weight gain (g)**	**SGR (%)**	**Condition factor (Kn)**	**Survival (%)**
Floating	6.81±0.33	16.02±0.35[a]	3.15±0.16[a]	1.16±0.03[a]	1.09±0.02[a]	97.87±0.39[a]
Sinking	6.81±0.33	12.40±0.23[b]	1.94±0.12[b]	0.81±0.02[b]	0.99±0.01[b]	95.97±0.38[b]
Maize bran	6.81±0.33	10.20±0.09[c]	1.24±0.08[b]	0.54±0.02[c]	0.96±0.02[b]	94.58±0.39[c]

Values in the same column with different superscript are significantly different at *P*< 0.05 according to Tukey's HSD.

The weight (g) of fish during the experimental period is shown in Fig. (2). Fish that were fed on floating feed indicated a higher weight gain during the culture period than other feeds.

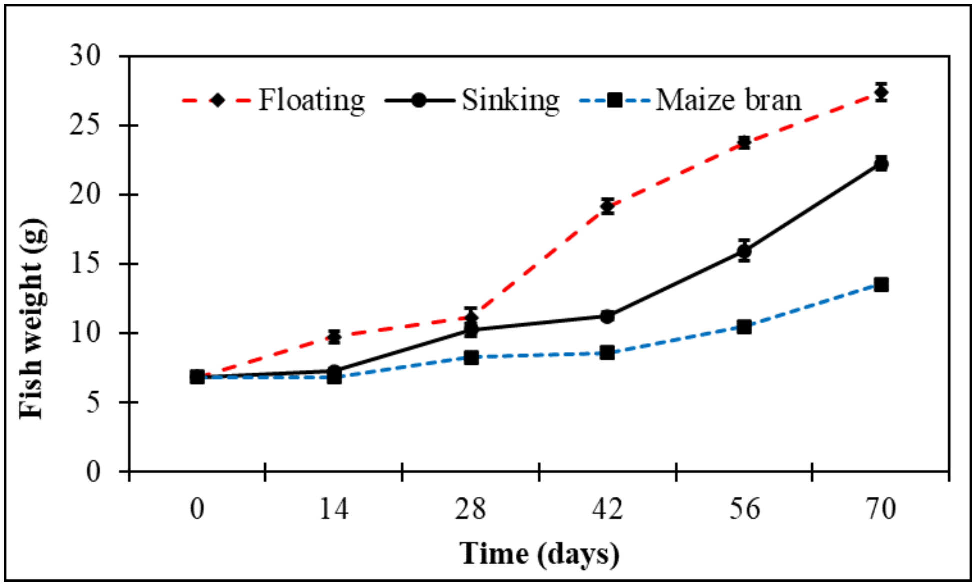

Fig. 2. Weight of *Coptodon rendalli* grown in hapas and fed on floating, sinking and maize bran diets (Mean ±SE)

Length weight relationship

Fig. (3) shows the length-weight relationship for *C. rendalli*. The fish exhibited negative allometric growth, with a growth exponent coefficient (b) of 1.84, which is less than the isometric growth reference value of 3. This indicates that the fish are increasing in length faster than in weight relative to the cube of their length.

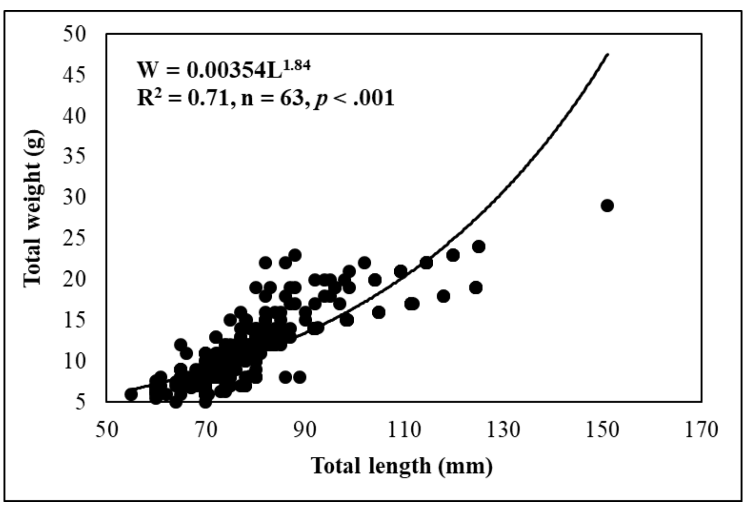

Fig. 3. Length-weight relationship of *Coptodon rendalli* during the experimental period across all treatments

The growth exponent coefficient (b value) results for the feed treatments are indicated in Table (4). The mean growth exponent coefficient “b” (1.47± 0.10) was significantly lower than the isometric value of 3, P =0.004.

Table 4. Length-weight relationship ($W = aL^b$) of *Coptodon rendalli* among all treatments

Feed	n	R^2	b value	*P*-value
Floating	21	0.66	1.28	<.001
Sinking	21	0.65	1.54	<.001
Maize bran	21	0.50	1.58	<.001

Feed utilization

Fig. (4) presents the results for feed utilization. Significant differences in the apparent feed conversion ratio (AFCR) were observed across all treatments (*P*< 0.001). The AFCR for the floating diet was significantly lower than that for other diets (*P*< 0.05), with the highest mean AFCR value being 2.23± 0.07 and the lowest being 1.08± 0.02.

Significant differences in the protein efficiency ratio (PER) of *C. rendalli* fingerlings were also recorded across all treatments (*P*< 0.001). The maximum PER mean value was 0.09 ± 0.00, while the minimum was 0.06 ± 0.00. Significant differences were observed between the floating feed and other feed treatments (*P*< 0.001), but no significant differences were found between sinking and maize bran feeds (*P* = 0.77). PER was significantly higher for the floating diet (*P*< 0.05). No significant difference was found between sinking and maize bran diets (*P*> 0.05). A positive relationship between fish weight and PER was observed (R = 0.70).

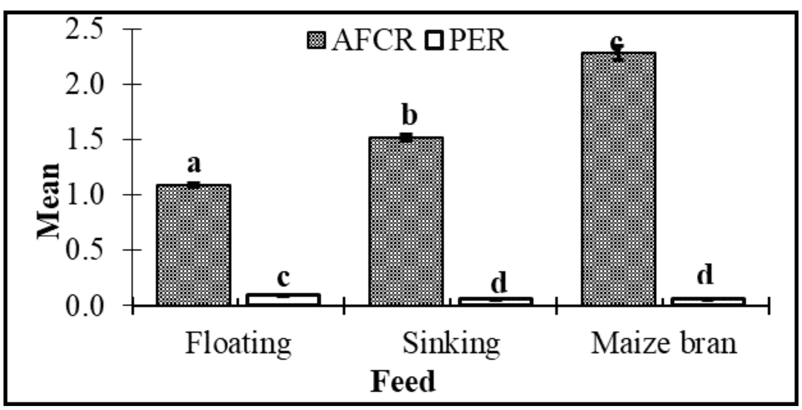

Fig. 4. Apparent feed conversion ratio and protein efficiency ratio of *Coptodon rendalli* calculated for the feed treatments (Mean ± SE)

Apparent digestibility

Results for the apparent digestibility coefficients of different nutrients of the floating and sinking diets are presented in Table (5). Significant differences in protein digestibility were observed, *P*< 0.001. However, no significant differences in fat, *P*= 0.22, ash, *P*= 0.53 and eenergy, *P* = 0.34 were observed. Protein digestibility was significantly higher for floating diet than the sinking diet, $P< 0.05$. No significant differences in digestibility of crude fat, ash and energy were observed for both diets, $P > 0.05$.

Table 5. Apparent digestibility coefficients (%) of various feed nutrients (Mean ±SE)

Nutrient	Crude Protein	Crude fat	Ash	Energy
Floating	74.66 ± 0.99[a]	90.79 ± 0.79[b]	69.49 ± 4.94[c]	89.44 ± 3.93[d]
Sinking	58.00 ± 2.33[b]	89.01 ± 0.31[b]	65.00 ± 1.49[c]	81.92 ± 5.88[d]

Values in the same column with different superscript are significantly different at $P< 0.05$.

Water quality parameters

Water quality parameters indicated a positive relationship between the growth parameters of length and weight **(**Figs. 5, 6). The regression model indicated a positive correlation between water quality parameters and fish length, R= 0.62. For the variance in length accounted for by water quality parameters, $R^2= 0.40$ was statistically significant, $P< 0.001$. The model revealed a positive correlation between water quality parameters and fish weight, R= 0.67 (Fig. 6).

The variance in weight that was accounted for by water quality parameters, $R^2 = 0.44$ was statistically significant, $P<0.001$. Dissolved oxygen mean values reported ranged between 7.90± 0.55 and 7.32± 0.54mg/ L, Temperature was 24.42± 0.21 and 24.18± 0.15°C; pH was 7.29± 0.12 and 7.11± 0.10 and finally, 59.46± 2.74 and 54.72± 2.71µS/ cm^{-1} for conductivity.

In the digestibility experiment, no significant difference was observed in the water quality parameters, $P >0.05$. Dissolved oxygen mean values ranged between 6.57± 0.06 and 6.45± 0.06mg/ L, temperature was 22.98 ± 0.08 and 22.89 ± 0.07°C, pH was 7.29± 0.01 and 7.30± 0.01 and finally, 90.45± 2.42 and 89.63± 5.83µS/ cm^{-1} for conductivity.

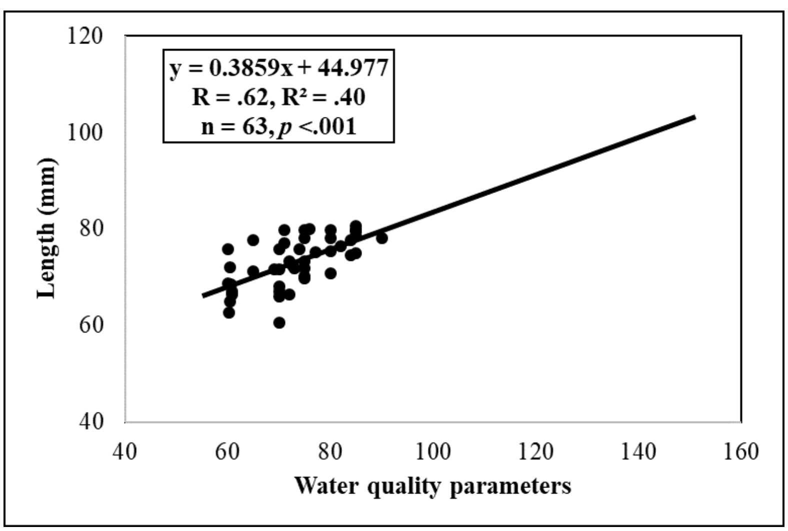

Fig. 5. Regression of water quality and *Coptodon rendalli* length

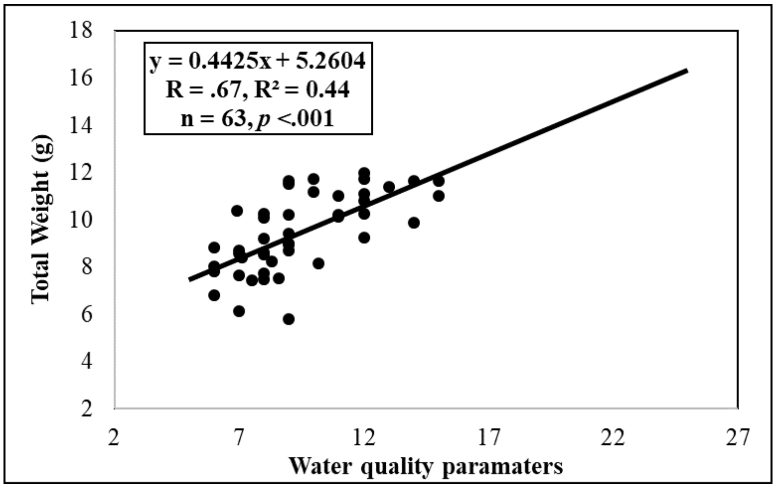

Fig. 6. Regression of water quality and *Coptodon rendalli* weight

DISCUSSION

Growth of fish

Fish fed on floating feeds exhibited a higher SGR compared to the other diets. Fish fed on sinking and maize bran were seen to spit out the pellets after swallowing suggestive of low palatability resulting into minimal nutrient intake and consequently, limited growth earlier observed by **Chutima (2014)**, concluding that a nutritionally palatable and organoleptically-pleasing feed is a prerequisite toward achieving satisfactory fish growth. The presence of varying sizes as *C. rendalli* cultured led to territorial behavior. The fast-growing fish tend to be aggressive to the smaller fish and thus, feed consumption to the whole fish stock is limited leading to poor growth. **Blanchet *et al.* (2007)** identified anti-predatory and territorial behavior as key factors in fish growth although results showed no effect on the Atlantic salmon (*Salmo salar*) fry. The high fish weight gain in floating diet could be as a result of the extrusion process which makes the feed palatable. Better performance of floating feed in improving fish weight gain in the current study is supported by previous work **(Yoo & Lee, 2016)**. The high condition factor of the fish could be attributed to the fish health condition, low stocking densities and better feed utilization, conforming to those previously reported by **Famoofi and Abdul (2020)**. Although gut (stomach) fullness was not investigated in this study and may require further investigation, it is apparent that it does not significantly affect fish condition **(Hanjavanit *et al.*, 2013)**.

Since the fish were fingerlings and had not reached breeding age, they experienced an increased feeding frequency and a minimal utilization of lipid reserves, resulting in better condition factor values. **Lizama and Ambrósio (2002)** associated decreased condition factors with breeding, which often leads to an excessive utilization of lipid reserves during spawning. Survival rates were relatively high (>90%) through all treatments. This could be ascribed to favorable water conditions in the ponds. **Anusuya *et al.* (2017)** associated favorable environmental conditions with higher fish survival rates. Fish across the treatments showed a negative allometric growth ($b<3$) which could be associated to the variation in fish sizes during growth. The mean recorded "b" value was lower than the ranges of 2.29 and 3.68, as recorded for the Nile tilapia in the Atbara River and Khashm El-Girba reservoir, respectively **(Ahmed *et al.*, 2011)**.

Feed utilization

Lower values of the AFCR are indicative of the effectiveness of the fish converting the consumed feed into body flesh **(Abaho *et al.*, 2020)**. The low AFCR in the floating and sinking feed treatments can be linked to the animal protein source which had a better amino acid profilation than the maize bran thus better feed utilization. The presence of anti-nutritional factors that limit nutrient intake and nutrition could have accounted for the high AFCR and reduced weight gain in the maize bran and sinking feed. Results by **Kemigabo *et al.* (2017)** on the African catfish in tanks indicated that, toasting of plant ingredients used in feed formulation had no effect on phytic acid. Substitution of feed in the water column by sinking feed could be one of the reasons for the high FCR. *C. rendalli* being a voracious fish, cannot consume the bottom feed when fed on sinking feed, but rather consume the feed in the water column. The high PER of *C. rendalli* fingerlings fed on floating feed could be attributed to the source of ingredients and their mode of preparation. Similar results for PER were reported by **Nalawade and Bhilave (2011)** on commercially formulated floating feeds in *Labeo rohita* cultured for 75 days. The difference in the PER of the various treatments could be attributed to genetic and non-genetic factors, as reported by **Buxbaum (2007)** who elucidated that protein deposition in organisms is dictated by animal's genetic and epigenetic codes. Specific targets are determined by endogenous (genetic, life stage) and exogenous (feed, environment) factors.

Nutrient digestibility

The differences in the ADCs of protein, energy and lipid can be explained by differences in the origin and quality of the ingredients used in the diets. **Kitagima and Fracalossi (2011)** attributed the low dry matter digestibility of fish and shrimp offal meal to high ash contents. Similar findings were reported for the hybrid Nile tilapia (*Oreochromis niloticus* x *Oreochromis aureus*) by **Zhou and Yue (2012)**. The high values in our study may be due to the degree of lipid unsaturation and the lipid level. Lipid digestibility is influenced by several factors, including the degree of unsaturation, various constituents, dietary lipid level, and factors affecting fatty acid chain length and melting points **(Yuan *et al.*, 2010; Oujifard *et al.*, 2012)**. Nonetheless, the crude protein and lipid values obtained in the current study were higher than those reported by **Xavier (2014)**, with values less than 37%.

Water quality parameters

The biology and physiology of the fish are greatly impacted by water quality, and thus, affecting the health and productivity of fish in a culture system **(Boyd, 2017)**. Good water quality maintenance in fish pond culture is in fact essential for an optimal fish growth. In this study, optimum and suitable water quality parameters were maintained by continuously replenishing the ponds with fresh aerated water. Water quality parameters across all treatments oscillated within accepted ranges required for the ideal tilapia growth as suggested by **Popma and Masser (2017)**, and therefore, had no effect on both growth and survival of the *C. rendalli* fish. Dissolved oxygen (DO) concentration, pH and temperature in this study are similar to those reported by **Asmah *et al.* (2014)**, who recommended DO concentrations and pH for the tilapia as >3mg/ L and 6-9 respectively, and optimal temperature between 27 and 32°C, which is also endorsed by **Mengistu *et al.* (2020)**.

Further, the low DO levels could be a result of inadequate exchange of water among the hapas **(Mensah *et al.*, 2018)**. Overall, obtained water quality parameter values were within the satisfactory ranges required for the tilapia growth. Water quality parameters for the growth experiment were within the optimal ranges for the tilapia culture similar to those reported by **El-Naggar *et al.* (2000)**. Therefore, the observed differences in fish growth may not be fully attributed to water quality parameters.

CONCLUSION

The study concluded that floating diets resulted in better growth and feed utilization even when the iso-nitrogenous diets are used. Consequently, the same applied to the digestibility of various nutrients for the floating and sinking diets. The biofortification of sinking feeds with probiotics that enhance fish growth needs to be intensified as a recommendation in fish culture.

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