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Length–weight relationship and prediction equations of body composition for growing-finishing cage-farmed Nile tilapia

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ABSTRACT - The objective of the present study was to develop models for predicting live weight from the length-weight relationship and body composition of Nile tilapia. A total of 3,000 juvenile fish (initial weight = 28.6±4.16 g and standard length = 13.8±0.16 cm) were distributed into three circular cages (12 m^3 each). The fish were hand-fed extruded diets containing 332 g kg^{-1} of crude protein and 3,230 kcal kg^{-1} of digestible energy, until apparent satiety, twice daily, for 100 days. Twelve fish were collected from each cage every 20 days for measurements of body weight and length, and proximate composition analysis; statistical analysis was conducted using linear regression. The value of the slope b and the intercept for the length-weight relationship were 3.0604 and 0.0203, respectively. The prediction equations obtained for body moisture (MO), crude protein (CP), crude lipid (CL), and ash against body weight (BW) in g/100 g of fish were as follows: MO = 70.0090 – 0.0071BW; CP = 13.7550 + 0.0037BW; CL = 9.2636 + 0.0057BW; and ash = 4.2392 – 0.0024BW. It is possible to develop equations to predict body weight and composition, which can be used to control the production of Nile tilapia and improve its commercial value.

Key Words: amino acids, aquaculture, fish, mathematical modeling

Introduction

Mathematical models of fish growth offer an objective and practical method for describing patterns of growth data and estimating fish weight at times between sampling intervals. Accurate estimations of standing biomass, and therefore, of the amount of feed that must be provided, are vital to aquaculture management. Additionally, knowledge of the relationships between body weight and composition supports selection during efforts for the improvement of aquaculture genetics. An accurate length-weight relationship equation allows for the conversion of growth-in-length to growth-in-weight in stock assessment models, as well as the estimation of biomass from the length frequency distribution, condition (Petrakis and Stergiou, 1995), and morphological characteristics of fish populations (Stergiou and Moutopolous, 2001); the relationship equation, thus, is an important aquacultural management tool.

Growth, which is defined as a change in magnitude, can be measured in size and tissue composition and represents one of the most significant parameters in aquaculture. The body composition of fish has recently received attention in studies on nutrition, genetics, and health (Tobin et al., 2006) because of the increasing interest in the quality and safety of fish products (Dumas et al., 2010). Body composition is an important aspect of nutritional quality (Kamal et al., 2007; Breck, 2014) and affects the nutritional value and consumption quality of fish (Azam et al., 2004). Despite the usefulness of the length-weight relationship and body composition, as well as the great economic importance of Nile tilapia (*Oreochromis niloticus*) to global aquaculture, little information on these factors is available in cage-farmed growing-finishing populations of the species. The present study was conducted to determine the length-weight relationship and develop prediction equations of body composition for growing-finishing cage-farmed Nile tilapia by using regression analysis.

Material and Methods

The management was in accordance with the guidelines of the Animal Care Committee of Universidade Estadual de Maringá, Paraná, Brazil.

A total of 3,000 masculinized juvenile Nile tilapia (initial weight = 28.6±4.16 g; standard length = 13.8±0.16 cm; age, 60 days) were randomly distributed into three hexagonal cages (11 m^3 each) placed at a local mean depth of 6.0±1.3 m in the Paranapanema River (22°34'07"S; 52°33'34"W). A mix of

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vegetable and animal protein sources was used to formulate an extruded diet (Table 1) containing 332 g kg^{-1} of crude protein and 3,230 kcal kg^{-1} of digestible energy (Table 2). Crystalline amino acids were added to maintain the quantitative and essential amino acid profile recommended for Nile tilapia as described in NRC (2011). Fish were hand-fed to apparent satiety twice daily for 100 days. Water quality parameters were monitored daily during the feeding trial. The average water temperature was 28.5±1.3 °C; pH, 7.34±0.21; and dissolved oxygen varied from 6.2 to 6.6 mg L^{-1}.

At the beginning of the experiment and every 20 days afterwards, 12 fish were randomly selected from each cage, starved for 24 h and collected to determine individual weight, standard length, and whole-body composition. Whole-body samples of fish were pooled, ground, and stored at −20 °C for proximate analysis.

Table 1 - Formulation of the experimental diet

Ingredient	g kg^{-1}
Corn flour	59.7
Soybean meal	157.0
Wheat bran	167.5
Sorghum flour	199.9
Meat and bone meal	119.5
Fish meal	75.0
Poultry by-products meal	164.5
Bean flour	45.0
DL-methionine	2.5
Choline chloride	2.6
Ascorbic acid	0.7
Mineral and vitamin mix[1]	1.1
Salt	5.00

[1] Composition per kg: vitamin A = 20,000,000 IU; vitamin D_3 = 6,400,000 IU; vitamin E = 160,000,000 IU; vitamin K_3 = 15,000,000 mg; vitamin B_1 = 15,000,000 mg; vitamin B_2 = 20,000,000 mg; vitamin B_6 = 16,000,000 mg; vitamin B_{12} = 14,000,000 mg; folic acid = 3,000 mg; pantothenic acid = 11,000,000 mg; biotin = 100,000,000 mg; choline = 142,000 mg; niacin = 200,000,000 mg; iron = 48 mg; copper = 24 mg; manganese = 36 mg; iodine = 6 mg; selenium = 0.48 mg.

Table 2 - Analyzed composition of the experimental diet (g kg^{-1} as fed basis)

Parameter	g kg^{-1}
Dry matter	922.1
Gross energy (kcal kg^{-1})	4240.0
Crude protein	332.1
Ether extract	46.4
Crude fiber	33.4
Ash	94.1
Calcium	17.2
Total phosphorus	9.1
Lysine	15.3
Arginine	20.6
Histidine	6.2
Isoleucine	11.4
Leucine	22.2
Methionine	6.5
Methionine + cystine	11.2
Phenylalanine + tyrosine	23.1
Threonine	11.0
Valine	14.6

The proximate composition analyses of the fish samples were performed following the procedures of the AOAC (1990). Water content was determined by placing the fish in a previously weighed aluminum foil tray, drying in an electric oven at 55 °C until constant weight was achieved, and then oven-drying at 105 °C for 24 h. Crude protein (nitrogen × 6.25) was determined using the micro-Kjeldahl method after acid hydrolysis. Lipid was extracted using petroleum ether in a Soxhlet apparatus and determined gravimetrically. Ash was determined by combustion at 550 °C in a muffle furnace for 6 h.

Gross energy was determined using an adiabatic bomb calorimeter. Dietary amino acids were analyzed by hydrolyzing 0.3 mg fish sample in 1 mL of 6N HCl for 22 h. The obtained sample was diluted in 0.02N HCl and injected in an automatic Amino Acid Analyzer. Recovery hydrolysis was performed in 4N methanesulfonic acid for the analysis of tryptophan and in performic acid for the recovery of sulfur amino acids.

Data on the total body length (L) and body weight were recorded from each fish. The parameters *a* and *b* of the length-weight relationship were estimated by logarithmic transformation of the equation $W = a \times L^b$, in which *W* is the body weight (g); *L* is the standard body length (cm); *a* is the intercept; and *b* is the slope. Length-weight relationships were used to provide the condition of fish and determine whether growth is isometric (b = 3) or allometric (negative allometric: b<3, or positive allometric: b>3) (Ricker, 1973). To check whether the average *b* value was significantly different from 3.0, the *t*-test was conducted at 0.05 significance. All statistical analyses were performed using the statistical package SPSS 14.0. The body composition data were analyzed by one-way analysis of variance (ANOVA) at a significance level of p<0.05. The prediction equations for body composition were developed using linear ($\hat{y}_i = ß_0 + ß_1x_i$) or second-order ($\hat{y}_i = ß_0 + ß_1x_i + ß_1x_i^2$) polynomial regression analysis (Zeiton et al., 1976). The degree of association between the variables was analyzed according to the determination coefficient (r^2) for each variable.

Results and Discussion

At the end of the experiment, a high daily weight gain (7.5 g) was observed (Table 3). Although indoor experiments offer uniform chemical and physical water-quality parameters that can be controlled, the advantage of conducting experiments in rivers is the high rates of water turnover, resulting in high and constant levels of dissolved oxygen and water temperature, which allow for a high daily weight gain in fish. The daily weight gain of fish in the present study was higher than that reported by Moraes et al. (2009) for Nile tilapia reared in indoor cages at the same density. Factors such as diet composition (Moraes et al., 2009), stocking density (Araujo et al., 2010), and chemical and physical parameters of the water may affect the fish growth; however, the higher weight gain of fish in this study was because the fish were fed until apparent satiation. Feed intake is a major factor for tilapia growth (Tran-Duy et al., 2012), and in our study, fish preferred to be fed to apparent satiation because of the constant and high dissolved oxygen concentration during trial studies. Besides this, all essential amino acids were supplied to meet the dietary requirement of Nile tilapia, as described in NRC (2011) based on the ideal-protein concept, to optimize protein (amino acids) utilization for fish growth and health (Li et al., 2009).

The length-weight relationship was established using the equation $W = 0.0203 \times L^{3.0604}$ ($R^2 = 0.9914$) (Figure 1). The mean value of *b* (3.0604) did not significantly differ ($P<0.05$) from the standard value of 3.0, implying that the "cube law" could be applied for this species (Ricker, 1973). When the weigh-length exponent *b* is equal to 3.0, the body form maintains a constant proportion to the length and the fish grows isometrically, resulting in an ideal shape (Pauly, 1983). However, when *b* is less than 3.0, the fish shows negative allometric growth, and when the *b* value is greater than 3.0, the fish shows positive allometric growth (Weatherley and Gill, 1987). Similar results were obtained for Nile tilapia collected from the Atbara River and Khashm El-Girba reservoir by Ahmed et al. (2011), who found a *b* value higher than 3.0 (3.415) for this species. Thus, the fish are expected to grow proportionally in all directions.

Changes in fish weight are generally greater than those in fish length (Ahmed et al., 2011). In general, when the value of *b* exceeds 3.0, fish become fatter, and when the value falls below 3.0, fish become leaner. The value of *b* found in the present study is within the interval of 2.5 to 3.5 recorded for many fish species by Froese (2006), as well as between the values of 2.299 and 3.684 recorded for Nile tilapia in the Atbara River and Khashm El-Girba reservoir, respectively (Ahmed et al., 2011). However, this value is slightly higher than the mean value (*b* = 2.908) described by Britton and Harper (2008) for Nile tilapia with 4.0-23.1 cm in length.

All linear regressions were significant, with coefficients of determination (r^2) ranging from 0.7743 to 0.8628. The relationships between body weight and body moisture, crude protein, and crude lipid were best expressed using linear regression analysis (Table 4). As shown in several studies, when the size of fish increase, more fat is deposited than the formation of other tissues (Salam and Davies, 1994; Salam et al., 2001). The compositions of various organs and bodily tissues may also show considerable differences (Weatherly and Gill, 1987). However, whole-body composition follows a similar pattern among different species as fish size increases (Lupatsch et al., 2001; Dumas et al., 2010), and the live weight of the majority of fishes consists of approximately 700-800 g kg^{-1} of water, 200-300 g kg^{-1} of protein, and 20-120 g kg^{-1} of lipid (Love, 1980).

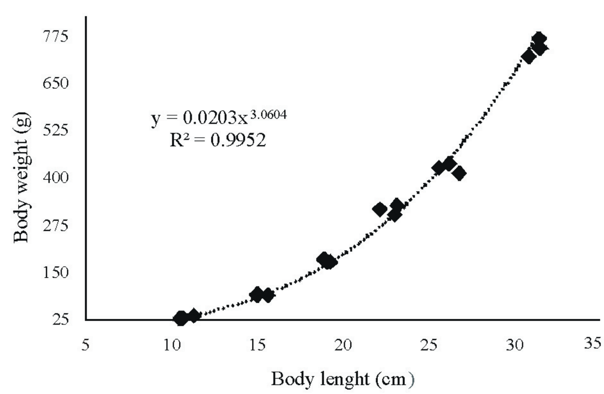

Figure 1 - Length-weight relationship of growing-finishing cage-farmed Nile tilapia (*Oreochromis niloticus*).

Table 3 - Growth and body composition (g 100 g^{-1} wet weight basis) of growing-finishing cage-farmed Nile tilapia (*Oreochromis niloticus*)[1]

Variable	Days of culture					
	1	20	40	60	80	100
Growth						
Body weight (g)	28.6±4.2	88.6±1.4	177.6±3.6	313.8±12.8	423.7±12.7	774.4±23.6
Standard length (cm)	10.9±0.4	15.3±0.4	19.1±0.2	22.8±0.5	26.3±0.6	31.3±0.4
Body composition						
Moisture	70.0±1.2	69.1±0.7	69.2±0.6	67.2±0.4	67.1±0.6	65.1±0.2
Crude protein	14.2±0.4	13.5±0.4	14.5±0.4	15.1±0.2	15.3±0.5	16.3±0.6
Crude lipid	8.6±0.3	10.1±0.6	10.5±0.3	11.5±0.3	12.1±0.7	12.8±0.4
Ash	4.2±0.4	4.2±0.2	3.5±0.5	3.6±0.2	3.5±0.4	2.4±0.1

[1] Values represent the mean±standard deviation of three replicate groups.

The whole-body composition of fish is affected by species (Ali et al., 2005), environmental parameters (Ali et al., 2001), nutrition, and body size (Ebrahimi and Ouraji, 2012). Information on body composition related to fish size can be used to select fish with higher protein contents at a specific size, for human consumption (Ali et al., 2005). Fish represents one of the main sources of protein in developing countries (Louka et al., 2004). The moisture content is a good indicator of body protein and lipid contents (Ali et al., 2005), as observed in this study (Figure 2); lower moisture percentages are associated with higher lipid contents in fish (Dempson et al., 2004). Hartman and Margraf (2008) reported a significant fat-water relationship and developed models to predict the proximate composition for chum salmon (*Oncorhynchus keta*), rainbow trout (*Oncorhynchus tshawytscha*), brook trout (*Salvelinus fontinalis*), and striped bass (*Morone saxatilis*).

In the present study, moisture and ash contents decreased linearly with the increase in body weight. However, the body fat content increased linearly as a function of body weight. This result is in agreement with that described by Salam et al. (2001), who observed an increase in fat content with increase in the size of Nile tilapia. Memid et al. (2006) reported that the body constituents of Russian sturgeon (*Acipenser gueldenstaedtii*) could be estimated with reasonable accuracy from the weight of the fish by using a predictive regression model. Pangle and Sutton (2005) described a linear regression model for estimating temporal changes in the proximate composition of juvenile lake herring (*Coregonus artedi*) during winter periods. Breck (2014) reviewed the close relationship of body size to body composition for many freshwater and marine fish species. Understanding the relationship between body weight and length, as well as developing prediction equations for body composition, provide important support for genetic improvement, fish management, feeding strategies, and marketing.

Table 4 - Number of studied fish (n), intercept ($ß_0$), slope ($ß_1$), P-values, and correlation coefficients of body composition parameters for growing-finishing cage-farmed Nile tilapia (*Oreochromis niloticus*)

Variable	n	$ß_0$	$ß_1$	P-value	r^2
Moisture	18	70.0090	–0.0071	<0.05	0.8628
Crude protein	18	13.7550	0.0037	<0.05	0.7743
Crude lipid	18	9.2636	0.0057	<0.05	0.8107
Ash	18	4.3280	–0.0025	<0.05	0.8189

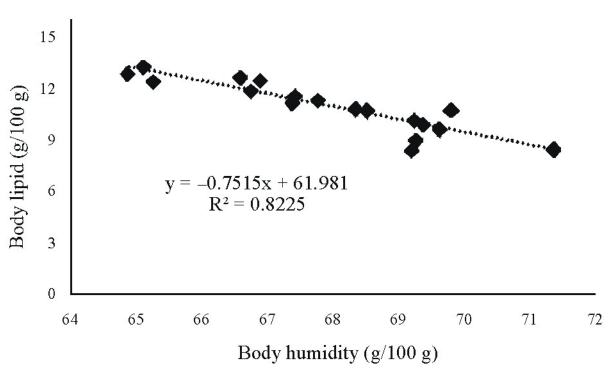

Figure 2 - Linear regression of body moisture against crude lipid for growing-finishing cage-farmed Nile tilapia (*Oreochromis niloticus*).

Conclusions

The body composition of Nile tilapia varies according to its body weight and can be estimated using the length-weight relationship. Prediction equations of body composition derived from linear regression analysis can be employed to address the requirements of specific consumer markets.

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