Description of growth and body composition of freshwater angelfish (*Pterophyllum scalare*) by Gompertz model

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ABSTRACT - The objective of this study was to describe the growth of freshwater angelfish (*Pterophyllum scalare*) using the Gompertz model, determining the relative growth and allometric coefficients of body components in relation to body weight and protein weight. Six hundred animals were grown until 233 days of age. Data on chemical composition (water, lipid, protein, and ash) and weight measurements were obtained each 30 days. The Gompertz growth equation was used to analyze chemical allometry and to estimate growth parameters. The relationship between chemical components and body protein was estimated. Protein and body weight increased proportionally, with ash being the earliest nutrient (209.2 days), while lipid deposition occurred later. Linear regression analysis showed an inverse relationship between lipids and body water. This study provided a useful equation to predict the growth, chemical body composition, and rate of nutrient deposition across the life stages of freshwater angelfish. The rates of nutrient deposition as a function of body weight are important to understand the growth process of freshwater angelfish. Thus, mature weight was estimated in 26.14 g. The allometric relationships of body components and deposition rates indicated that protein and body weight are highly correlated across the life stages of freshwater angelfish. The Gompertz equation is a useful tool to describe the growth and body composition of freshwater angelfish.

Key Words: allometry, growth curve, ornamental fish

Introduction

The freshwater angelfish (*Pterophyllum scalare*) is an ornamental fish native to the Amazon, Orinoco, and Essequibo rivers in South America. It is a popular aquarium species because of its characteristics such as beauty, reproductive behavior, and adaptability to captivity (Sharon et al., 2013). Breeding and improvement of this species have resulted in different strains such as marmorate, gold, siamese, koi, leopard, black, smoke, and clown freshwater angelfish (Ribeiro et al., 2007). However, although several studies on different strains are available, very little is known about the nutrition, growth, and nutritional requirements of this species, factors that are essential for the release of a species on the aquaculture market.

Knowledge about body composition and nutrient deposition rates is important to reduce overall feed waste, improve feed efficiency, and increase profitability (Chowdhury and Bureau, 2009), as well as optimize nutrient conversion into biomass and improve the quality of the final product (Neme et al., 2006; Dumas et al., 2010). Growth and nutrient deposition are accurate parameters to investigate the feed efficiency and nutrient requirements of fish; therefore, to predict the quantitative relationship between nutrient intake and growth and/or nutrient deposition, it is necessary to apply an appropriate model (Belal, 2005).

Mathematical models are analytical solutions of differential equations that can be adjusted to the growth data of animals using nonlinear regression (Sarmento et al., 2006; Thornley and France, 2007; Dumas et al., 2010). Two important factors need to be considered for the selection of an appropriate growth curve model: the possibility of biological interpretation of the parameters and quality adjust (Fitzhugh Jr. and Taylon, 1971; Galeano-Vasco et al., 2014). Several nonlinear mathematical models exist to describe the growth and deposition of body nutrients. One of these

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models is the Gompertz model (Hota, 1994; Marcato et al., 2010; Allaman et al., 2013). An advantage of this model is its sensitivity to estimate the initial values of rapidly growing animals with a very low initial weight, as the example of tadpoles that have a weight of 0.01 g at the beginning of their lives (Mansano et al., 2012, 2014).

For a better explanation and understanding of the freshwater angelfish growth, the allometric growth method can still be used, which refers to changing different dimensions of body parts that are correlated with the whole-body changes (Gayon, 2000; Garcia et al., 2009). Thornley and France (2007) define allometric growth as the growth of a body part (*x*) at a different proportional rate from that of the whole body (*y*). Isometric and allometric relationships based on regression analysis prevail as the best methods to estimate body composition in farmed fish (Dumas et al., 2010). The objective of this study was to describe and predict the growth, chemical body composition, and rate of nutrient deposition in relation to body weight (BW) and protein weight of freshwater angelfish by using the Gompertz and allometry models.

Material and Methods

The experiment was conducted in Jaboticabal, SP, Brazil (Latitude: −21.2554, Longitude: −48.3224 21° 15'19"South, 48° 19' 21" West). All procedures followed in the trial were according to the ethical guidelines adopted by the Brazilian College of Animal Experimentation (COBEA) and were approved by the local Ethics Committee on Animal Use (Case no. 8827/15).

Six hundred freshwater angelfish fry (30 days old, 0.2422±0.055 g) were used. The animals were kept in twelve 200-L plastic tanks, 50 fish per tank. The diets were formulated according to Zuanon et al. (2006) and Ribeiro et al. (2007) (Table 1), given at 6% body weight, four times a day during the grower phase (30-83 days of age) and twice a day during the finisher phase (84-233 days of age). Fifty percent of the tank water was replaced daily. The water quality parameters, such as temperature and dissolved oxygen, were maintained at proper levels and were noted as 28.6±1.02 °C and 6.04±1.33 mg/L, respectively, during the grower phase, while 26.7±1.47 °C and 5.93±1.10 mg/L, respectively, during the finisher phase. The photoperiod consisted of 12 h light and 12 h darkness.

Every two weeks, a sample of 20 fish previously starved for 24 h was randomly chosen. These animals were subjected to body weight determination. The body composition was evaluated monthly. During the first four months, a pooled sample from all tanks was taken for body composition

analysis due to the low weight of the individuals. After this period, samples of each tank were selected. The animals were anesthetized with benzocaine (0.4 g/L) and euthanized for subsequent analysis. After this procedure, the animals were freeze-dried and ground. The protein, lipid, and ash contents of the samples were determined using the methods described by the AOAC (2000).

The following Gompertz equation was used to describe the growth and nutrient deposition of freshwater angelfish (Gous et al., 1999):

$$W_t = W_m . \exp\{-\exp[-B_W(t - t^*)]\},$$

in which W_t is the weight (g) of the animal at time *t*; W_m is the maturity weight (g) of the animal; B_w (g per day) is a rate of maturing parameter; and *t**(days) is the time at which the growth rate is at its maximum. The growth rate and nutrient deposition rate were calculated using the first derived of Gompertz equation. The absolute growth rate is:

$$dW/dt = B_W . W . \ln\left(W_m/w\right)$$

The classic allometric equation $y = a \times x^b$ was linearized using natural logarithm, as described by Thornley and France (2007), and was used for allometric evaluation:

$$\ln y = \ln a + b \ln x,$$

in which *y* is a whole body; *x* is a body component; *a* is the normalization constant; and *b* is the dimension of the allometric parameters. The analysis for obtaining the

Table 1 - Composition (g/kg) of the experimental diets of freshwater angelfish

Ingredient[1]	Grower phase (up to 70 days)	Finisher phase (after 70 days)
Fish meal	130.5	135.0
Poultry byproduct meal	95.7	94.0
Soybean meal	350.0	356.7
Corn starch	50.0	60.0
Rice meal	79.0	75.0
Corn	150.0	135.0
Wheat bran	83.0	83.0
Soybean oil	13.0	13.0
Dicalcium phosphate	10.0	3.0
Vitamin and mineral supplement[2]	10.0	10.0
Vitamin C	0.3	0.3
Kaolin	28.5	35.0
Composition analyzed		
Dry matter (g/kg)	903.9	914.0
Crude protein (g/kg)	364.2	325.5
Crude energy (kcal/kg)	4,149.29	4,150.42
Extract ether (g/kg)	63.0	60.0
Crude fiber (g/kg)	40.1	39.9
Ash (g/kg)	78.0	72.9
Calcium (g/kg)	12.3	11.7
Phosphorus (g/kg)	10.2	9.0

[1] Values are reported on a fresh matter basis.
[2] Vitamin and mineral supplement: vitamin A, 500,000 IU; vitamin D₃, 200,000 IU; vitamin E, 5,000 IU; vitamin K₃, 1,000 mg; vitamin. B₁, 1,500 mg; vitamin B₂, 1,500 mg; vitamin B₆, 1,500 mg; vitamin B₁₂, 4,000 mg; vitamin C, 15,000 mg; folic acid, 500 mg; pantothenic acid, 4,000 mg; biotin, 50 mg; Hill, 40 g; cobalt, 10 mg; copper, 500 mg; iron, 5,000 mg; iodine, 50 mg; manganese, 1,500 mg; selenium, 10 mg; zinc, 5,000 mg; vehicle q.s.q., 1,000 g.

allometric coefficients were performed using SAS software (Statistical Analysis System, version 9.2). To verify the hypothesis b = 1, we applied the Student's t-test (P<0.05). When b = 1, the growth rates x and y are similar and the interval is called isogonic. Otherwise, when b ≠ 1, the interval is called heterogenic.

The weight and chemical component data were analyzed using the SAS. Once outliers and influential observations were excluded, the normality of errors was verified. Next, nonlinear regression analysis was performed using the PROC NLIN command. Then, using the method of least squares with the Gauss-Newton algorithm, the parameters A, B, K, and M were estimated through the assigned initial values or "priors" taking into consideration the under study species.

Results

The growth potential of freshwater angelfish was described in relation to maturity weight and whole-body composition. At the end of the trial (233 days), the average body weight (BW) of the fish population was 10.895±0.804 g. For BW, the asymptotic weight (W_m) was 26.1356 g, the maturation rate (B_w) was 0.008857 g/day, and $t*$ parameter was 216.93 days, interpreted as the time that the daily growth can reach its maximum value (Table 2). The model showed a good fit to the data.

The growth curve of freshwater angelfish weight was estimated using the Gompertz model. The curve generated by the model had a sigmoidal shape and consistency of the biological interpretation of parameter Wm (g), which was the weight at maturity (Figure 1).

Body weight and body protein were related and indicated that the maximal deposition rate of both was equal at the same time (216 days old) (Table 2).

The first derivative of the Gompertz equation showed the protein, lipid, water, and ash deposition rates (Table 3). First, the deposition rate was close to zero for all components, with greater deposition of water. After 60 days, nutrient deposition increased at an accelerated rate

until it reached a peak between 216-225 days, followed by self-deceleration. Nutrient deposition was minimal at 550 days of age (Figure 2).

The maximum rate of protein deposition was achieved when the fish had a weight of 9.54 g and maximum lipid deposition was achieved at a weight of 9.62 g. Fifty percent of the population reached maturity after 258 days for BW, after 256 days for protein, after 257 days for fat, after 245 days for ash, and after 268 days for water.

The allometric relationship between body protein and BW showed an isogonic trend (b = 1.037), with protein increasing proportionally to the increase in BW (Table 4). The allometric coefficients, depending on body protein and BW, were similar, but body lipid (BL) and ash (BA) were slightly more correlated with body protein than BW. The performance of the BL about BW was higher, up to 1,105 units of deposited lipid per unit of BW. However, the exchange rate of BL was increased faster than BW, thus the lipid is the most dynamic macromolecule.

For each body protein unit, there was a tendency to deposit 1.058 units of fat and 0.925 units of water (Table 5 and Figure 3). The growth was isometric for body protein, lipids, and ash in relation to BW (Table 4). Linear regression analysis of body water (BWa) and BW showed a close relationship (Figure 4). In this respect, 3.7426 g of water was retained per gram of protein deposited.
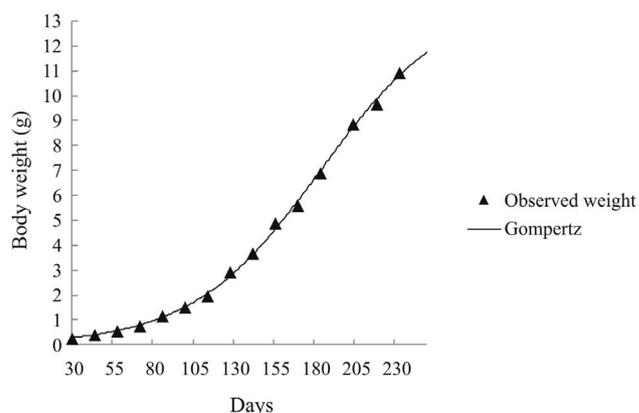

Figure 1 - Body weight of freshwater angelfish fitted by Gompertz model.

Table 2 - Estimates of Gompertz equation parameters for body weight, protein, water, lipid, and ash in freshwater angelfish

Parameter	Body weight	Body component			
		Body protein	Body water	Body lipid	Body ash
W_m	26.1356±2.164	4.5604 ±1.347	18.5911±6.525	2.2871±0.585	1.1725±0.365
B_w	0.008857±0.0005	0.00918±0.002	0.00857±0.002	0.00959±0.0017	0.0103±0.005
$t*$	216.9±12.001	216.1±32.367	225.8±40.155	217.3±26.818	209.2±26.869
$R^2_{adj.}$	0.9983	0.9956	0.9949	0.997	0.996

W_m - asymptotic weight or maturity weight for each component (g); B_w - rate of maturing parameter for each variable (g/day); $t*$ - time at which the growth rate is maximized for the variables (days); $R^2_{adj.}$ - adjusted coefficient of determination.

Linear regression analysis showed an inverse relationship between the percentage of BL and BWa. According to the regression coefficients (y = −1.635x + 80.31), each gram of lipid deposited resulted in a decrease of 1.635 g in BWa (Figure 5).

Discussion

The Gompertz model has been widely used to analyze growth in many species because of its desirable properties. Moreover, it was estimated that the initial body mass was greater than zero, which reflects the fact that the animal was born with some weight (Santos et al., 2007), being advantageous to describe the growth of young fish together with the parabolic models (Gamito, 1998). The maturity weight is considered an asymptote, which determines a constant condition on a nonlinear model for the chemical

Table 3 - Rate of deposition protein, lipid, water, and ash as a function of age (days) of freshwater angelfish

Age (days)	Protein (g/day)	Lipid (g/day)	Water (g/day)	Ash (g/day)
30	0.0009[1]	0.0003	0.0040	0.0001
58	0.0024	0.0010	0.0099	0.0005
86	0.0050	0.0023	0.0192	0.0013
114	0.0082	0.0040	0.0306	0.0022
142	0.0114	0.0058	0.0420	0.0033
170	0.0138	0.0072	0.0512	0.0040
204	0.0153	0.0080	0.0575	0.0045
233	0.0152	0.0079	0.0575	0.0043

Values estimated by first derivative of the Gompertz equation.

Table 4 - Allometric coefficients between body chemical components and body weight in freshwater angelfish

Body component	Coefficient		t test Ho:b = 1	R^2
	a	b		
Protein	−1.794	1.037	*	0.998
Lipid	−2.645	1.105	*	0.999
Ash	−3.306	1.022	*	0.999
Water	−0.347	0.969	*	0.995

a - normalization constant; b - dimension of the allometric parameters; R^2 - coefficient of determination.
* Significant at 5% of probability.

Table 5 - Allometric coefficients of body lipid and body water weight (g) for body protein weight (g) in freshwater angelfish

Body component	Coefficient		t test Ho:b = 1	R^2
	a	b		
Water	1.322	0.925	*	0.99
Lipid	−0.739	1.058	*	0.99

R^2 - coefficient of determination.
* Significant at 5% of probability.

composition of a body in a production environment. Parameter *Wm* represents the genetic growth potential and the interactions of genes that determined the growth; thus, this asymptomatic measure is a parameter resulting from previous growth stages (Silva et al., 2004).
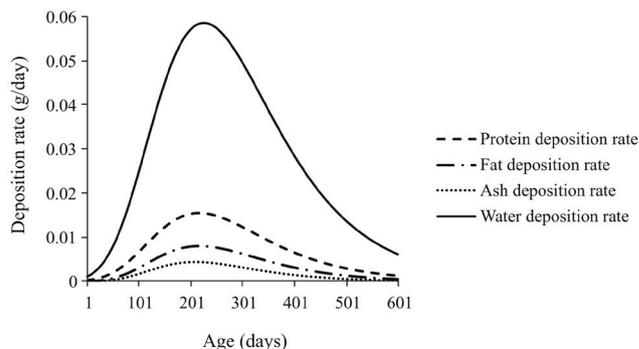

Figure 2 - Gompertz curves of daily deposition rate of body nutrients in the freshwater angelfish.
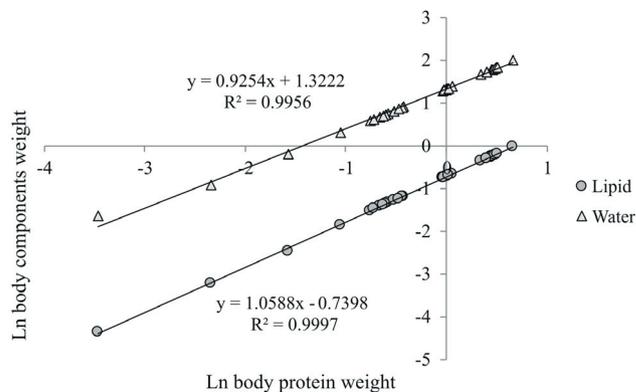

Figure 3 - Allometric relationship between body component weight (lipid and water) and body protein weight in freshwater angelfish.
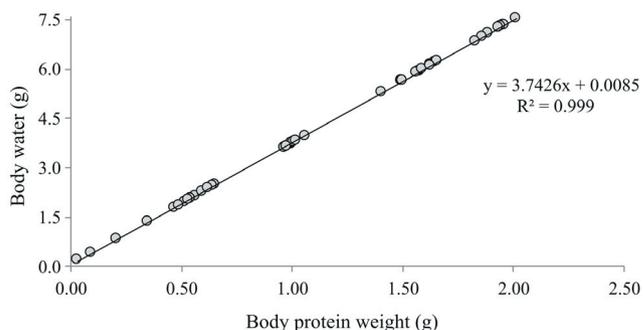

Figure 4 - Allometric relationship between body protein weight and body water in freshwater angelfish.
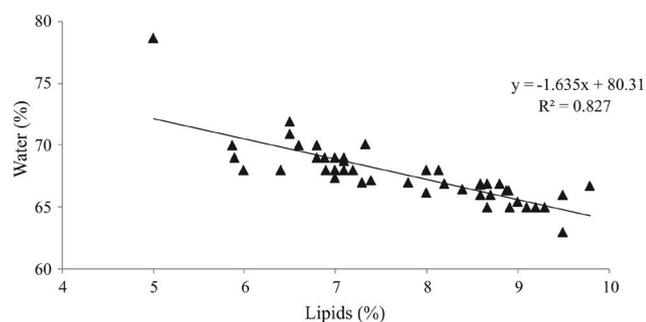
Figure 5 - Linear regression analysis between body water and body lipids in freshwater angelfish.

Body weight and body protein showed a relationship with each other and indicated that their maximal deposition rate was equal at the same time. Similar results have been reported for rainbow trout (*Oncorhynchus mykiss*), although the environmental factors were different (Dumas et al., 2007). The deposition of body lipid occurred later than that of body protein. Protein deposition is regulated by genetic factors, while lipid deposition depends on environmental and dietary factors (Dumas et al., 2010). Growth rates are highly flexible when environmental interactions influence the size of the animals, with specific growth and mortality being the fundamental factors that characterize the growth of a fish population (Vuori et al., 2006).

After 60 days, nutrient deposition increased at an accelerated rate until it reached a peak between 216-225 days, followed by self-deceleration. According to Dumas et al. (2010), the direction of the growth of individuals demonstrates an initial acceleration phase and is reduced when this individual is in adulthood or during the breeding season for certain species, considering this step as inhibiting the growth phase. Various aquaculture species can grow after reaching maturity, with a large plastic gain (Dumas et al., 2010).

The accuracy of growth models depends on the consistent mathematical description of the relationship between nutrient deposition and weight gain (Dumas et al., 2010). The allometric equations estimate the relationship of body nutrients compared to protein weight or body weight, so the prediction of nutrients in function of protein weight corrects variations in diet-related body fat (Marcato et al., 2010). In this study, the allometric relationship between body protein and BW showed an isogonic trend, with protein increasing proportionally to the increase in BW. This finding can be explained by the fact that protein weight is related to BW. Similar results have been obtained

for rainbow trout (Dumas et al., 2007). The deposition of lipid and protein depends on different nutritional factors, such as the balance of essential amino acids and especially the proportion of digestible protein and energy in the diet (Bureau et al., 2002).

The exchange rate of BL was increased faster than BW; thus, the lipid is the most dynamic macromolecule. A similar intercept and slope has been obtained for rainbow trout (Dumas et al., 2007). Linear regression analysis of BWa and BW showed a close relationship. According to Schmidt-Nielsen (1975) and Jobling (1994), 1 g of protein is deposited per 3 g of water. The results obtained in this experiment agree with the study of Dumas et al. (2007), who found an allometric coefficient of 3.894, evaluating nutrient deposition from 66 studies conducted with rainbow trout between 1976 and 2005.

Linear regression analysis showed an inverse relationship between the percentage of BL and BWa. Similar results have been reported for other fish species such as rainbow trout (Dumas et al., 2007) and alpine trout (*Salvelinus alpinus* L.) (Lyytikainen et al., 1997).

This study found a linear trend between water and fat for freshwater angelfish (Figure 3). Iles and Wood (1965), analyzing Wood (1958) data, established a close linear relationship between percentage of fat and percentage of water for herring (*Clupea harengus*); similar results were recorded by Brandes and Dietrich (1953) for muscle fillets from the same species. In addition, it has been found that the relationship is constant under the widely different conditions associated with seasonal cycles of feeding, somatic growth, and gonad maturation (Iles and Wood, 1965).

Emmans (1981) stated that an ideal method to calculate the nutritional requirements and indicate the food intake of an animal during its development is firstly to discover its growth potential. Each animal species has a particular growth curve, which depends on suitable and non-limiting environments. It emphasizes the fact that many aspects, such as maturity, composition, and deposition rates of body nutrients, might interfere with the growth curve. Therefore, the use of mathematical models is necessary to show clearly and with a better precision the growth of these animals according to their age, research, and feeding programs (Gous et al., 1999). Growth models are useful tools that, in addition to evaluating variables within a population, permit to improve the curve points, select desirable traits within a production system, and improve feeding strategies for freshwater angelfish. These findings enhance the understanding of growth prediction equations, chemical

body composition, and nutrient deposition rates across the life cycle of freshwater angelfish. Nutrient deposition rates as a function of protein weight are important to understand the growth process of freshwater angelfish.

Conclusions

The Gompertz equation is a useful tool to describe the growth and body composition of freshwater angelfish. The allometric relationships of body components and deposition rates indicates that protein and body weight are highly correlated across the life stages of freshwater angelfish.

Acknowledgments

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