Predicting Body Composition of Nile Tilapia (*Oreochromis niloticus*)

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Abstract

Accurate prediction of proximate composition for a commercially cultured fish at a particular body weight could help to reduce overall feed waste, improve feed efficiency, and increase profitability. We studied the relationship between biochemical composition of Nile tilapia and its wet weight for the range of minimum and maximum body weight found in the published literature. We also tested the predictive value of regression equations. Logarithmic trends of the proximate composition showed a linear trend for tilapia up to 0.4 g. The trend formed a plateau for tilapia larger than 5 g. The slopes (*b*) for water, protein, fat, and ash contents as percent body-weight were -0.008, 0.003, 0.003, and 0.002 respectively. The slopes were close to "0" and did not change significantly after removing data from fishes smaller than 5 g in all four cases. Mean percent error of water (-0.145) and protein (-0.769) showed no differences between them. A large percent error mean for fat (-39.179) suggested presence of variations in fat contents to whole body weight. Our findings suggested no significant changes in percent water and percent protein over the life-span of Nile tilapia partially rejecting the null hypothesis that percent composition of Nile tilapia varies over their lifetime.

Introduction

Tilapias have recently gained importance as a valuable component of subsistence and commercial aquaculture production. In 2006, tilapia export to North America has surpassed that of catfish and has become the third most important cultured fish in the world followed by carps and Salmonids. Nile tilapia (*Oreochromis niloticus*) is the main culture species out of the nine tilapia species farmed around the world and is responsible for the significant increase in global tilapia production. Since 1990, global aquaculture production of Nile tilapia has increased almost seven folds and has been increasing exponentially since then (FAO 2005). Ever increasing demand for fish protein carries a lot of potential of future expansion of tilapia aquaculture to improve nutrition and livelihood status of the people in developing countries (Chowdhury and Bureau

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2006). Few species match tilapias in terms of their potential to become the cultured fish of future. A range of systems is suitable for tilapia, from low-input pond and paddy fields to intensive production in feedlot cages and cement tanks. Although genetic improvement indicated that overall tilapia production could be increased through the use of improved strains such as GIFT tilapia (ICLARM-ADB 1998), attaining an even and higher production standard has been a major challenge for the tilapia industry as a whole.

Studies of growth, nutrition, and bioenergetics of fish and other animals often rely on the ability of measuring body composition of individuals accurately. Whole body composition is a key parameter in determining protein for mass balance models used to estimate N losses from fish culture facilities (Cho et al. 1994; Cho and Bureau 1998; Silverstein et al. 1999; Cho 2004; Azevado et al. 2004; Dumas et al. 2007). Knowledge of the proximate composition of fish and factors affecting that composition allows assessment of fish health, determination of nutrient transfer efficiency from the feed to the fish, and makes it possible to predictably modify carcass composition (Shearer 1994). Accurate prediction of proximate composition for a commercially cultured fish at a particular body weight could help to reduce overall feed waste, improve feed efficiency, and increase profitability of the operation. Numerous studies analyzed carcass of the fish at the beginning and end of the experiment to determine the change in body composition (Ramseyer 2002), but few have attempted to predict the whole body composition from live body weight (e.g. Northern pike, Salam & Davies 1994). Paucity of information on determining whole body composition of Nile tilapia is one of the impediments because improved feed management efficiency could be attained with the predictability of whole body composition. Ramseyer (2002) predicted whole-fish nitrogen content for 60 fish species and six hybrids, including Nile tilapia, using regression analysis. However, maximum weight of Nile tilapia was 198 g for that calculation, making the developed equation impossible to be used for fish larger than 198 g as stated by Shearer (1994). Albeit a plenty of studies available on tilapia growth and nutrition in published literatures, none covered the whole range of body weight (from fry to market size) to predict proximate composition of the species.

Direct measurements of body composition involve sacrificing the animal, grinding the carcass, and taking a representative subsample for analysis of water, fat, protein, and ash content. An indirect measurement of body composition is thus desirable to avoid destruction of animals and to allow fish farmer's to adjust and optimize the feeding ration more frequently. Strong linear relationship between whole body protein and body weight have been observed for the rats (Miller and Weil 1963), carcass composition and whole body for white-tailed deer (Bois et al. 1997), and 14 species of fish (Groves 1970;

Shearer 1994). The objectives of the study were to: (1) determine whether water, protein, fat, and ash contents of Nile tilapia were related to its wet weight for the range of minimum and maximum body weight found in published literature; (2) determine the difference between the prediction results of log transformed data and absolute data; and (3) present regression equations for predicting fish whole body composition from fish live body weight.

Materials and methods

Whole-body composition and corresponding whole-body weight (WBW) values for Nile tilapia were collected from 34 articles published between 1982 and 2005. Most data were compiled through a manual search of Aquaculture (1983-2004), Aquaculture Research (1996-2005), and Journal of the World Aquaculture Society (1999-2002). Data were selected only from the studies where fish were fed at satiation or near satiation irrespective of the diet composition or types of feed, and where body composition contents were determined by the industry standard methods (AOAC 1990). Any data from studies with variable feeding regimes, or that included fertilization without feeding, or examined the effect of water quality were excluded. Data presented as dry matter content were converted to wet weight for the purpose of our study following Shearer's (1994) recommendation that proximate composition should be reported on a wet basis. A total of 224 samples were taken where the body weight ranged between 0.016 g to 559 g, water content ranged from 66.3 % to 81.9 %, protein ranged from 10.9 % to 18.9 %, fat content ranged from 4.9 % to 13.0 %, and ash content ranged from 1.4 % to 7.5 %. The mean temperatures ranged between 10°C and 31°C during these experiments.

Univariate linear regressions (ULR) were calculated by the least squares method with both untransformed and log_{10} transformed data. The ULR models for both regressions were

$$Y = bX + c ,\qquad\qquad\qquad (1)$$
$$LnY = bLnX + c,\qquad\qquad (2)$$

where Y = untransformed amount (g) of water, protein, fat, and ash contents and X is fish wet weight. The log_{10} transformed data are presented as $log_{10} Y$ and $log_{10} X$, respectively. In a regression analysis, when the slope (b) equals 1, both components are increasing at the same rate. When $0<b<1$, then body weight is increasing faster than the component and when $b>1$, the component is making up an increasing portion of the fish. If $b=0$, then the component is not increasing, and if $b<0$, then the absolute amount of component is decreasing.

Absolute amount (g) and percent wet weight of water, protein, fat, and ash were analyzed against the absolute (g), and log_{10} transformed weight were analyzed against

the log_{10} transformed values of WBW. A null hypothesis that percent wet composition components varies significantly for Nile tilapia over its lifetime was tested by regressing percent wet weight of a proximate component against fish wet weight.

Residual plots were examined to assess the validity of the assumption of homogeneous error variance and to detect the presence of outliers. Normal probability plots were examined visually to ascertain whether or not the sample distribution was normal. Body composition predictions were validated by removing the tenth observation into an independent data set ("observed" values). A ULR equation was computed with the remaining data and used to predict body composition values ("predicted values") in the independent data set. A null hypothesis of equality between observed and predicted values was tested with a two-tailed pair sample *t*-test. The percentage error (PE) between observed and predicted values was calculated as

$$PE = \frac{\backslash observed - prediced/}{observed} X\ 100 \qquad (3)$$

Efficacy of using absolute values (g) and log_{10-} transformed values for each proximate component were tested from the percent error of the regressions between each component and WBW.

Results

The logarithmic trends of the percent proximate components showed a linear trend for the fishes up to 0.4g and formed a plateau for the fishes larger than 5g (Fig.1)
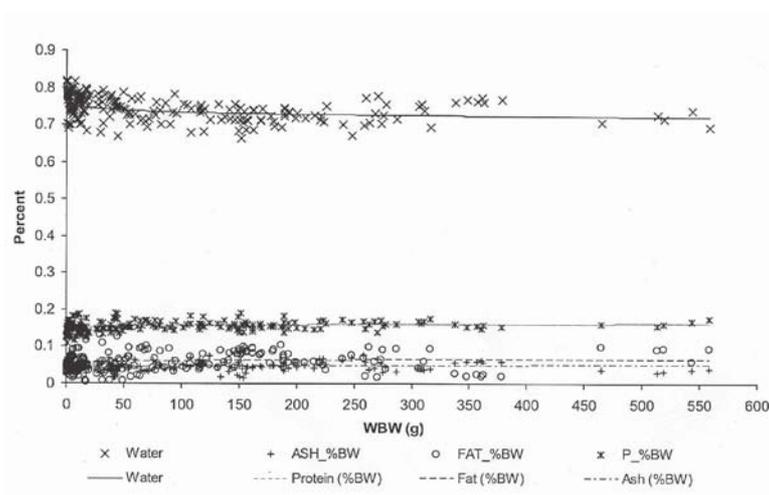

Figure 1. Percent composition of water, fat, ash and protein in relation to whole body weight (WBW) of Nile tilapia (*O.niloticus*)

The slopes (*b*) for percent of water, protein, fat, and ash contents were -0.008, 0.003, 0.003 and 0.002, respectively. In all four cases, the slopes were close to "0" and did not change significantly after removing data from fishes smaller than 5 g (Table 1) Mean PE of percent values of water (-0.145) and protein (-0.769) showed no differences between them. Mean PE was large for percent of fat (-39.179) indicating presence of variations in fat contents in relation to WBW. Regression equation of percent values of water, ash, fat and protein has very little or no value in predicting body composition except for fishes smaller than 1 g (Eq. 3: Table1) .

Table 1. Relationship of % water, % protein, %fat and % ash contents and whole body weight (WBW) of Nile tilapia; Eq. 1: 0.016-559g; Eq. 2: fishes smaller than 5 g; Eq. 3: fishes smaller than 1g; Eq. 4: fishes larger than 5 g.

	Water (%)			Protein (%)			Fat (%)			Ash (%)		
	$adjR^2$	*b*	a	$adjR^2$	*b*	a	$adjR^2$	*b*	a	$adjR^2$	*b*	a
Eq.1	0.22	-0.01***	0.77***	0.161	0.00***	0.14***	0.05	0.00***	0.05***	0.08	0.00***	0.04***
		±0.00	±0.00		±0.00	±0.00		±0.00	±0.00		±0.00	±0.00
Eq.2	0.43	-0.02***	0.76***	**0.23**	0.01***	0.14***	0.40	0.01***	0.05***	**0.18**	0.00***	0.04***
		±0.00	±0.00		±0.00	±0.00		±0.00	±0.00		±0.00	±0.00
Eq.3	**0.58**	-0.01***	0.78***	0.194	0.00^{ns}	0.14***	**0.43**	0.01**	0.05***	-0.08	0.00^{ns}	0.03***
		±0.00	±0.00		±0.00	±0.00		±0.00	±0.00		±0.00	±0.00
Eq.4	0.17	-0.01***	0.78***	0.09	0.00***	0.14***	0.05	0.01*	0.04***	0.00	0.00^{ns}	0.04***
		±0.00	±0.00		±0.00	±0.00		±0.00	±0.04		±0.00	±0.00

Note. *b* =coefficient and a = intercept. *** *P<0.0001*, ** *P<0.001*, * *P<0.01* of *t*- values; ^{ns} not significant

No differences were observed between the prediction results of absolute and log-transformed values of water, ash, and protein contents (Table 2).

In all these cases, PE values were relatively low and did not improve much after log-transformation. However, the PE values were much higher for the absolute ash-values and fat-values and were significantly reduced after logarithmic transformation. As a result, the adjusted R^2-values were also improved significantly from 0.89 to 0.98 for the ash and from 0.77 to 0.93 for the fat values.

Table 2. Comparison between the Univariate linear regressions (ULR) of absolute and log transformed values of water, protein, fat and ash contents with whole body weight (g).

	Regression with absolute values				Regression with log transformed values			
	$^1adjR^2$	^2b	^2a	PE	$^1adjR^2$	^2b	^2a	PE
Water	1.00***	0.73***	0.18	-15.26	1.00***	0.99***	-0.27***	-0.41
		±0.002	±0.338	±8.69		±0.001	±0.005	±0.401
Protein	0.99***	0.16***	-0.22	122.60	1.00***	1.02***	-1.95***	0.66
		±0.001	±0.119	±68.34		±0.003	0.012	±3.460
Fat	0.77***	0.07***	-0.25	589.82	0.93***	1.05***	-3.16***	-86.29
		±0.002	±0.351	±376.24		±0.019	±0.073	±78.510
Ash	0.89***	0.05***	0.10	-283.04	0.98***	1.04***	-3.32***	229.57
		±0.001	±0.158	±146.74		±0.01	±0.039	±194.21(

* Significance of F-values from the analysis of variance (***<0.0001); Significance of *t* values (***<0.0001) & ± Standard error deviation from mean. PE is percent error mean Oi-Pi*100/Oi of each regression, b=coefficient and a = intercept of the regressions.

Water and protein content could be predicted from the absolute values by the equations $y = 0.7277WBW + 0.1812$ (adj-$R^2 = 0.998$) and $y = 0.1607WBW - 0.2194$ (adj-$R^2 = 0.995$), respectively (Figure 2A and 2D) .

We suggest to use log-transformed values to predict ash and fat content from WBW with the equations $y = WBW^{1.0421} \bullet 10^{-1.4426}$ (adj-$R^2 = 0.980$) $y = WBW^{1.0473} \bullet 10^{-1.375}$ (adj-$R^2 = 0.934$), respectively (Figure 3B and 3C).
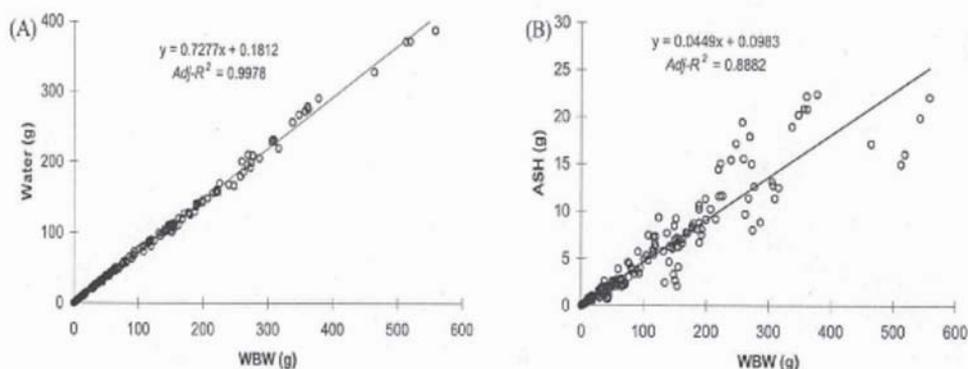

Figure 2. A) Relationship between absolute values of water and whole body weight
            B) Relationship between absolute values of ash and whole body weight
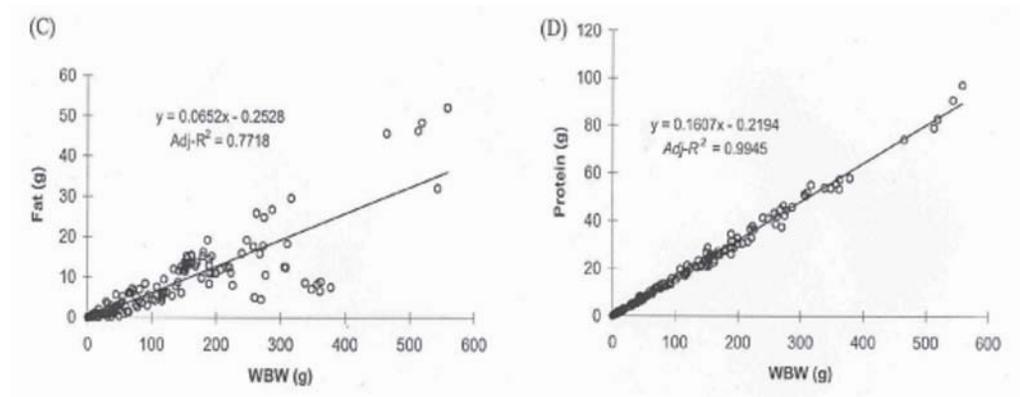
Figure 2. C) Relationship between absolute values of fat and whole body weight
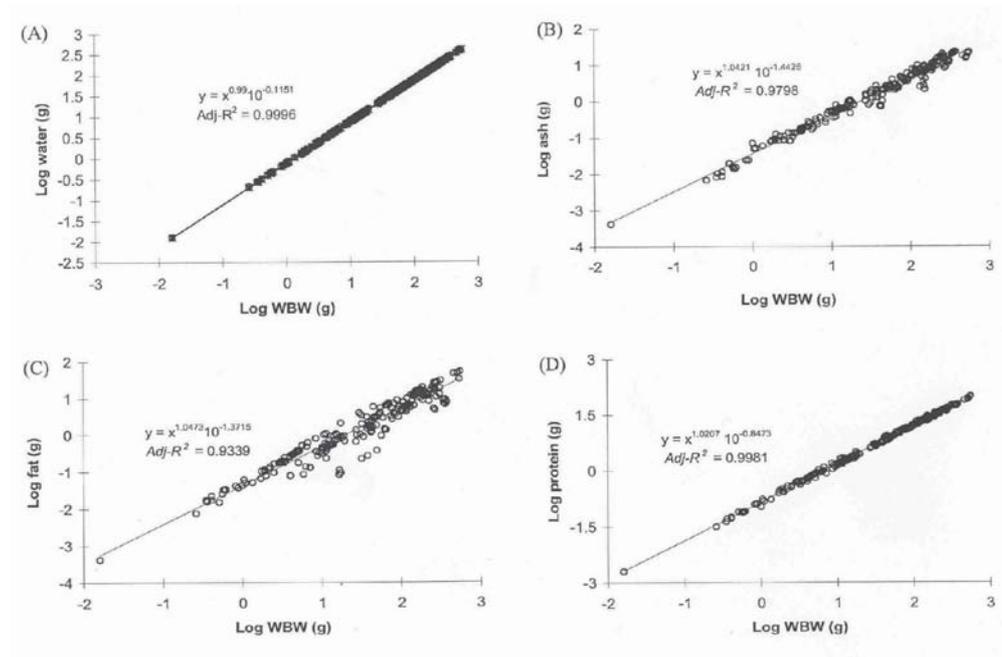   D) Relationship between absolute values of protein and whole body weight

Figure 3:A) Relationship between log-transformed values of water and whole body weight
   B) Relationship between log-transformed values of ash and whole body weight
   C) Relationship between log-transformed values of fat and whole body weight
   D) Relationship between log-transformed values of protein and whole body weight

Discussion

The relationships between nutrient intake and chemical and physical body composition are affected by a range of factors associated with nutrition, genotype, environment and stage of maturity (De Lange et al. 2003). Similar to the terrestrial animals (De Lange et al. 2003), our findings suggested a close association of water content in tilapia body with protein present in both the lean tissue and visceral organs. There were no significant changes in percent values of water and protein of Nile tilapia up to 600 g. Given these similarities, water can be accurately predicted from protein with a reasonable accuracy, using allometric relationships (Weis 2001; De Lange et al.2003).

Large variations in both the percent values of fat and ash contents were observed for tilapia larger than 400 g. Tilapia fed low-protein and low-energy diets, tends to burn body fat to compensate the energy requirement for maintenance. Overall growth rate is reduced increasing the percent protein content. Burned fat is usually replaced by water to maintain the body mass. Ali et al. (2005) observed similar changes in body composition in Rohu (*Labeo rohita* Hamilton), when fish were put in stress induced by fasting. This finding suggests proper adjustment of lipid content in tilapia diet to satisfy the energy requirement to maintain proper growth and suitable flesh quality. While adjusting lipid content in diet, it is important to understand the effect of genotypes in body lipid composition that varies between genotypes or even between strains (Garduno-Lugo et al. 2007).

Knowledge on tilapia body composition at different stages could help to determine the growth requirement for an essential element. Shearer (1984) observed the whole body composition of rainbow trout were homeostatically controlled and were affected by life-cycle stage, fish size, and reproductive state. The effect of reproductive stage on the body composition of commercially farmed tilapia is minimal due to the emphasis on the culture of all-male tilapia. Also genetic improvements of farmed tilapia showed that tilapia could reach market size i.e. upto 600 g before sexual maturity. In conclusion, it needs to be emphasized here that predicting body composition is only a preliminary step to determine dietary requirements for essential elements of fish. Apart from that it also facilitates to model fish growth and protein deposition rate at different dietary levels.

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