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Application of electrical conductivity for non-destructive measurement of channel catfish, *Ictalurus punctatus*, body composition

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Abstract

A non-destructive method for determining water, protein, lipid and ash content along with lean body mass (LBM; total body mass – total lipid mass) in live channel catfish was evaluated. This non-invasive technique involved placing the fish within a low-frequency electromagnetic field and measuring the total body electrical conductivity (TOBEC) based on the distinct electrical characteristics of body fat and fat-free tissues. The correlations between TOBEC and whole-body composition were examined using age-1^+ channel catfish ranging from 44 to 175 g. Significant linear relationships between TOBEC, body weight, and total length, or combinations of these parameters, and LBM, ash, lipid, protein, and water content were found; r^2 values ranged from 0.863 to 0.998. Equations for predicting body composition from TOBEC and morphometric measurements were developed. Analysis of an independent group of fish demonstrated TOBEC equations to be reliable predictors of body composition. This technique should allow successive monitoring of body composition of individual fish at different times and provide additional insight into the body composition dynamics of channel catfish.

Keywords: *Ictalurus punctatus*, channel catfish, body composition, electrical conductivity measurement.

La conductivité électrique utilisée comme mesure non destructrice de la composition corporelle du poisson-chat Ictalurus punctatus.

Résumé

Une méthode non destructrice de détermination de la teneur en eau, en protéine, en lipide et en cendre en fonction de la masse maigre corporelle (LBM = poids corporel total – poids des lipides totaux) a été testée chez le poisson-chat américain vivant. Cette technique, qui préserve l'animal, consiste à mesurer la conductivité électrique du corps entier (TOBEC) en plaçant les poissons dans un champ électromagnétique de basse fréquence. La mesure est basée sur les différences entre les caractéristiques électriques des graisses corporelles et celles des masses maigres. Les corrélations entre TOBEC et la composition du corps entier ont été examinées chez des poissons-chats américains d'âge 1^+ et de 44 à 175 g. Une relation significative a été trouvée entre TOBEC, le poids corporel, la longueur totale ou la combinaison de ces paramètres et le taux corporel de masse maigre, de cendre, de lipide, de protéine et d'eau (r^2 compris entre 0,863 et 0,998). Des équations de prédiction de la composition corporelle à partir de TOBEC et des mesures morphométriques ont été établies. L'analyse d'un groupe indépendant de poissons a démontré la validité de ces équations. Cette technique devrait permettre d'évaluer dans le temps la composition corporelle d'un même poisson et de fournir des informations sur l'évolution de la composition corporelle du poisson-chat américain.

Mots-clés : *Ictalurus punctatus*, poisson-chat américain, composition corporelle, mesure de conductivité électrique.

INTRODUCTION

Body composition of fishes is an important characteristic that fish culturists and fisheries managers often must evaluate since it reflects nutritional history of the fish. Body condition and composition are influenced by both energy availibility and allocation, and affect the efficiency of various physiological and ecological processes. The final quality of processed fish products also may be influenced by body composition.

Currently, the most common method of assessing body composition is by proximate analysis. Unfortunately, this is expensive, time-intensive, and necessitates sacrificing the subject animals. Therefore, due to the destructive nature of proximate analysis, body composition of individual fish typically can be evaluated at only one point in time. Near infrared reflectance analysis (NIRA) recently has been used to rapidly determine carcass composition of rainbow trout, *Oncorhynchus mykiss* (Gjerde and Martens, 1987; Valdes *et al.*, 1989); however, this procedure requires homogenization of the samples and thus is destructive in nature. Non-destructive methods are desired to give the capability of successively monitoring body composition of individual fishes along with reducing the number of specimens and associated costs required for certain experimental designs as well as lessening concerns about experimental animal use.

Computerized tomography is one non-destructive technique that has been used to accurately estimate carcass fat and dry matter of rainbow trout (Gjerde, 1987) and Atlantic salmon, *Salmo salar* (Rye, 1991). Another non-destructive and reliable means of estimating a variety of body composition parameters in mammals (Presta *et al.*, 1983), birds (Walsberg, 1988) and fish (Brown *et al.*, 1993; Bai *et al.*, 1994) is based on measurement of total body electrical conductivity (TOBEC). The equations developed using TOBEC to predict body composition are, however, species specific. Therefore, the objective of this study was to develop standard equations using TOBEC measurements and determine prediction accuracy of this non-destructive technique in measuring whole-body proximate composition of live channel catfish.

MATERIALS AND METHODS

Experimental animals

This study was conducted at the Texas A&M University Aquacultural Research and Teaching Facility, College Station, Texas, using age-1 channel catfish, *Ictalurus punctatus* produced at this facility. Relationships between TOBEC analysis and body composition were examined for 74 channel catfish ranging from 44 to 175 g. The fish had been subjected to various feeding regimes: one group of 27 fish had been maintained in concrete holding tanks and fed a 32% crude-protein commercial diet to satiation every other day for 3 months; the other 47 fish were from a diet formulation feeding trial which had been conducted in indoor aquaria for 8 weeks. The crude protein of four different diet formulations was either 28 or 36% but the energy to protein ratio was maintained between 9 and 10 kcal/g protein. Crude fat was approximately 6.5% in all diets. *Table* 1 provides a summary of the number of fish and dietary treatments (formulation, crude protein level and feeding rate) used in this study.

All fish were fasted for 48 h to evacuate the gut prior to TOBEC analysis. Individuals were then placed in a 25 mg/l solution of MS-222 (tricaine methanesulfonate) until total loss of equilibrium. They were then prepared for scanning with a small animal body composition analyzer, model SA-2® (EM-SCAN, Inc., Springfield, IL) in the peak mode. This scanning unit will accomodate animals up to 7.9 cm in diameter and 25 cm in length and therefore limited the size of fish included in this study. However, a new unit with multiple detector chambers of various sizes has recently been introduced. The principle of TOBEC measurement has been previously described (Fiorotto *et al.*, 1987; Walsberg, 1988; Brown *et al.*, 1993). Individual fish were blotted dry, and placed on the carrier sled lying on their right side with the anterior premaxilla even with the leading edge of the sled. Blotting and use of the same orientation prior to scanning minimized potential variability due to water conductivity and body orientation, respectively. This step is especially critical since ions in external water may bias body conductivity. Fish were fully inserted into the scanning chamber over a 10-sec interval; each individual fish was scanned three times to obtain a mean TOBEC reading although all replicate readings were very similar (coefficient of variation <2.0). All fish were scanned at 27 ± 1 °C. Fish were placed in fresh water and allowed to recover to demonstrate the non-destructive nature of this method. Fish were immediately killed and frozen once equilibrium was regained. A longer recovery period was undesirable because it could possibly affect body composition due to changes associated with feeding and/or metabolism.

Nineteen fish were selected randomly to be used as an independent test group for validating the developed equations; seven were from treatment 7 and two from each of the remaining treatments. These fish were selected from the central 85% of the sample weight range to allow a broad size-range to be used in equation development and validation.

Body composition and proximate analysis

Individual whole-body samples were homogenized by dicing with a cleaver followed by grinding in a blender. Samples were then frozen before being re-homogenized in the previously described manner. Water content was determined by oven-drying homogenate samples at 125 °C for 3 h (AOAC, 1984). Samples were placed in a muffle furnace at 650 °C for 3 h for ash determination. A chloroform-methanol extraction (Folch *et al.*, 1957) was used to determine total lipid content. Determination of nitrogen was accomplished with the macro-Kjeldahl procedure (AOAC, 1984) in order to calculate crude protein (nitrogen × 6.25). At all stages of analysis, duplicate samples for each individual fish were processed and mean values were used in all statistical analyses.

Statistical modelling and analyses

All modelling and statistical analyses were conducted with SAS (1985) routines (*i.e.* MEANS, REG, RSQUARE, and UNIVARIATE procedures) with a statistical significance of $p \leq 0.05$. The response variables used were whole-body ash, lipid, protein, water and lean body mass (LBM). The measured variables used for modelling were TOBEC value, total length, and whole-body weight; logarithmic and higher order transformations, and combinations thereof, were included as variables to determine if they could significantly improve the predictive models. Relative weight, a measure of body condition, was also considered in model development but was subsequently excluded because its contribution to the models was limited. Data from all fish were included in the modelling as no outliers were observed. Independent variable subsets to be considered were selected based on lower mean square error, higher r^2 coefficient, C_p statistic, and the minimum number of variables (Ott, 1988). Plots of the residual versus predicted values were examined to ensure constant variance. The p-value for each variable (H_0: $\beta = 0$) within a model was examined to ensure its significance in the model. The paired-t test was used to detect if the mean differences between actual values and predicted values for fish in the validation group were different from zero.

RESULTS

The use of fish from different feeding regimes provided a rather broad range of body compositions which were incorporated into model development. This in turn allowed the development of more general prediction equations. The treatment means and ranges are provided in *table* 1.

The r^2 values for regression models which included TOBEC, length (L), or weight (W) measurements, or a combination thereof, and measured body components ranged from 0.863 to 0.998. Regression equations, coefficient standard errors, r^2 coefficients, dependent means, and mean square errors are provided in *table* 2.

In the model for predicting ash, a length correction factor (LCF) which accounts for the cross-selectional area being scanned was included (B. Kerekes, EM-SCAN, Inc., pers. comm.). Length also was an important variable because a majority of the minerals are incorporated into skeletal tissue. For this same reason, a direct relationship between TOBEC and ash may not be conspicuous. The inclusion of weight also improved the prediction equation.

The model for estimating protein included all three measurements, without any transformations or combinations. The p-value for the slope of the length coefficient was 0.072. The model for estimating water content only required the use of TOBEC and weight. The larger coefficient for the TOBEC variable, relative to the other models, demonstrated the relationship between tissue hydration and TOBEC measurement. When only the weight variable was used for estimating water content, the mean square error was 10.389. However, this was reduced to 4.218 when the TOBEC variable was included. This model contained the same variables as that for red drum (Bai *et al.*, 1993).

Like the model for estimating water content, the models for predicting LBM and lipid only required the use of TOBEC and weight. The inverse relationship between lipid and water would indicate that these response variables should have the same independent variables. The selection procedure used for development of the LBM model was effective

Table 1. – Means and ranges of proximate composition (percentage wet basis) by treatment for channel catfish used in this study.

Treatment	n	Diet formulation/ % crude protein	Feeding regime	Ash	Lean body mass	Lipid	Protein	Water
1	8	1/28	4% body weight/d	3.2	89.7	10.3	16.0	67.9
2	8	2/28	4% body weight/d	2.9	90.0	10.0	16.0	68.6
3	7	3/36	4% body weight/d	3.3	90.3	9.7	16.6	65.9
4	8	4/36	4% body weight/d	2.9	91.8	8.2	16.5	70.6
5	8	2/28	to satiety twice daily	3.0	89.6	10.3	16.5	68.4
6	8	4/36	to satiety twice daily	2.9	89.3	10.7	16.5	67.7
7	27	5/32	to satiety every other day	3.4	93.2	6.8	15.5	73.8
Ranges								
Low				2.0	87.1	4.1	13.8	63.1
High				4.7	95.9	12.9	18.3	77.8

Table 2. – Least-squares regression equations for estimating body components (g) of channel catfish based on TOBEC, total length (L) and weight (W) measurements ($p \leq 0.0001$).

Predictive models	$\beta_0$se	$\beta_1$se	$\beta_2$se	$\beta_3$se	r^2	Dependent mean	Mean square error
Ash = 3.249 + 0.010 LCF[a] – 0.023 L + 0.035 W	1.545	0.004	0.011	0.004	0.863	2.871	0.170
LBM[b] = 1.798 + 0.034 TOBEC + 0.857 W	0.497	0.004	0.007	----	0.998	83.665	1.547
Lipid = – 1.798 – 0.034 TOBEC + 0.143 W	0.497	0.004	0.007	----	0.903	8.147	1.547
Protein = – 6.097 – 0.020 TOBEC + 0.033 L + 0.171 W	2.903	0.005	0.018	0.008	0.981	14.843	0.666
Water = 1.396 + 0.063 TOBEC + 0.623 W	0.820	0.007	0.012	----	0.993	64.540	4.218

[a] Length correction factor (LCF) = $(\text{TOBEC} \times \text{L})^{1/2}$

[b] Lean body mass.

since the variables and coefficients were the same as those which would have been derived through algebraic substitution of the lipid model into the LBM definition, weight – total lipid content.

Validity of the models was confirmed by paired-*t* tests between the actual measured values of body components and their respective predicted values for the independent test group (*table* 3); the results from these analyses are in *table* 4. The null hypothesis (mean difference between the observed and predicted values equals zero) was determined to be true for all body constituents. None of the predicted values exhibited any trends in regard to over- or underestimating the body components. The proposed models were shown to predict accurately ash, LBM, lipid, protein, and water content of channel catfish with the use of TOBEC, length, and weight measurements without demonstrating any biases.

DISCUSSION

For comparison, models developed for predicting LBM, water, and protein of hybrid striped bass (Brown *et al.*, 1993) required a natural log transformation for weight and the TOBEC variable. The TOBEC measurement alone was used for estimating lipid and ash content of hybrid striped bass. With the exception of lipid, these components were successfully predicted. Body composition estimation models for red drum (Bai *et al.*, 1994) were more complex than those presented in this study or that of Brown *et al.* (1993) and included

Table 3. – Individual body measurements, observed (O) and predicted (P) composition data for channel catfish used to evaluate the predictive equations developed in the present study.

Treatment	Weight (g)	Length (mm)	TOBEC	Ash (g)		Lean body mass (g)		Lipid (g)		Protein (g)		Water (g)	
				O	P	O	P	O	P	O	P	O	P
1	110.12	227	87	2.90	3.26	99.01	99.11	11.11	11.01	18.39	18.49	77.67	75.51
1	70.88	200	50	2.89	2.13	63.52	64.23	7.36	6.65	10.91	11.64	47.56	48.72
2	74.55	200	62	1.69	2.37	66.93	67.78	7.62	6.77	11.62	12.02	50.45	51.76
2	72.44	199	52	2.23	2.22	63.78	65.63	8.66	6.81	11.60	11.83	47.71	49.82
3	74.30	205	61	2.92	2.25	67.88	67.53	6.42	6.77	12.42	12.16	46.92	51.54
3	73.06	202	42	2.17	2.08	66.14	65.82	6.92	7.24	11.81	12.24	46.83	49.58
4	71.60	201	53	2.53	2.16	66.05	64.95	5.55	6.65	11.31	11.73	49.58	49.36
4	112.26	220	93	3.06	3.52	102.56	101.15	9.70	11.11	19.80	18.50	80.02	77.22
5	87.79	207	52	2.55	2.59	78.46	78.78	9.33	9.01	15.29	14.72	59.95	59.39
5	69.59	199	51	1.66	2.12	62.52	63.16	7.07	6.43	11.33	11.36	48.08	47.98
6	93.22	216	69	2.03	2.75	83.41	84.02	9.81	9.20	14.95	15.60	62.54	63.84
6	115.88	228	89	3.42	3.46	101.72	104.11	14.16	11.77	18.35	19.47	77.66	79.22
7	58.30	195	69	1.81	1.96	53.41	54.10	4.89	4.20	9.03	8.93	42.36	42.07
7	82.19	222	125	2.41	2.66	75.84	76.47	6.35	5.72	13.25	12.77	58.97	60.48
7	107.20	244	148	5.00	3.25	97.74	98.68	9.46	8.52	15.92	17.31	77.13	77.51
7	64.71	204	83	2.90	2.12	61.09	60.07	3.62	4.64	10.69	10.04	47.51	46.94
7	104.83	247	169	3.02	3.24	98.68	97.37	6.15	7.46	16.17	16.57	80.76	77.35
7	122.30	254	183	3.76	3.79	113.10	112.81	9.20	9.49	18.45	19.50	91.67	89.12
7	74.98	215	125	3.27	2.55	68.93	70.30	6.05	4.69	11.67	11.30	53.10	55.98

Table 4. – Results from paired-*t* test analysis of observed and predicted body components (g) for channel catfish from validation set (n = 19).

Statistic	Ash	Lean body mass	Lipid	Protein	Water
Mean difference	0.09	−0.28	0.28	−0.17	−0.36
se	0.14	0.24	0.24	0.16	0.48
sd	0.62	1.05	1.05	0.68	2.11
t	0.65	−1.16	1.16	−1.09	−0.75
P value	0.53	0.26	0.26	0.29	0.46

other variables such as $\log_e$TOBEC and TOBEC^2. All of these models accurately estimated body composition. In neither of the previous studies were various feeding regimes implemented to stratify body composition more widely. Differences in physiological condition and morphology, especially between channel catfish and hybrid striped bass or red drum, may be some of the reasons why no common trends between models for the same components were observed for the different species.

There are several distinct advantages that this technique for assessing body composition has over traditional methods of proximate analysis. First, it does not require the sacrificing of subject animals; thus, changes in body composition of individuals can be measured over time or throughout experiments. This attribute is particularly desirable for many research applications in fisheries management and aquaculture. Secondly, this new method can easily be incorporated into existing laboratories and food production facilities by the addition of a single scanning unit. Ease of operation and virtually instantaneous results are other advantages this technique provides.

In conclusion, this study demonstrated TOBEC to be a practical and technologically feasible non-destructive technique of predicting channel catfish body composition. If more accurate prediction models are required, it is recommended that models be developed using individuals that differ widely in length and weight but have similar body composition.

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REFERENCES

AOAC (Association of Official Analytical Chemists), 1984. Methods of Analysis. AOAC, Arlington, VA, 1141 p.

Bai S. C., G. R. Nematipour, R. P. Perera, F. Jaramillo Jr., B. R. Murphy, D. M. Gatlin, III, 1994. Total body electrical conductivity measurement of body composition in red drum, *Sciaenops ocellatus. Prog. Fish-Cult.*, in press.

Brown M. L., D. M. Gatlin, III, B. R. Murphy, 1993. Non-destructive measurement of sunshine bass, *Morone chrysops* (Rafinesque) × *M. saxatilis* (Walbaum), body composition using electrical conductivity. *Aquacult. Fish. Manage.*, **24**, 585-592.

Fiorotto M. L., W. J. Cochran, R. C. Funk, H. Sheng, W. J. Klish, 1987. Total body electrical conductivity measurements: effects of body composition and geometry. *Am. J. Physiol.*, **252**, R795-R800.

Folch J., M. Lees, G. H. Sloan-Stanley, 1957. A simple method for the isolation and purification of total lipids from animal tissues. *J. Biol. Chem.*, **226**, 497-509.

Gjerde B., 1987. Predicting carcass composition of rainbow trout by computerized tomography. *J. Anim. Breed. Genet.*, **104**, 121-136.

Gjerde B., H. Martens, 1987. Predicting carcass composition of rainbow trout by near-infrared reflectance spectroscopy. *J. Anim. Breed. Genet.*, **104**, 137-148.

Ott L., 1988. An introduction to Statistical Methods and Data Analysis, (3rd edition). PWS-KENT Publishing Company, Boston, 945 p.

Presta E., J. Wang, G. G. Harrison, P. Bjorntorp, W. H. Harker, T. B. Van Itale, 1983. Measurement of total body electrical conductivity: a new method for estimation of body composition. *Am. J. Clin. Nutr.*, **37**, 735-739.

Rye M., 1991. Prediction of carcass composition in Atlantic salmon by computerized tomography. *Aquaculture*, **99**, 35-48.

SAS Institute, Inc., 1985. SAS User's Guide: Statistics (version 5 edition). Cary, NC, 956 p.

Valdes E. V., J. L. Atkinson, J. W. Hilton, S. Leeson, 1989. Near infrared reflectance analysis of fat, protein and gross energy of chicken and rainbow trout carcasses. *Can. J. Anim. Sci.*, **69**, 1087-1090.

Walsberg G. E., 1988. Evaluation of a nondestructive method for determining fat stores in small birds and mammals. *Physiol. Zool.*, **61**, 153-159.