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Evaluation of Bioelectric Impedance to Predict Carcass Yield, Carcass Composition, and Fillet Composition in Farm-Raised Catfish

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Abstract.—Bioelectric impedance analysis (BIA) was evaluated as a method for predicting carcass yield, fat, and moisture in live channel catfish, *Ictalurus punctatus* (N = 20), and fat and moisture in fillets from channel catfish (N = 20) and channel catfish female × blue catfish male, *I. furcatus*, hybrids (N = 20). Fish were cultured in ponds, fed a commercial catfish diet (28% protein), and harvested at market weight (450 g–900 g, ~ 19 months post-hatch). Live channel catfish were tranquilized, weighed, and sexed. Resistance and reactance were measured with a four-terminal impedance analyzer. Fish were then deheaded, eviscerated, weighed, and carcass yield was calculated. Fillets from channel catfish and channel catfish × blue catfish hybrids were measured for weight, resistance, and reactance. Carcasses and fillets were ground and fat and moisture were determined by chemical analysis. Regression models including total weight, resistance, and reactance as independent variables explained 71%, 75%, and 65% of the variation in carcass yield, fat, and moisture, respectively, in live fish. Regression models with fillet weight, resistance, and reactance as independent variables explained 62% and 41% of the variation in fillet fat and moisture, respectively, in channel catfish, and 53% and 58% of the variation in fillet fat and moisture, respectively, in channel catfish × blue catfish hybrids. Models including resistance and reactance explained significantly more variation in the traits measured than did models containing only whole weight as an independent variable. Improvements in prediction accuracy will be needed to make BIA a useful tool for predicting carcass yield, carcass composition, and fillet composition in farm-raised catfish.

Improvements in meat yield (amount of saleable meat products/whole animal weight) and composition (fat, protein, moisture) through selective breeding have increased production efficiency and profitability in many livestock industries (Lasley 1987). Selection for increased carcass yield (headless, skinless, eviscerated carcass weight/whole weight) and decreased carcass fat in catfish could benefit the catfish farming industry. Farm-raised catfish are processed and sold as carcasses or fillets, therefore increasing meat yield will result in more saleable product per unit weight of whole catfish produced. The increased incidence of off-flavor (Johnsen and Lloyd 1992) and poor frozen storage quality (Bjarnason 1979) associated with increased fat in farm-raised fish could be reduced by selection for lower fat levels. Selection for carcass traits, however, is hindered because direct measurement of carcass traits is expensive, time-consuming, and requires fish be sacrificed and removed from the pool of potential breeders. Development of accurate, quick, economical, and non-destructive methods to predict carcass yield and composition would improve selection efficiency for these traits in catfish.

Bioelectric impedance analysis (BIA) is a non-destructive technique based on conductance of low-frequency electrical current within the body. BIA has been used to predict carcass yield and composition in sheep (Cosgrove et al. 1988; Slanger et al. 1994; Berg et al. 1996), swine (Marchello and Slanger 1992; Swantek et al. 1992), and cattle (Johns et al. 1992; Slanger and Marchello 1994). This study evaluated the potential for using BIA to predict carcass yield, carcass composition, and fillet composition in farm-raised catfish.

Materials and Methods

Fish used in the study were cultured in 0.04-ha ponds, fed a commercial catfish diet (28% protein), and harvested in January at market weight (450 g–900 g, ~ 19 mo post-hatch). A four-terminal bioelectric

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impedance analyzer (Model BIA-101, RJL Systems, Detroit, Michigan, USA) was used to measure resistance and reactance in live fish and fillets. Resistance measures the conductive characteristics of the body and fluids and increases as the proportion of fat and bone, poor conductors of electricity increase, and decreases as the proportion of water and muscle mass, good conductors of electricity, increase. Reactance is a measure of the cell membrane capacitance and is related to intracellular volume and extracellular water volume (Segal et al. 1985).

Twenty live channel catfish *Ictalurus punctutus* (mean weight = 628 g) were removed from a pond and placed in a 200-L tanks for 1 d (well water temperature 26 C) prior to collecting data. Fish were held at 26 C to allow evacuation of stomach contents and to allow collection of impedance data at a constant temperature. Impedance data are affected by temperature (Slanger and Marchello 1994) and holding fish at 26 C allowed collection of impedance data at a constant temperature and eliminated the need to include effects of temperature in our analysis. Fish were then anesthetized with 2% tricaine methanesulfonate, blotted dry, weighed to the nearest 0.1 g, placed on a plastic tray, and impedance data was collected using lateral and dorsal electrode placements (Fig. 1). An alternating current of 800 μA at 50 kHz was transmitted from each of two outer, transmitter electrodes and resistance and reactance were measured in the area of the fishes body between the two inner, detector electrodes (Fig. 1). A four terminal impedance analyzer measures biological resistance and reactance in the area between the two detector electrodes and is superior to a two terminal analyzer for BIA (Settle et al. 1980). Four, 21-gauge hypodermic needles inserted just into the muscle were used as electrodes. The lateral electrode placement had electrodes placed along the lateral line: one transmitter electrode 1 cm posterior to the pectoral fin, the other transmitter electrode below the adipose fin, and detector electrodes 4 cm from

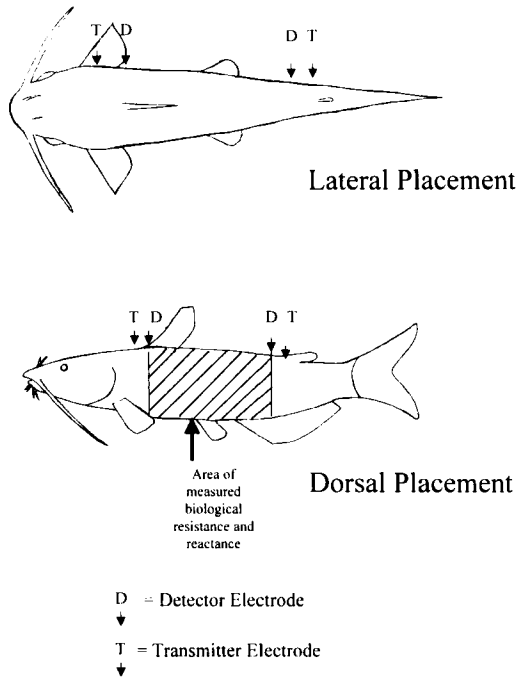

FIGURE 1. *Dorsal and lateral transmitter and detector electrode placement for bioimpedance analysis in live channel catfish.*

the transmitter electrodes on a straight line between the transmitter electrodes. The dorsal placement had electrodes placed along the dorsal midline: one transmitter electrode 2 cm anterior of the dorsal fin, the other transmitter electrode just anterior to the adipose fin, and detector electrodes 4 cm from each transmitter electrodes on a straight line between the transmitter electrodes. A small strip of rubber was used as a "harness" to insure that distance between the transmitter and detector electrode (4 cm) in each pair of electrodes remained constant from fish to fish. Distance between the inner, detector electrodes varied depending on fish length. Since distance between transmitter and detector electrodes was constant it did not need to be included in the analysis. Data collected on live fish included whole weight (nearest 0.1 g), sex, resistance (ohms), reactance (ohms), and the distance between detector (inner) electrodes.

Fish were then killed by over-dose of tri-

caine methane sulfonate, deheaded with a research-scale heading machine (Barth Design, Buhl, Idaho, USA), and eviscerated. Carcass weight was recorded and carcass yield [100(carcass weight/whole weight)] was calculated. Carcasses were stored at −20 C for subsequent proximate analysis.

Left-side fillets from 20 channel catfish (mean fillet weight = 161.2 g, range = 129.6 to 226.1 g) and 20 channel catfish female × blue catfish *Ictalurus furcatus* male hybrids (mean fillet weight = 177.4 g, range = 98.6 to 239.9 g) were held in 26 C water for 1–2 h, blotted dry, weighed, placed on a plastic tray, and impedance data was collected. Transmitter electrodes were inserted into the inner surface of each fillet, midway between the dorsal and ventral margin of the fillet, and about 4 cm from each end of the fillet. Detector electrodes were placed 4 cm from transmitter electrodes on a straight line between the transmitter electrodes. Data collected from fillets included fillet weight, resistance, reactance, and distance between detector electrodes. Fillets were frozen at −20 C for subsequent proximate analysis.

Prior to proximate analysis, carcasses were skinned and ground twice through a meat grinder with a 4.5-mm plate (Universal Trading Co., Woodale, Illinois, USA). Fillets were skinned and ground to homogeneous consistency with a food processor. Fat and moisture of ground carcass and fillet samples were determined in duplicate using AOAC (1990) methods.

The GLM procedure of SAS (1988) was used to determine if carcass yield and composition were affected by sex, and if fillet composition differed between channel catfish and channel catfish × blue catfish hybrids. Data were then examined for outliers (influence diagnostics, Proc Reg; SAS 1988), and prediction models for carcass yield, carcass composition, and fillet composition were developed using the regression procedures of SAS (Proc Stepwise and Proc Reg). Regression models to predict carcass yield, fat, and moisture included whole weight, resistance, reactance, and distance between detector electrodes as independent variables. Carcass yield differed between male and female channel catfish, therefore sex-adjusted residuals (carcass weight of individual − mean carcass weight for fish of that sex) were used in the regression model for predicting channel catfish carcass yield. Models to predict fillet fat and moisture included fillet weight, resistance, reactance, and distance between detector electrodes as independent variables. A significance level of $P < 0.10$ was used to determine if independent variables were included in final models. The mean accuracy (mean of absolute values of the difference between predicted − actual values) and residual standard deviations (square root of sum of squares of residuals/ n − 1) were determined for each trait to provide additional insight on prediction accuracy.

Results

Carcass yield was significantly higher ($P < 0.05$) for females (69.7%) than for males (67.3%), but sexes were not different for whole weight (males = 629.1 g, females = 623.5 g) (Table 1). Means for other variables did not differ among sexes or between channel catfish and channel × blue catfish hybrids. Fillet fat increased and moisture decreased significantly ($P < 0.05$) as fillet weight increased in channel catfish fillets, but fillet weight did not affect fillet composition in channel × blue hybrids.

Prediction models based on dorsal electrode placement were superior to those based on lateral electrode placement. Therefore, data from lateral electrode placement are not presented. Channel catfish carcass yield was negatively associated with whole weight ($P = 0.01$) and resistance ($P = 0.0004$), and positively associated with reactance ($P = 0.026$) and distance between electrodes ($P = 0.023$), $R^2 = 0.71$ (Table 2). Mean accuracy and the residual standard deviation (RSD) for carcass yield were 0.53% and 0.82%, respectively. Carcass fat

TABLE 1. *Means, standard deviations, and ranges for carcass traits and impedance data collected from live channel catfish and fillets from channel catfish and channel catfish × blue catfish hybrids.*

	Channel catfish					Channel × blue				
Variable	N	Mean	SD	Min	Max	N	Mean	SD	Min	Max
Whole fish										
Whole weight, g	20	628.3	128.0	439.9	891.3	—	—	—	—	—
Carcass yield, %	20	67.9	1.7	63.5	69.5	—	—	—	—	—
Fat, %	20	11.01	1.44	9.26	14.22	—	—	—	—	—
Moisture, %	20	71.37	1.02	69.58	73.64	—	—	—	—	—
Resistance, ohms	19	104.2	8.4	91.0	122.0	—	—	—	—	—
Reactance, ohms	19	18.6	4.9	8.0	26.0	—	—	—	—	—
Probe distance, cm	19	9.6	1.4	7.7	12.4	—	—	—	—	—
Fillet										
Fillet weight, g	20	161.2	27.8	129.6	226.1	20	177.4	35.3	98.6	239.9
Fat, %	20	6.94	1.69	4.6	10.4	20	7.06	1.91	3.59	11.63
Moisture, %	20	77.67	2.12	73.79	80.95	20	77.41	2.62	72.22	80.68
Resistance, ohms	20	159.1	38.3	101.0	231.0	20	165.4	49.5	116.0	271.0
Reactance, ohms	20	42.1	8.6	28.0	55.0	20	40.7	7.6	26.0	58.0
Probe distance, cm	20	6.4	1.4	4.4	9.3	20	6.8	1.7	4.4	11.3

was positively associated with whole weight (P = 0.094) and resistance (P = 0.039), and negatively associated with reactance (P = 0.0001), R^2 = 0.75. Mean accuracy and the residual standard deviation (RSD) for carcass fat were 0.51% and 0.69%, respectively. Channel catfish carcass moisture was positively associated with reactance (P = 0.0009) and negatively associated with whole weight (P = 0.016), R^2 = 0.65. Mean accuracy and the residual standard deviation (RSD) for carcass moisture were 0.55% and 0.86%, respectively. Models including total weight as the only independent variable had R^2-values of 0.05, 0.04, and 0.25 for channel catfish carcass yield, fat, and moisture respectively.

Fillet fat in channel catfish was positively associated with fillet weight (P = 0.005) and resistance (P = 0.017), and negatively associated with distance between electrodes (P = 0.002), R^2 = 0.62 (Table 3). Mean accuracy and the residual standard deviation (RSD) for channel catfish fillet fat were 0.98% and 1.16%, respectively. Fillet moisture in channel catfish was negatively as-

TABLE 2. *Regression coefficients (SE, P-value) for predicting carcass yield, fat, and moisture from bioelectric impedance measurement in live channel catfish.*

	Carcass yield	Carcass fat	Carcass moisture
Intercept	15.78	4.86	73.86
Total weight	−0.011 (0.004, 0.01)[a]	0.007 (0.003, 0.094)[a]	−0.008 (0.003, 0.016)[a]
Resistance	−0.193 (0.041, 0.0004)[a]	0.095 (0.041, 0.039)[a]	−0.038 (0.034, 0.286)
Reactance	0.095 (0.038, 0.026)[a]	−0.242 (0.041, 0.0001)[a]	0.144 (0.034, 0.0009)[a]
Probe distance	0.959 (0.381, 0.023)[a]	−0.394 (0.386, 0.370)	0.411 (0.315, 0.215)
Full model R^2	0.71	0.77	0.69
Reduced model R^2[b]	0.71	0.75	0.65
Mean accuracy, %	0.53	0.51	0.55
Residual standard deviation, %	0.82	0.69	0.86

[a] Significant independent variable.
[b] Reduced model contains only significant (P < 0.1) independent variables.

TABLE 3. *Regression coefficients (SE, P-value) for predicting fillet fat and moisture from bioelectric impedance measurement in channel catfish and channel catfish × blue catfish hybrids.*

Variable	Channel catfish	
	Fillet fat	Fillet moisture
Intercept	2.99	83.04
Fillet weight, g	0.07 (0.022, 0.005)[a]	−0.083 (0.034, 0.029)[a]
Resistance, ohms	0.088 (0.032, 0.017)[a]	−0.096 (0.051, 0.082)[a]
Reactance, ohms	−0.036 (0.057, 0.535)	0.065 (0.091, 0.488)
Probe distance, cm	−3.058 (0.81, 0.002)[a]	3.176 (1.30, 0.027)[a]
Full model R^2	0.63	0.43
Reduced model R^2[b]	0.62	0.41
Mean accuracy, %	0.98	1.49
Residual standard deviation, %	1.16	1.77

[a] Significant independent variable.
[b] Reduced model contains only significant ($P < 0.1$) independent variables.

sociated with fillet weight ($P = 0.029$) and resistance ($P = 0.082$), and positively associated with distance between electrodes ($P = 0.027$), $R^2 = 0.41$. Mean accuracy and the residual standard deviation (RSD) for hybrid fillet moisture were 1.49% and 1.77%, respectively. Models including total weight as the only independent variable had R^2-values of 0.15 and 0.20 for channel catfish fillet moisture and fat, respectively.

Fillet fat in channel catfish × blue catfish hybrids was positively associated with resistance ($P = 0.042$) and negatively associated with distance between electrodes ($P = 0.100$), $R^2 = 0.53$. Mean accuracy and the residual standard deviation (RSD) for hybrid fillet fat were 1.01% and 1.21%, respectively. Fillet moisture in channel × blue catfish hybrids was negatively associated with resistance ($P = 0.007$) and positively associated with distance between electrodes ($P = 0.003$), $R^2 = 0.58$. Mean accuracy and the residual standard deviation (RSD) for hybrid fillet moisture were 1.25% and 1.39%, respectively. Models including total weight as the only independent variable had R^2s of 0.14 and 0.12 for channel × blue catfish hybrid fillet moisture and fat, respectively.

Discussion

Bioelectric impedance technology is based on the measurement of resistance and reactance as an electrical current passes through the body. BIA is commonly used in human medicine to measure total body moisture, fat, and lean muscle mass (Kushner 1992; Houtkooper et al. 1996) and has been used to predict carcass yield and composition in livestock with accuracy similar to those we observed for catfish (Slanger and Marchello 1994; Slanger et al. 1994; Berg et al. 1996). This is the first study we are aware of evaluating use of BIA to predict carcass yield and composition in fish. A related technique, total body electrical conductivity, which measures conductivity in a low-frequency magnetic field, has been used to predict body compostion in juvenile sunshine bass, *Morone chrysops* × *M. saxatilis* (Brown et al. 1993).

Regression models using BIA data had R^2-values ranging from 0.41 to 0.75 for carcass yield, carcass composition, and fillet composition, suggesting that BIA has potential as a tool for predicting these traits in catfish. Resistance decreased as carcass yield (or muscle mass), and carcass and fillet moisture increased. Resistance increased as carcass and fillet fat increased. Similar relationships between resistance and carcass yield and composition have been reported in swine, sheep, and cattle (Cosgrove et al. 1988; Johns et al. 1992; Marchello and Slanger 1992; Swantek et al. 1992; Slanger and Marchello 1994; Slanger et al. 1994;

TABLE 3. *Extended.*

Channel catfish × Blue catfish	
Fillet fat	Fillet moisture
6.96	77.36
−0.005 (0.016, 0.774)	−0.023 (0.020, 0.274)
0.041 (0.018, 0.042)[a]	−0.070 (0.022, 0.007)[a]
−0.015 (0.082, 0.862)	0.005 (0.101, 0.959)
−0.803 (0.46, 0.100)[a]	14.66 (0.61, 0.003)[a]
0.53	0.63
0.53	0.58
1.01	1.25
1.21	1.39

Berg et al. 1996). The positive association of reactance with catfish carcass yield and moisture has been reported in other studies with livestock (Slanger and Marchello 1994; Slanger et al. 1994; Berg et al. 1996), but Berg and Marchello (1994) found no significant relationship among reactance and carcass yield or composition in sheep. Many of the models developed for traditional livestock species have higher R^2-values than those we reported. However, most of these models have fat-free mass as the dependent variable, and this trait is highly dependent on whole-animal weight. Whole-animal weight is included in these models and frequently whole weight alone explains over 90% of the variation. When fat-free mass is expressed as a percentage of whole animal weight, as is carcass yield in our study, R^2-values are lower for the other studies cited.

Collection of bioimpedance data is fast, equipment is fairly inexpensive (<U.S. $2,000), measurements can be taken on live fish, and BIA appears to have potential for predicting carcass yield and composition based on the limited sample size used in this study. Using BIA-predicted values for carcass yield and composition as selection criteria in an applied breeding program could improve of selection efficiency for yield and composition. However, the moderate R^2-values for the models we developed and the fairly small ranges in values of the traits we studied (~ 6% to 8%) combine to limit the ability to accurately rank individuals for the traits measured (Prairie 1996).

Improvements in predicting yield and compostion in catfish with BIA may be achieved by evaluating the influence of electrode placement and cross-sectional area of the fish on prediction models. The site of electrode placement influences prediction accuracy of BIA (Hall et al. 1989) and prediction models developed for live fish using data from dorsal electrode placement were better than those using lateral electrode placement. Studies in livestock (Swantek et al. 1992; Berg and Marchello 1994) have established that dorsal placement of electrodes generally produces superior results. Varying electrode placement along the dorsal midline could result in improved prediction accuracy. Impedance increases as conductor length increases and cross-sectional area decreases. Although distance between electrodes was included in models as a measure of conductor length, no measure of cross-sectional area was included. Including a measure of circumference or cross-sectional area in models could improve prediction accuracy in both fillets and whole fish.

Improvements in prediction accuracy are needed before this tool can be used as a reliable, accurate predictor of catfish meat yield and composition. Information from models based on larger sample sizes, testing of prediction accuracy for yield and compostion in independent data sets, and determination of heritabilities for yield and composition are needed before the benefits of using BIA in a breeding program to improve catfish carcass yield and composition can be realized.

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