Short Communication

Bioelectrical impedance analysis for the prediction of hot carcass weight in buffalo calf

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ABSTRACT

Twenty young buffalo male calves were fed *ad libitum* with a total mix ration and with vitamin-mineral integration for 14 months. Seven days before slaughter, the animals were weighed and bioelectrical impedance measurements were collected in live animals. Physical and chemical characteristics were assessed on the *Longissimus dorsi* muscle after slaughter. Correlations and regression equations were calculated to determine the possible use of bioelectrical impedance for evaluating hot carcass weight. Bioelectrical impedance analysis at different frequencies, simple correlation and analysis of regression were examined for all the data collected, supporting the possibility of hot carcass weight prediction with equation at multi-frequency.

The results show that, probably due to the variability in animal live weight, the distribution of the colour parameters was not normally distributed. Moreover, using different frequencies of resistance and reactance, hot carcass weight in buffalo may be predicted with the following equation:

$Y=98.47–8.84(Rs_{100KHz})+4.41(Rs_{1000\,KHz})-116.27(Xc_{5\,KHz})+51.04(Xc_{50\,KHz})+20.30(Xc_{100\,KHz})-33.92(Xc_{500\,KHz})+9.01(Xc_{1000\,KHz})\pm\varepsilon$

(Adjusted R Square value of .907 and SE of 5.728)

However, further studies are required to improve the technique also in buffalo, after standardization of the method.

Key words: Buffalo, Bioelectrical impedance, Hot carcass weight.

RIASSUNTO

POSSIBILE UTILIZZO DELL'IMPEDENZA BIOELETTRICA AL FINE DI PREDIRE IL PESO DELLA MEZZENA NEL VITELLO BUFALINO

Diversi studi hanno ben definito le potenzialità produttive della filiera carne di bufalo sia per ragioni di ordine economico che per le ottime caratteristiche nutrizionali che la carne stessa possiede. Diversi sono stati

gli approcci finalizzati alla valutazione delle caratteristiche d'accrescimento del maschio bufalino destinato alla produzione della carne e delle caratteristiche chimico-nutrizionali della carne stessa. Innovativa risulta essere in tal senso l'applicazione dell'impedenza bioelettrica anche in questa specie animale sia in considerazione della relativa esattezza che per la semplicità d'utilizzo. L'obiettivo di questo studio è stato quello di sviluppare una equazione di predizione del peso della mezzena. Venti maschi bufalini, alimentati ad libitum con la tecnica unifeed, sono stati macellati all'età di circa 14 mesi. Al momento della macellazione sono stati prelevati tagli campione, ed isolato il muscolo longissimus dorsi sul quale sono state eseguite le analisi concernenti la valutazione delle caratteristiche chimico-nutrizionali. Le correlazioni e l'equazioni di previsione sono state effettuate, partendo dai dati ottenuti, al fine di calcolare la possibilità di utilizzare le informazioni ottenute con l'analisi dell'impedenza per predire i peso della carcassa. Tali determinazioni sono state eseguite utilizzando il pacchetto statistico SPSS. L'analisi descrittiva e la correlazione semplice sono state utilizzate su ciascun parametro considerato. I risultati ottenuti hanno mostrato che è possibile predire il peso della carcassa, anche se un ulteriore approfondimento è necessario al fine di perfezionare la tecnica della bioimpedenza anche nella specie bufalina.

Parole chiave: *Bufalo, Impedenza bioelettrica, Peso della carcassa calda.*

Introduction

Buffalo meat is gaining increasing interest both for economic reasons and due to improved knowledge on how to obtain a good quality product (Ferrara and Infascelli, 1994; Gigli *et al.*, 2001). Given the highly-prized nutritional characteristics of buffalo meat, the buffalo's aptitude for meat production has been amply described. The main characteristics of buffalo meat are a low content of intramuscular fat (Gigli *et al.*, 2001), a low level of cholesterol and high content of micro- and macro-elements (Cutrignelli *et al.*, 1996). Moreover, buffalo meat can withstand different food processing methods.

Various techniques and procedures have been used in different species, under specific conditions, for estimating body composition of live animals. Bioelectrical impedance analysis (BIA) is a commonly used method for estimating body composition. Since the advent of the first commercially available devices in the mid-1980s the method has become popular owing to its ease of use, portability of the equipment and its relatively low cost compared to some of the other methods of body composition analysis, especially electrical meat measuring equipment (EMME) and body electrical conductivity (TOBEC). BIA technology, previously developed for humans, has been applied with interesting results in many animal species. Impedance is a geometric system and depends on the conductor length, cross-sectional area and signal frequency. The repeatability of impedance measurements can be improved by using a fixed signal frequency and a constant conductor configuration. The impedance of a biological tissue comprises two components, the resistance and the reactance. The conductive characteristics of body fluids provide the resistive component, whereas the cell membranes, acting as imperfect capacitors, contribute a frequency-dependent reactive component, because, theoretically, a low-frequency current (<5 kHz) should move only in the extra cellular fluid, while a high frequency current (>500 kHz) should also go through all cells containing electrolyte solutions.

A complex impedance (Z) measurement, based on both resistance (Rs) and reactance (Xc) measurements, was calculated as $Z=(Rs^2+Xc^2)^{.5}$. According to Twyman and Liedtke (1987), Rs is equal to the voltage drop of a conductor divided by the current applied, and Xc is equivalent to the quantity of electricity divided by the applied voltage

drop. Impedance measurements made over a range of low (5 KHz) to high (1 MHz) frequencies allow the development of predictive equations; this is known as multi-frequency bioelectrical impedance analysis (MFBIA).

Bioelectrical impedance analysis (BIA) has been proposed in humans (Janssen *et al.*, 2000; Miyatani *et al*., 2001; Salinari *et al.*, 2003; Stahn *et al.*, 2007). Because of its accuracy, simplicity and portability, this technology has been conveniently applied in pigs (Swantek *et al*., 1991, 1992), in sheep (Cosgrove *et al.*, 1988; Jenkins *et al.*, 1988; Berg *et al.*, 1996), in beef cattle (Marchello and Slanger 1992; Marchello *et al.*, 1999; Velazco *et al.*, 1999), in horses (Forro *et al.*, 2000) and in buffalo beef for evaluating the fat free mass (Sarubbi *et al*., 2008), that meat tenderness is correlated with, ultimate muscle pH (Purchas, 1990; Watanabe *et al.*, 1996), and muscle colour (Jeremiah *et al.*, 1991; Wulf *et al.*, 1997); measurements of electrical bioimpedance have also been shown to be related to muscle pH and water-holding capacity (Oliver *et al.*, 1991; Whitman *et al*., 1996). However, none of these research papers examined the possibility to develop prediction equations of the hot carcass weight in buffaloes.

In accordance with these considerations the aim of this study is to define the relationships between colour, pH, hot carcass weight, and meat characteristics of *Longissimus dorsi,* muscle weight and impedance measures collected on live buffalo calves in order to develop predictive equations of hot carcass weight in buffaloes.

Material and methods

Our research involved 20 young buffalo male calves, born and bred on a farm near Salerno (Italy). They were fed with a milk substitute until weaning, 60 days after birth, subsequent to colostrum administration. Animals had *ad libitum* access to a total mix ration (49% maize silage, 32% lolium, 7% alfalfa hay, 6% flaked barley and 5% soybean meal). The diet was calculated assigning .87 Milk Forage Units/kg of Dry Matter, 15% crude protein and 50% NDF, supplemented with a premix containing vitamins and minerals. Slaughter and dissection were carried out according to the ASPA Commission (1991). The sample cut was taken, after slaughter, from the left carcass side at the 10^{th} thoracic vertebra level, according to Lanari's (1973*)* recommendations. On the *Longissimus dorsi* section, located between the cranial margin of the 9^{th} and the caudal margin of the last thoracic vertebra at the right side, cut off immediately after slaughter, the chemical and nutritional characteristics of meat were assessed following ASPA guidelines (1996).

For the *in vivo* BIA measurements the buffalo were sedated using Rompum® with a dosage of 0.25mg/100 kg LW, enough to immobilise the animals. *In vivo* impedance measurements (KHz) of resistance (Rs) and reactance (Xc) were made using two electrodes that were placed transdermally approximately 1 cm from the dorsal midline, 10-15 cm from the last cervical vertebra and approximately 5 and 10 cm cranial from the first sacral vertebra. Twenty-gauge Vacutainer needles (Becton Dickinson,Rutherford, NJ) were used as electrodes.

For Rs and Xc measurements we used Human Im Plus II® (Astel electronics and industrial automation ®-Turin-Italy) and frequency differences of 5 kHz to 1 MHz. Chemical analyses (dry matter, ash, protein, fat , etc) were carried out on freeze-dried meat (AOAC, 1997). The colour characteristics were performed on *Longissimus* samples on raw meat and on meat cooked in a bain-marie for 1 hour at 75°C. Colour was determined using a colorimeter Minol-

ta CM-2006d (Minolta Corp., Ramsey, NJ), on samples exposed to the air for 1 hour, using the illuminant D 65 with a 50mm-diameter measurement area. The parameters considered were brightness (L), yellowness (a), redness (b) and reflectance in the visible spectrum (360-740nm) at 10 nm intervals.

All statistical methods of evaluation of data were carried out to determine the possible use of BIA for predicting hot carcass weight and relationships among all considered data using SPSS 12.0 (2003) listed in Tables 2, 3, 4 and 5.

Results and discussion

Table 1 shows that resistance decreased almost linearly with increasing frequency. Reactance increased when the frequency was increased up to 100 kHz. This may well

Table 1. Descriptive statistics of the parameters considered.

		Mean	SD	Variance
Dry matter	%	24.16	.77	.60
Ash	% DM	4.45	.11	.01
Intramuscular fat	"	5.11	1.22	1.48
Intramuscular protein	"	90.44	1.17	1.38
Lightness L*		42.78	2.73	7.43
Redness A*		19.00	1.76	3.08
Yellowness B*		15.59	1.53	2.34
pH		5.52	.07	.005
Fat weight	kg	20.88	5.07	25.67
Muscle weight	"	63.25	9.37	87.72
Carcass weight	"	127.24	18.44	340.19
Longissimus dorsi weight	"	4.17	.60	.355
Frequency (KHz):				
Rs	5	30.62	2.52	6.34
	10	29.58	2.76	7.62
	50	24.49	6.53	42.66
	100	21.69	6.35	40.26
	500	16.97	6.08	36.97
	1000	13.39	5.80	33.70
Xc	5	1.56	.25	.055
	10	2.49	.47	.217
	50	3.09	.79	.617
	100	3.23	1.83	3.34
	500	-6.89	1.44	2.08
	1000	-17.84	2.49	6.19

Rs: resistance; Xc: reactance.

be caused by the fact that electrical impedance is a measure of the opposition to the flow of an electric current through muscle tissue, which is related to the amount of free water in the muscle. Hence at higher frequencies current dispersion may well occur.

The L*value (Figure 1) exhibited a non-normal distribution, and the majority of the samples fell within the 42 to 46 range. a* and b* values normal. The distribution of a* and b* values for the majority of the samples fell within the range of 17 to 19 and 15 to 16, respectively (Figure 2).

The non-normal distribution of L*, a* and b* were correlated to different LW of the animals in the experiment and then to

Figure 1. Distribution of the *longissimus* L* value.

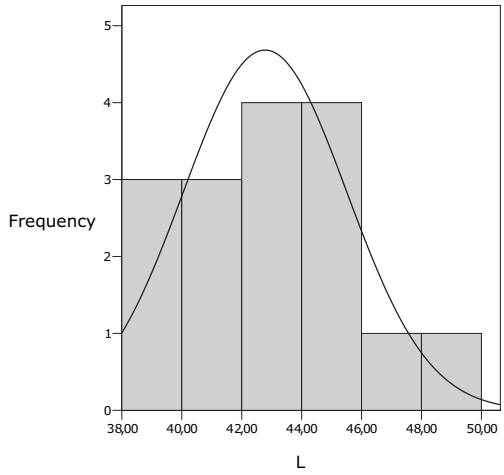
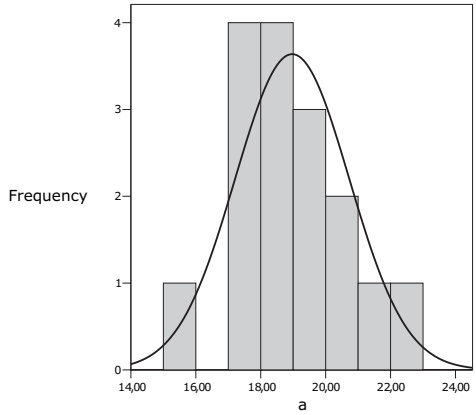
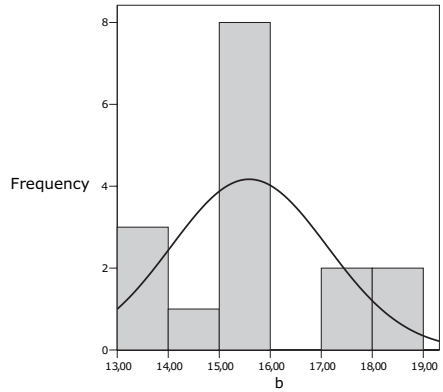


Figure 2. Distribution of the *longissimus* a* and b* value.





the different maturity of the muscle in question. Over one-half of the carcasses evaluated were in the pH range 5.32-5.65 (Figure 3), and 80% were in the range of 5.45-5.60, a range considered as the "normal" pH for the *Longissimus* muscle following normal postmortem metabolism (Lawrie, 1958; Tarrant and Mothersill, 1977; Page *et al.*, 2001).

In Table 2 we report the correlation matrix among the considered parameters. The correlation between a* and b* shown in Table 2 is an indication of good meat colour. However, a* is probably more useful than b* when measuring beef colour stability (surface metmyoglobin formation) over time, because a* varies from red to green and the metmyoglobin formation changes the colour of beef from red to greenish brown. The a* value was also correlated with meat chemical characteristics. In addition, values of b*, L* and a* were intercorrelated, as reported by Page *et al.* (2001). With cooking there is a degradation of myoglobin equal to 41.55% and the presence of grey brown compounds that increase compared with the raw meat of 28.74%.

No significant correlation was found between pH and muscle colour. However, when muscle pH declines the colour gets worse with a tendency to greenish brown, as previously demonstrated by Wulf *et al*. (1994) and Page *et al.* (2001).

As regards resistance measurements, there are no correlations between resistance and all the considered parameters. However, when frequency of the reactance measurements reaches high values, we found a negative correlation with L*, a* and b* values.

In Table 3 we report the correlation matrix among the BIA parameters.

In Table 4 we report the ANOVA for the regression model considered. Examination of the table shows the goodness of the forecast model chosen, as highlighted by the low value of the residue. The predictive model summary for evaluating carcass weight shown high R^2 and Adjusted R^2 values (Table 5).

Using different frequencies of resistance and reactance, hot carcass weight in buf-

Figure 3. Distribution of the *longissimus* ultimate muscle pH value.

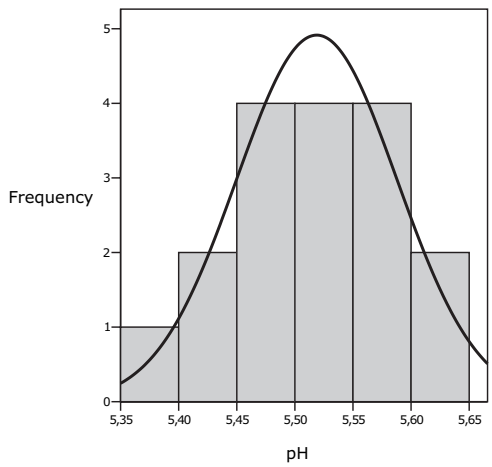


Table 2. Correlation between parameters at any frequency.

	L*	a*	b*	area	pH	Rs_5	Rs_10	Rs_50	Rs_100	Rs_500	Rs_1000	Xc_5	Xc_10	Xc_50	Xc_100	Xc_500	Xc_1000
L	1	-.028	.638**	-.210	-.275	.269	.232	-.005	.003	-.080	-.154	.005	.114	.225	-.089	-.224	-.444
a		1	.635**	-.078	.121	-.062	-.093	-.128	-.141	-.207	-.250	-.015	.019	.025	-.157	-.292	-.231
b			1	-.169	-.232	.052	-.026	-.200	-.208	-.313	-.387	.009	.138	.084	-.175	-.351	-.417
area				1	-.193	-.155	-.136	-.011	-.041	.016	.093	-.625**	-.618(*)	-.643(**)	-.067	.172	.626(**)
cooking					-.021	-.298	-.247	-.142	-.130	-.116	-.107	-.085	.112	-.115	-.303	-.279	-.291
pH					1	.294	.560*	.706**	.718**	.719**	.681**	.070	.227	.263	-.286	-.374	-.045

	Muscle dry matter	Muscle ash	Muscle fat	Muscle protein
L*	-.610*	-.023	.064	-.064
a*	.335	-.618*	.562*	-.522*
b*	-.238	-.371	.416	-.395
Muscle dry matter	1	-.503*	.309	-.271
Muscle ash		1	-.407	.325
Muscle fat			1	-.996**

***Correlation is significant at P<0.01.*

**Correlation is significant at P<0.05.*

Table 3. Correlation between BIA parameters at any frequency.

	Rs_5	Rs_10	Rs_50	Rs_100	Rs_500	Rs_1000	Xc_5	Xc_10	Xc_50	Xc_100	Xc_500
Rs_5											
Rs_10	.664**										
Rs_50	.586*	.125									
Rs_100	.554*	.488	.766**								
Rs_500	.246	.155	.619*	.877**							
Rs_1000	.208	.593*	.340	.769**	.741**						
Xc_5	.816**	.592*	.593*	.550*	.217	.227					
Xc_10	.586*	.443	.492	.409	.044	.058	.782**				
Xc_50	.731**	.487	.420	.382	.133	.086	.927**	.756**			
Xc_100	.961**	.621*	.553*	.457	.086	.051	.847**	.720**	.776**		
Xc_500	.746**	.538*	.823**	.834**	.545*	.468	.739**	.693**	.570*	.750**	
Xc_1000	.289	.280	.481	.620*	.604*	.558*	.274	.255	.199	.196	.666**

***Correlation is significant at P<0.01 level.*
**Correlation is significant at P<0.05.*

Table 4. ANOVA for the regression model.

Model	Sum of Squares	Mean Square	F	Sign.
Regression	5040.238	630.030	19.200	.000
Residual	229.700	32.814		
Total	5269.938			

Table 5. Model Summary.

R	R Square	Adjusted R Square	SE of the Estimate
.978	.956	.907	5.728

Predictors: Xc_5. Xc_500. Xc_1000. Rs_1000. Xc_50. Xc_100. Rs_100.
Dependent variable: hot carcass weight.

falo may be predicted with the following equation:

$Y=98.47–8.84(Rs_{100KHz})+4.41(Rs_{1000\ KHz})-116.27(Xc_{5\ KHz})+51.04(Xc_{50\ KHz})+20.30(Xc_{100\ KHz})-33.92(Xc_{500\ KHz})+9.01(Xc_{1000\ KHz})\pm\varepsilon$

(Adjusted R Square value of .907 and SE of 5.728)

In Figure 4 we report the relationship between observed and predicted carcass weights with the confidence interval at 95% obtained with linear regression model. Figure 5 reports the histogram for frequency of regression standardized residuals. The distribution of the standardized residuals confirms the correctness of the model applied in our buffalo sample.

Figure 4. Relationship between carcass weights observed and predicted.

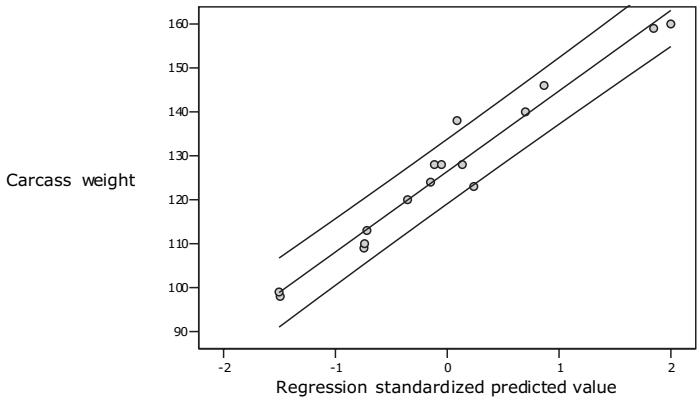
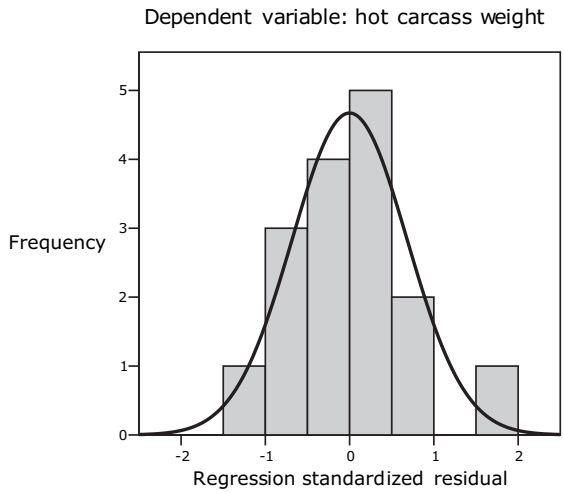


Figure 5. Frequency of regression standardized residual value.



Conclusions

The quality of BIA measurement depends on homogeneity of parameters, size/volume of the species studied, and significant sampling. Impedance measurements may be more precise when larger volumes are measured. This study indicates that BIA can be used to evaluate hot carcass weight in buffaloes, although further studies are necessary to improve the technique in buffaloes under different experimental conditions for the purpose of model validation.

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