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

Fiorella Sarubbi, Rodolfo Baculo, Leopoldo Iannuzzi

Istituto per il Sistema Produzione Animale in Ambiente Mediterraneo.
Consiglio Nazionale delle Ricerche, Napoli, Italy

Corresponding author: Dr. Fiorella Sarubbi. ISPAAM, CNR. Via Argine 1085, 80147 Napoli, Italy - Tel. +39 081 5966006 - Fax: +39 081 5965291 - Email: fiorella.sarubbi@ispaam.cnr.it

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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:

\[
Y = 98.47 - 8.84(R_{s100KHz}) + 4.41(R_{s1000KHz}) - 116.27(X_{c5KHz}) + 51.04(X_{c50KHz}) + 20.30(X_{c100KHz}) - 33.92(X_{c500KHz}) + 9.01(X_{c1000KHz}) \pm \varepsilon
\]

(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

POSSIBLE 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...
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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 il 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 $Z = (Rs^2 + Xc^2)^{\frac{1}{2}}$. 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.
Carcass weight and BIA

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 10th thoracic vertebra level, according to Lanari’s (1973) recommendations. On the Longissimus dorsi section, located between the cranial margin of the 9th 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. |
|-----------|-------------------------------------------------|
| Dry matter | Mean | SD  | Variance |
| %         | 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       | Mean | SD  | Variance |
|----------|------|-----|----------|
| 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       | Mean | SD  | Variance |
|----------|------|-----|----------|
| 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 1](image1)

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

![Figure 2](image2)
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 post-mortem 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 R² and Adjusted R² 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.

| Parameter | 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 | -.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 | .025 | -.003 | -.114 |
| pH        | 1  | .294 | .560* | .706** | .718** | .719** | .681** | .070 | .227 | .263 | -.374 | -.286 | -.045 | .016 | .006 | .007 |

| Parameter          | 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:

\[ Y = 98.47 - 8.84(R_{1000 \text{ KHz}}) + 4.41(R_{1000 \text{ KHz}}) - 116.27(X_{5 \text{ KHz}}) + 51.04(X_{50 \text{ KHz}}) + 20.30(X_{100 \text{ KHz}}) - 33.92(X_{500 \text{ KHz}}) + 9.01(X_{1000 \text{ KHz}}) + \varepsilon \]

(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 4](image)

Figure 5. Frequency of regression standardized residual value.

![Figure 5](image)
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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