In vivo ultrasound and biometric measurements predict the empty body chemical composition in Nellore cattle

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ABSTRACT: Evaluation of the body chemical composition of beef cattle can only be measured postmortem and those data cannot be used in real production scenarios to adjust nutritional plans. The objective of this study was to develop multiple linear regression equations from in vivo measurements, such as ultrasound parameters [backfat thickness (**uBFT**, mm), rump fat thickness (**uRF**, mm), and ribeye area (**uLMA**, cm²)], shrunk body weight (**SBW**, kg), age (**AG**, d), hip height (**HH**, m), as well as from postmortem measurements (composition of the 9th to 11th rib section) to predict the empty body and carcass chemical composition for Nellore cattle. Thirty-three young bulls were used (339 ± 36.15 kg and 448 ± 17.78 d for initial weight and age, respectively). Empty body chemical composition (protein, fat, water, and ash in kg) was obtained by combining noncarcass and carcass components. Data were analyzed using the PROC REG procedure of SAS software. Mallows' *C_p* values were close to the ideal value of number of independent variables in the prediction equations plus one. Equations to predict chemical components of both empty body and carcass using in vivo measurements presented higher *R*² values than those determined by postmortem measurements. Chemical composition of the empty body

using in vivo measurements was predicted with *R*² > 0.73. Equations to predict chemical composition of the carcass from in vivo measurements showed *R*² lower (*R*² < 0.68) than observed for empty body, except for the water (*R*² = 0.84). The independent variables SBW, uRF, and AG were sufficient to predict the fat, water, energy components of the empty body, whereas for estimation of protein content the uRF, HH, and SBW were satisfactory. For the calculation of the ash, the SBW variable in the equation was sufficient. Chemical compounds from components of the empty body of Nellore cattle can be calculated by the following equations: protein (kg) = $47.92 + 0.18 \times \text{SBW} - 1.46 \times \text{uRF} - 30.72 \times \text{HH}$ (*R*² = 0.94, RMSPE = 1.79); fat (kg) = $11.33 + 0.16 \times \text{SBW} + 2.09 \times \text{uRF} - 0.06 \times \text{AG}$ (*R*² = 0.74, RMSPE = 4.18); water (kg) = $-34.00 + 0.55 \times \text{SBW} + 0.10 \times \text{AG} - 2.34 \times \text{uRF}$ (*R*² = 0.96, RMSPE = 5.47). In conclusion, the coefficients of determination (for determining the chemical composition of the empty body) of the equations derived from in vivo measures were higher than those of the equations obtained from rib section measurements taken postmortem, and better than coefficients of determination of the equations to predict the chemical composition of the carcass.

Key words: beef cattle, chemical composition, ultrasound

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INTRODUCTION

Accurate methods for estimating chemical composition (water, protein, fat, and ash contents) of live cattle are essential to determine maturity and nutrient requirements in beef production systems and have been studied over the years (Lofgreen and Garrett, 1968; Garrett, 1980; Oltjen et al., 1986; Tedeschi et al., 2004). Knowledge of weight at maturity can avoid premature slaughter, allowing the animal to express the true genetic potential for muscle growth and for an ideal fat deposition at carcass finishing (Trenkle and Marple, 1983). Since any gains after maturity require excessive increases in feed intake, accuracy in identifying maturity can also be helpful in preventing feed waste. Most of the techniques used for direct or indirect evaluation of the chemical composition of the animal are still carried out postmortem (Hankins and Howe, 1946; Lofgreen, 1965; Costa e Silva et al., 2013), in noble carcass parts, implying a high cost for determination, and cannot be used in real production scenarios to adjust nutritional plans in each phase of growth. Therefore, new tools are necessary to allow the prediction of these characteristics in the live animal. Noninvasive methods such as ultrasonography and biometrics have been tested to predict adipose depots (Ribeiro and Tedeschi, 2012) and muscle growth of beef cattle (Herring et al., 1998; Greiner et al., 2003; Scholz et al., 2015). However, no methods have yet been published to predict major chemical compounds such as water, protein, and ash using these techniques as auxiliary tools and allowing the use of *in vivo* measurements in real time.

Thus, this study employed ultrasonography and biometry of live animals to determine equations in order to estimate the chemical composition of the body and carcass of Nellore cattle, assessing their precision through comparison with equations determined from parameters obtained postmortem.

MATERIALS AND METHODS

The experimental procedures were reviewed and approved by the Ethics Animal Use Committee (protocol number 179/2012-CEUA) of the School of Veterinary Medicine and Animal Science (FMVZ), São Paulo State University (UNESP), Botucatu, SP, Brazil.

Location, Animal Housing, and Trial Period

The experiment was conducted at the Advanced Center for Research and Technology in Beef Cattle,

of the Institute of Animal Science of the State of São Paulo. The Center is located in the northern region of the state of São Paulo, in the municipality of Sertãozinho, located at 21°10'S latitude and 48°5'W longitude, a region with a humid tropical climate, with an average annual temperature of 24 °C and average annual rainfall of 1,312 mm.

Thirty-three young Nellore bulls were used, with mean weight and initial age of 339 ± 36.15 kg and 448 ± 17.78 d, respectively. The animals underwent an adaptation period of 35 d, receiving feed *ad libitum*, in which the roughage:concentrate ratio was changed gradually each week until the proportion of the concentrate reached 82% of the total diet on DM basis.

The diet (Table 1) was formulated based on the recommendations of energy and protein requirements, adjusted using level 2 of the NRC (2000). Feed was provided daily at 0800 and 1500 h, with *ad libitum* access to diet and water. The voluntary intake of each animal was calculated by the difference between the feed offered and the orts. All orts were collected daily during the whole experiment, weighed and sampled in 10% of their weight, and the intake was adjusted to allow daily values of orts from 5% to 10% of the initial amount. Samples of the diet and orts were collected for further analysis.

Shrunk body weights (SBW) were recorded at the beginning and end of the adaptation period (35

Table 1. Percent composition of dietary ingredients and nutrients

Item	% DM
Palisade grass hay	18.60
Cottonseed	12.30
Citrus pulp pellet	18.20
Corn grain	39.40
Cottonseed meal	7.70
Urea	1.20
Ammonium sulfate	0.10
Mineral premix ^a	2.00
Limestone	0.50
Nutrients ^b	
DM, %	84.00
CP, % DM	14.80
TDN, % DM	73.00
NE _m , Mcal/kg DM	1.72
NE _g , Mcal/kg DM	1.10
NDF, % DM	29.00
Calcium, % DM	0.67
Phosphate, % DM	0.37

^aComposition of the mineral premix (kg of product): 180 g Ca, 90 g P, 10 g Mg, 13 g S, 93 g Na, 145 g Cl, 17 mg Se, 1,000 mg Cu, 826 mg Fe, 4,000 mg Zn, 1,500 mg Mn, 150 mg I, 80 mg Co, 900 mg F.

^bValues calculated by the NRC (2000) level 2.

d), as well as every 28 d during the experimental period (84 d), in which the animals were fasted for 16 h of water. At the same time, hip height (**HH**, m) was measured with a measuring tape in the squeeze chute, as well as ultrasound measurements were also performed by Pie Medical Aquila equipment (3.5 MHz linear grafting transducer and 17 cm length; Esaote Europe B.V., Maastricht, The Netherlands) on the *Longissimus dorsi* muscle (12th and 13th ribs) for determination of the ultrasound LM area (**uLMA**; cm²), the ultrasound backfat thickness (**uBFT**; mm), and the ultrasound rump fat thickness (**uRF**; *Biceps femoris*; mm), which were used as in vivo measures (independent variables) for the determination of the prediction equations.

After the adaptation period (35 d), 9 animals were selected by uBFT means of the experimental group ($n = 33$) and slaughtered to use as reference for estimation of empty body weight (**EBW**). The remaining animals ($n = 24$) were randomly slaughtered at 3 different times ($n = 8$) with intervals of 28 d to allow amplitude in the chemical composition of the body and carcass and, consequently, to determine more comprehensive equations to predict the evaluated characteristics.

Slaughter and Sampling

The animals were slaughtered at the University of São Paulo (USP), Pirassununga-SP abattoir, and followed the Industrial and Sanitary Inspection of Products of Animal Origin regulations (Brasil, 1997). The slaughter was humane. Blood was drawn through the jugular vein, followed by skinning, evisceration, and symmetrical separation of the 2 halves of the carcass.

During slaughter, blood, feet, head, hide, tail, gastrointestinal tract (rumen, reticulum, omasum, and abomasum, and intestines), liver, kidneys, internal fat (renal, pelvic, and inguinal), and other internal organs (tongue, esophagus, trachea, lung, heart, spleen, pancreas, and reproductive system) from each animal were weighed and collected. The gastrointestinal tract of each animal was weighed full, emptied, and washed, and its weight after washing was added to that of the organs and other parts of the body for EBW determination (Lofgreen et al., 1962; Garrett and Hinman, 1969). All collected material was identified, packed in plastic bags, and frozen at -20°C .

The carcasses were identified and stored in a cold room ($T = 0 \pm 2^{\circ}\text{C}$) for 22 h. After 22 h of cooling, the half-carcasses were removed from the cold room and samples were processed. The rib

section (9th to the 11th ribs) was taken from the right half-carcass of each animal, according to the methodology proposed by Hankins and Howe (1946). The left half-carcass was reduced to small pieces, which were packed in plastic bags, identified, and frozen at -20°C for further analysis of the chemical composition.

Determination of Body Chemical Composition

Samples were collected at the abattoir and sent to the Institute of Animal Science of Nova Odessa. The body chemical composition of the animals was determined by the direct technique. The components for analysis were divided: blood, hide, tail, head and feet, viscera and organs, and carcass (muscle, bone, and fat). The hide and head were cut in half and only the left side was used for processing the material. With the exception of the hide which was ground several times and sampled (chopped and ground fresh), all the collected samples were frozen separately, and then reduced to smaller pieces using a bandsaw. Then, the sawed material was ground in a large grinder (P-33A, 15 HP; Frigmann Hermann, SP, Brazil). The samples were ground twice with a 50 mm perforated plate, 3 times with a 30 mm perforated plate, and once with a 12 mm perforated plate. At the last grinding, representative samples of about 400 g of the homogenized material were collected, which were divided into 4 Petri dishes.

Chemical analyses were performed according to AOAC (1997) except for protein analysis. The partial water content of the samples was determined by freeze drying of approximately 200 g of fresh sample for approximately 80 h until a constant weight was reached. Then, the samples were ground in a blender with dry ice (solid CO_2), and stored in airtight plastic containers for further analyses of DM (method 950.46), ether extract (EE; method 960.39), CP (method 928.08), and ash (method 920.153). The final DM was determined by the drying of the lyophilized subsamples at 105°C . For the determination of EE content (method 960.39), 2-g aliquots of the samples stored in cartridges consisting of qualitative filter paper were extracted in an Ankom XT15 extractor (AnKom Technology Corp., Fairport, NY) using a 24-h extraction in petroleum ether. Ash was determined by the burning of approximately 2 g of the samples in a muffle furnace at 550°C for 8 h. Protein content was calculated by subtracting EE, water, and ash content from 100% as described by Bonilha et al. (2013). For the estimation of the retained energy

the following equation based on the body protein (BP, kg) and body fat (BF, kg) contents and their caloric equivalents: $EC = 5.6405 \text{ BP} + 9.3929 \text{ BF}$ (ARC, 1980) was used.

Statistical Analysis

All data were initially tested for normality using the Shapiro–Wilk test from the UNIVARIATE procedure of SAS (version 9.3; SAS Inst. Inc., Cary, NC), with all data normally distributed ($W = 0.90$). Animal was considered the experimental unit. Data were analyzed using the PROC REG procedure of SAS (SAS Inst. Inc., Cary, NC, version 9.3). Suspected outliers were tested by plotting studentized residual vs. the predicted values and characterized if the studentized residual was outside the range from -2.0 to 2.0 . Then, suspected outliers were removed whether identified as influential points by the difference in fit (DFBETS) and Cook's distance (D), as described by Neter et al. (1996). Three data points were identified as outliers and deleted from the data set for the calculation of the equations of the chemical composition of the EBW (Table 3). For in vivo dependent variables one data point for CP_EBW and one for Ash_EBW were removed; and for postmortem dependent variables another data point for CP_EBW, Water_EBW, and Ash_EBW was deleted. For the calculation to predict the chemical composition of the carcass (Table 4) a single data point was identified as outlier for the following dependent variables, namely CP_Carcass (in vivo), CP_Carcass, Water_Carcass, and Ash_Carcass (postmortem) and deleted from the data set. Stepwise regression method (Montgomery and Peck, 1992) was used to obtain the best model and develop the equations to estimate the chemical composition of the body and carcass. The in vivo independent variables used in the development of the prediction equation were ultrasound measurements (uLMA, uBFT, and uRF), body measurements (SBW and HH), and age (AG) at the time of slaughter; and chemical compounds obtained from rib section (CP_rib, EE_rib, H2O_rib) were used as postmortem independent variables. A critical level of significance of $P \leq 0.15$ was considered in order to determine the inclusion and retention of variables in the prediction model. The best equations for each dependent variable were developed and evaluated via the model fit statistics adjusted R^2 , root mean square predicted error (RMSPE), and Mallows' C_p statistics (Mallows, 1973). The independent variables included in the models were tested for multicollinearity using the variance inflation

factor (VIF). In addition, CORR procedure (SAS Inst. Inc., Cary, NC) was used to calculate the Pearson correlation coefficients between dependent and independent variables data. Significance correlation was declared at $P \leq 0.05$.

RESULTS AND DISCUSSION

In order to evaluate whether ultrasound and biometric measures would yield precision comparable to the method of composition of the 9th to 11th rib section for the prediction of chemical composition in live animals, both methods, as well the full body chemical analysis, were applied to a sample of Nellore cattle in the finishing phase. The results of these measurements are shown in Table 2. The chemical composition values are in the same range as reported in other studies performed with the Nellore breed (Paulino et al., 2005; Paixão, 2008), indicating that the outcomes from our study are representative for this breed. All parameters showed a considerable variation. This allows the generated equations can be used into a range in which it is possible the separation of the animals according to their different body weights in the beginning of the finishing phase. It was possible due to the measurements performed at different moments of the finishing phase, namely the data for the reference animals collected at the beginning of the experiment and the data for the test animals over time (sequential slaughter).

The C_p methodology (Mallows, 1973) was employed to identify the parameters which yielded the highest precision in the equation for determining empty body and carcass chemical composition from in vivo measurements. Desirable models are those whose C_p values are close to the corresponding number of parameters of the model (Reddy, 2011) in association with high R^2 values. In our study, C_p values fluctuated from -2.73 to 14.60 when a single independent variable was included to the models; and showed a range from 1.84 to 4.94 when 2 to 4 independent variables were added in the models, respectively, to predict the chemical composition of the empty body and the carcass. The results in Table 3 indicate that shrunk BW is the independent variable accounted for 0.89%, 0.64%, 0.95%, 0.73%, and 0.85% of the variation for the prediction of protein, fat, water, ash, and energy, respectively. However, the addition of uRF and/or age to SBW in the multiple regressions improved the precision of the equations (R^2) in predicting the water, energy, and mainly fat components of the empty body, by 2.07%, 4.41%, and 16.82%,

Table 2. Descriptive statistics of the independent and dependent characteristics used to determine the prediction equations, measured by ultrasound and biometric in vivo measures and by the composition of the 9th to 11th rib section determined postmortem

Item	Mean $\pm$ SD	Minimum	Maximum
Independent			
Shrunk BW, kg	398.05 $\pm$ 48.85	306.00	470.00
Age, d	541.27 $\pm$ 32.17	461.00	591.00
HH ^a , m	1.41 $\pm$ 0.07	1.29	1.50
uLMA ^b , cm ²	77.58 $\pm$ 10.65	47.60	99.80
uBFT ^c , mm	4.05 $\pm$ 0.74	3.10	5.90
uRF ^d , mm	5.33 $\pm$ 1.12	3.70	9.60
Dependent			
Empty body^e			
Protein, kg	70.12 $\pm$ 7.54	54.39	84.40
Fat, kg	51.94 $\pm$ 8.38	38.17	71.26
Water, kg	228.04 $\pm$ 29.08	173.58	272.56
Ash, kg	17.68 $\pm$ 2.98	11.67	22.82
Energy, Mcal	883.8 $\pm$ 112.1	693.5	1105.0
Carcass, kg	243.1 $\pm$ 32.14	181.3	290.0
Carcass^f			
Protein, kg	42.73 $\pm$ 5.80	29.36	52.57
Fat, kg	34.04 $\pm$ 7.98	25.11	53.93
Water, kg	153.57 $\pm$ 21.48	114.57	182.12
Mineral, kg	12.70 $\pm$ 2.36	7.98	17.02
Energy, Mcal	696.02 $\pm$ 50.25	575.42	790.22

^aHH = hip height.

^buLMA = LM area by ultrasonography.

^cuBFT = backfat thickness (12th rib) by ultrasonography.

^duRF = rump fat thickness (*Biceps femoris*) by ultrasonography.

^eChemical composition of the empty body.

^fChemical composition of the carcass.

respectively (data not shown). For the estimation of the protein content, adding the uRF and HH variables to the shrunk BW increased the precision by 2.87%. For the calculation of ash content, the shrunk BW variable was sufficient. Although the percentage increases of R^2 has been small with the addition of other independent variables to shrunk BW, Mader et al. (2006) report that an independent variable should be included in the model only if its addition produces an increase of 0.01 in total R^2 . On other hand, the changes in CP and RMSPE values were more evident, decreasing with the inclusion of those variables (Table 3). In addition, the independent variables added to models show no VIF values that indicate collinearity problems since all VIF values demonstrated have reached the range from 1.03 to 6.01 and were lower than 10 as suggested by Schabenberger and Pierce (2002). The precision increase of the prediction equations obtained by including uRF and age is consistent

with the positive correlation of the deposition of subcutaneous fat with the deposition of total adipose tissue between birth and maturity, reported by Robelin and Casteilla (1990).

Positive values for the independent variables SBW and uRF and negative for AG were observed in the estimators of the equations for empty body fat and empty body energy (Table 3). Therefore, comparing 2 animals of the same weight but different ages, the composition of fat and energy between them are distinct, in which the earlier animal deposit greater amount of fat and, consequently, own higher energy value. Similar observation was reported in a study regarding the effects of weight, frame size, and rate of gain on the composition of gain of beef steers, in which the authors demonstrated that the large-framed animals have less energy gain and deposit less fat than medium-framed animals (Oltjen and Garrett, 1988). In the prediction equation of the protein in the empty body, the estimator of the independent variable HH was also negative (Table 3). Thus, when comparing two animals of the same weight and different heights, the higher animal shows lower protein values. This biological behavior was also presented by the Beef Improvement Federation (2016) when the authors used these same independent variables (AG and HH) to determine the frame score, which is a linear measurement that converts the HH (inches) and age (5 to 21 mo) into a score. The frame score can be monitored for fatness level and maturing rate, in which large-framed animals tend to be heavier, leaner, and have later maturing, whereas small-framed animals tend to be lighter, fatter, and have earlier maturing (BIF, 2016). Furthermore, the frame score is also used to determine the EBF in equations; however, the determination of the chemical composition using the frame score is not obtained in 1 step; it is necessary to use other equations as proposed by Tylutki et al. (1994), unlikely the equations shown previously in the present study. As reported, these proposed equations allow an easier way to obtain the animal chemical composition.

The equations for prediction using biometric and ultrasound measurements in the living animal presented high coefficients of determination ($R^2 = 0.73$ to $R^2 = 0.96$) to estimate the chemical composition of the empty body, whereas the equations for prediction using rib section measurements in the postmortem showed low coefficients of determination ($R^2 = 0.52$ to $R^2 = 0.84$) for the same chemical components (Table 3) when compared to coefficients of determination of the chemical composition of the empty body. The values found for

Table 3. Multiple regression equations for predicting the chemical composition of the empty body by ultrasound and biometric in vivo measures and by the composition of the 9th to 11th rib section determined postmortem

		VIFs ^b			RMSPE ^c	R ²	Cp ^d	P-value ^e			
Dependent variables	n	Equations ^a	1	2				3	1	2	3
In vivo											
Protein, kg	32	9.06 + 0.15 × SBW				2.16	0.89	11.97	<0.001		
		14.45 + 0.15 × SBW − 0.82 × uRF				1.97	0.93	7.02	0.001	0.020	
		47.92 + 0.18 × SBW − 1.46 × uRF − 30.72 × HH	4.80	1.79	6.01	1.79	0.94	3.41	<0.001	0.001	0.024
Fat, kg	33	−2.49 + 0.14 × SBW				4.98	0.64	11.61	<0.001		
		−14.99 + 0.14 × SBW + 1.85 × uRF				4.55	0.70	7.02	<0.001	0.022	
		11.33 + 0.16 × SBW + 2.09 × uRF − 0.06 × AG	1.15	1.05	1.13	4.18	0.74	3.66	<0.001	0.007	0.027
Water, kg	33	−2.43 + 0.58 × SBW				6.60	0.95	13.77	<0.001		
		−44.10 + 0.56 × SBW + 0.09 × AG				6.27	0.96	8.49	<0.001	0.019	
		−34.00 + 0.55 × SBW + 0.10 × AG − 2.34 × uRF	1.15	1.13	1.05	5.47	0.96	4.04	<0.001	0.005	0.019
Ash, kg	32	−3.22 + 0.05 × SBW				1.51	0.73	−2.73	<0.001		
Energy, Mcal	33	44.64 + 2.11 × SBW				43.45	0.85	7.60	<0.001		
		−44.20 + 2.16 × SBW + 3.12 × uRF				41.00	0.86	5.66	<0.001	0.027	
		185.99 + 2.27 × SBW + 15.3 × uRF − 0.53 × AG	1.15	1.05	1.13	37.85	0.88	2.79	<0.001	0.026	0.032
Postmortem											
Protein, kg	32	32.02 + 58.58 × CP_rib				4.30	0.68	0.06	<0.001		
Fat, kg	33	21.81 + 45.43 × EE_rib				7.13	0.52	2.86	<0.001		
Water, kg	32	65.00 + 75.77 × H2O_rib				12.98	0.80	8.13	<0.001		
		70.30 + 59.40 × H2O_rib + 50.42 × EE_rib	1.90	1.90		11.58	0.84	2.79	<0.001	0.011	
Ash, kg	32	5.02 + 18.05 × CP_rib				1.81	0.58	0.60	<0.001		

^aSBW = shrunk body weight; uRF = rump fat thickness (*Biceps femoris*) by ultrasonography; AG = age; HH = hip height; CP_rib = protein of the rib section (9th to 11th ribs); EE_rib = ether extract of the rib section (9th to 11th ribs); H2O_rib = water of the rib section (9th to 11th ribs).

^bVIFs = variance inflation factors.

^cRMSPE = root mean square predicted error as kg.

^dC_p = Mallows' C_p statistics.

^eP-value = P-values of the independent variable for each equation.

protein ($R^2 = 0.94$) and water ($R^2 = 0.96$) in the empty body were higher than those reported in a study (Marcondes et al., 2012) which used postmortem measures to predict those characteristics ($R^2 = 0.66$ and $R^2 = 0.75$ for protein and water, respectively). Other studies (Bonilha et al., 2011; Marcondes et al., 2015) showed similar prediction coefficients for protein and water in the empty body; however, the authors used the EBW (Marcondes et al., 2015) and the chemical composition of carcass (Bonilha et al., 2011) to determine the equations for chemical composition of the empty body, requiring higher cost to obtain these parameters and resulting in the destruction of the carcass. Studies which used in vivo measurements reported lower values of fat prediction coefficients (Guiroy et al., 2001), similar values (Baker et al., 2006), and higher values (De Paula et al., 2013) than those found in our study. However, the other chemical components were not determined in those studies and, in addition,

the variables used in our study to determine the equations are simple to measure, noninvasive, and can be measured and calculated during the animal growth. Although the prediction coefficient of the total ash in the empty body was lower than other components evaluated, the literature also reports a great variation regarding the values of coefficients for this parameter when obtained by postmortem measurements (Hankins and Howe, 1946; Perón et al., 1993; Bonilha et al., 2011), showing lower values than those found in our study (Paulino et al., 2005; Galati et al., 2007; Bonilha et al., 2008; Bonilha et al., 2011).

In the present study, the use of in vivo objective measures (weight, age, HH, US) in prediction equations for chemical composition for empty body and carcass is proposed. Some studies also used those measures to predict the chemical composition; however, the values of R^2 were lower ($R^2 = 0.59$; Guiroy et al., 2001) when compared to the ones found in

Table 4. Multiple regression equations for predicting the chemical composition of the carcass by ultrasound and biometric in vivo measures and by the composition of the 9th to 11th rib section determined postmortem

Dependent variables		<i>n</i>	Equations ^a	VIFs ^b				RMSPE ^c	<i>R</i> ²	Cp ^d	<i>P</i> -value ^e			
				1	2	3	4				1	2	3	4
In vivo														
Protein, kg	32		5.83 + 0.10 × SBW					2.69	0.74	8.58	<0.001			
			9.34 + 0.10 × SBW – 1.76 × uRF	1.13	1.13			2.39	0.80	3.02	<0.001	0.010		
Fat, kg	33		–10.40 + 0.11 × SBW					5.73	0.47	4.45	<0.001			
			–22.00 + 0.12 × SBW + 1.71 × uRF					5.42	0.52	2.92	<0.001	0.070		
			–16.45 + 0.14 × SBW + 1.76 × uRF – 0.17 × uLMA	1.35	1.03	1.32		5.20	0.56	2.56	<0.001	0.058	0.126	
Water, kg	33		–13.02 + 0.42 × SBW					6.46	0.91	14.6	<0.001			
			–59.77 + 0.40 × SBW + 0.10 × AG					5.69	0.93	6.82	<0.001	0.006		
			–105.52 + 0.34 × SBW + 0.09 × AG + 52.63 × HH					5.40	0.93	5.45	<0.001	0.010	0.084	
			–112.06 + 0.32 × SBW + 0.03 × AG + 28.71 × HH + 0.11 × uLMA	4.14	1.14	3.80	1.34	5.17	0.94	4.94	<0.001	0.014	0.060 0.124	
Ash, kg	33		–0.94 + 0.03 × SBW					1.49	0.55	–1.12	<0.001			
Postmortem														
Protein, kg	32		21.23 + 34.26 × CP_rib					3.60	0.54	0.91	<0.001			
Fat, kg	33		11.16 + 37.19 × EE_rib					4.98	0.60	2.98	<0.001			
Water, kg	32		31.66 + 55.11 × H2O_rib					9.23	0.80	6.35	<0.001			
			35.31 + 43.84 × H2O_rib + 34.74 × EE_rib	1.90	1.90			8.31	0.84	1.84	<0.001	0.014		
Ash, kg	32		3.97 + 3.79 × CP_rib					1.56	0.50	–0.45	<0.001			

^aSBW = shrunk body weight; uRF = rump fat thickness (*Biceps femoris*) by ultrasonography; uLMA = LM area by ultrasonography; AG = age; HH = hip height; CP_rib = protein of the rib section (9th to 11th ribs); EE_rib = ether extract of the rib section (9th to 11th ribs); H2O_rib = water of the rib section (9th to 11th ribs).

^bVIFs = variance inflation factors.

^cRMSPE = root mean square predicted error as kg.

^dC_p = Mallows' C_p statistics.

^eP-value = P-values of the independent variables for each equation.

our study. Moreover, other studies (Tylutki et al., 1994; Tedeschi et al., 2004) used subjective measures (e.g., quality grade, yield grade) in their equations to predict such characteristics, mainly regarding the prediction of empty body fat. This restricts the use of those equations in markets in which the USDA beef quality and yield grades classification is not used.

The equations for the determination of the chemical components of the empty body using the independent variables obtained from the rib section show that the independent variable corresponds to the same dependent variable for almost all predicted components, except for ash. For this latter component, the protein in the rib section demonstrated the best coefficient of determination and explains the best variation of the ashes in the empty body. The growth patterns of the tissues show bone growing at a steady, but slow rate, and muscle growing relatively fast, increasing the ratio of muscle to bone (Berg and Butterfield, 1976). This may explain the results observed in our study for prediction equations for ash of the empty body

to which the protein was the selected independent variable rather than the ash.

As observed in the equations for the prediction of the chemical composition of the empty body, SBW was also the main independent variable for determining the chemical composition in the carcass and accounted for 0.68%, 0.52%, 0.84%, and 0.58% of the variation for the prediction of protein, fat, water, and ash, respectively (Table 4).

Previous studies used biometric measurements to predict fat composition of the carcass and of the empty body (Fernandes et al., 2010; De Paula et al., 2013), obtaining good precision. Other studies used physical-chemical measurements in carcass fractions to estimate the chemical composition of the whole carcass and the empty body in several bovine breeds (Hankins and Howe, 1946; Marcondes et al., 2009; Bonilha et al., 2011). However, these estimations are only possible postmortem, precluding their use in nutritional planning for live. Our results showed a high value for energy ($R^2 = 0.88$). Another study on the use of indirect method for the prediction of energy in the empty body in cattle

Table 5. Simple correlation coefficients (Pearson) between in vivo or postmortem measures and the predicted traits by the equations obtained from empty body and carcass

Traits ^a	Empty body ^b					Carcass ^b			
	Protein	Fat	Water	Ash	Energy	Protein	Fat	Water	Ash
In vivo									
SBW, kg	0.95***	0.80***	0.97**	0.80***	0.92***	0.71***	0.68***	0.95***	0.74***
uRF, mm	-0.26	0.11	-0.23	0.09	-0.02	-0.24	-0.13	0.21	-0.03
HH, m	0.80***	0.59***	0.87***	0.64***	0.72***	0.59***	0.52**	0.87***	0.63***
AG, d	0.30	0.07	0.39*	0.23	0.16	0.10	0.12	0.43	0.21
uLMA, cm ²	0.49**	0.29	0.53**	0.44*	0.39*	0.52**	0.17	0.54**	0.46**
Postmortem									
CP_rib, kg	0.60***	0.54**	0.88***	0.62***	—	0.45**	0.58***	0.88***	0.54*
EE_rib, kg	0.51**	0.72***	0.77***	0.55**	—	0.36*	0.77***	0.77***	0.45**
H2O_rib, kg	0.54*	0.46**	0.87***	0.56**	—	0.42*	0.49**	0.89***	0.49**
Ash_rib, kg	0.56**	0.37*	0.77***	0.60**	—	0.38*	0.44**	0.78***	0.52**

^aSBW = shrunk body weight; uRF = rump fat thickness (*Biceps femoris*) by ultrasonography; AG = age; HH = hip height; CP_rib = protein of the rib section (9th to 11th ribs); EE_rib = ether extract of the rib section (9th to 11th ribs); H2O_rib = water of the rib section (9th to 11th ribs).

^bFor all the dependent variables, kg unit was used, except for energy (Mcal).

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

(Jorge et al., 2000) reported the same coefficient of determination ($R^2 = 0.88$).

Overall, the most precise equations describing the chemical components of the empty body and the ultrasound and biometric characteristics of the live animal were those that presented the independent variables associated to the degree of maturity and structure of the animal as independent estimators, such as quantity of rump fat, HH, and the SBW. This suggests that the most precise equations to predict the chemical components in the empty body are those that use in vivo measurements.

The results concerning the equations for the prediction of the chemical components of the carcass from ultrasonography and biometric characteristics in the animal in vivo and from the composition of the 9th to 11th rib section determined postmortem (Table 4) show that water and protein presented satisfactory determination coefficients ($R^2 > 0.80$), compared to the other components ($R^2 < 0.56$) which used the in vivo measurements to determine the equations. For the equations that used the composition of the 9th to 11th ribs, only the water presented a satisfactory coefficient of determination ($R^2 = 0.84$); however, it is still smaller than the value for the equation using the in vivo measurement in addition it showed higher values for RMSPE (RMSPE = 8.31 kg vs. 5.17 kg, for postmortem and in vivo equations, respectively). With the exception of fat, all other components presented lower values than those determined by the equations obtained by in vivo measurement. Studies that determined these parameters by postmortem measurement also report values of the lower coefficients for water and

protein (Carvalho et al., 2003; Bonilha et al., 2011), reinforcing the idea that in vivo measurements may be used to precisely predict the chemical composition of the carcass.

In contrast to the results presented, some authors (Fernandes et al., 2010; De Paula et al., 2013) reported coefficients of determination for carcass fat prediction higher than those found in the present study; however, this may be due to the use of a greater number of biometric variables and in vivo characteristics by those authors. Further studies are needed to elucidate the relationship between the fat component and the measurements taken on the animal in vivo.

Pearson's correlations between in vivo or postmortem measures and the predicted traits by the equations are shown in Table 5. Overall, higher correlations coefficients were obtained for in vivo measurements when compared to those obtained on the postmortem. Similar behavior was also observed between the equations generated for the prediction of chemical components using in vivo and postmortem measures, in which higher R^2 values were obtained with in vivo measurements when compared to the postmortem (Tables 3 and 4). Those strong correlations between in vivo independent variables and predicted chemical components to empty body and carcass were mainly due to the SBW and HH measurements, which showed correlation coefficients ranging from 0.71 to 0.97 and 0.52 to 0.87, respectively. Rump fat thickness and AG did not significantly correlated ($P > 0.05$) with the traits used in the models (Table 5); however, they were included as independent variable in

some equations, aiding in the prediction power of the models (Tables 3 and 4).

Higher correlation coefficients were also observed for the chemical components of the empty body compared to the chemical components of the carcass (Table 5) providing higher R^2 values for the prediction equations of the chemical components in the empty body when compared to the chemical components predicted for carcass.

In the present study, the equations generated from measurements obtained in vivo and postmortem were compared. The in vivo measures demonstrated a great potential to predict the chemical composition of the beef cattle along the time and it may be used as a tool for the marketing decision, such as the time in feeder, this way decreasing waste of the feed and, consequently, avoiding the excess of carcass backfat thickness. Thus, there is an increase of the efficiency in the finishing phase which can be considered the most critical phase of the beef cattle production since any unsuitable planning can impair rather than favor the profit of the activity.

In conclusion, our results show that the coefficients of determination (for determining the chemical composition of the empty body) of the equations derived from in vivo measures were higher than those of the equations using the composition of the 9th to 11th rib section obtained postmortem, and better than coefficients of determination resulting of the equations to predict the carcass chemical composition. Further studies are warranted to evaluate the potential of other in vivo measurements that may aid in the prediction of chemical composition related to the animal body and to the carcass components.

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