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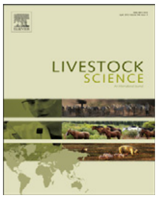

Evaluation of equations to predict body composition in Nellore bulls ☆

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ABSTRACT

The equations developed by Hankins and Howe (1946, HH), Marcondes et al. (2010, M10), Marcondes et al. (in press, M11) and Valadares Filho et al. (2006, V6) were evaluated to predict the body composition from the 9–10–11th rib cut in Nellore bulls. The evaluated equations estimated the physical and the carcass chemical composition, the empty body chemical composition and the noncarcass chemical composition. Thirty-seven Nellore bulls (14 ± 1 months old initially) with shrunk body weight of 259 ± 24.9 kg were used in this experiment. The bulls were randomly divided into three groups: five bulls to the reference group, four bulls were fed at maintenance level and twenty-eight bulls were fed *ad libitum*. The bulls fed *ad libitum* were separated into four groups, one of which was slaughtered every 42 days. The diet was composed of corn silage and concentrate (55:45). After slaughter, the 9–10–11th rib cut was dissected into muscle, fat and bone fractions. The remaining carcass was similarly dissected. The others parameters that were evaluated as partial predictors included the empty body weight, the dressing percentage, the visceral fat percentage, the organ and viscera percentage and the composition of the noncarcass components. The values estimated with prediction equations were compared to the observed values. The equations obtained by M11 predicted correctly the carcass physical composition. However, the muscle and fat tissues were under- and overestimated, respectively, by HH. Some constituents of the noncarcass components can be predicted from equations developed by M10. The equations obtained by M10 predicted correctly the carcass and empty body chemical composition. The carcass water was underestimated by HH. The equations by V6 did not predict the carcass or empty body chemical composition. The carcass physical and chemical composition and empty body chemical composition can be predicted from the composition of 9–10–11th rib cut by equations obtained by Marcondes et al. (2010, in press) while the composition of these components cannot be predicted by Hankins and Howe (1946) and Valadares Filho et al. (2006) in Nellore bulls.

1. Introduction

The major method to quantify the body composition of an animal, half of the carcass must be completely dissected. This process is laborious and expensive. In beef cattle, one way to reduce the work of dissecting a carcass is to use equations that estimate the body composition (Nour and Thonney, 1994). Some authors (Crouse and Dikeman, 1974; Hankins and Howe, 1946; Tulloh, 1963) developed equations to estimate the carcass composition using the composition of

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the 9–10–11th rib cut section. These equations have become the basis of most of experiments conducted throughout the world. However, these equations consider the carcass physical and chemical composition only of the edible parts of the animal, rather than the whole body composition. Some differences of errors in prediction of carcass composition have been associated in the difficulty of uniform separation of the carcass that vary widely in fatness (Berg and Butterfield, 1976; Schroeder et al., 1987; Schroeder, 1990).

Table 1
Proportions of feed in concentrate and diet and concentrate fraction composition in dry matter basis.

Ingredients	Concentrate	Diet
Proportion (g/kg DM)		
Corn silage	–	550.0
Corn	816.4	367.4
Soybean meal	136.9	61.6
Mineral mix	9.9	4.4
Limestone	6.8	3.0
Salt	10.0	4.5
Urea	18.0	8.1
Ammonium sulfate	2.0	0.9
Chemical composition (g/kg DM)		
Dry matter	875.8	554.9
Organic matter	946.5	944.7
Crude protein	194.9	123.4
Ether extract	30.1	26.2
Neutral detergent fiber[a]	134.3	347.0
Non-fiber carbohydrates	615.8	460.9

[a] Corrected to ash and protein.

Valadares Filho et al. (2006) proposed equations that predicted complete carcass composition from the 9–10–11th rib cut section using 66 observations obtained from experiments conducted in Brazil.

Some years late, Marcondes et al. (2010) conducted a meta-analysis using a database of 329 animals and developed equations to estimate the carcass chemical composition using the 9–10–11th rib cut section dissection. New variables were introduced to improve the adequacy of the models. Additionally, Marcondes et al. (2010) also developed equations to estimate the noncarcass chemical composition, which is less influenced by diet, age or gender (blood, hide, head, limbs, organs and viscera).

Therefore, the aim of this study was to evaluate the equations developed by Hankins and Howe (1946), Marcondes et al. (2010, in press) and Valadares Filho et al. (2006) in predicting carcass physical and chemical composition, empty body chemical composition and

Table 2
Equations to estimate the physical and chemical carcass and empty body chemical composition of Zebu.

Item	Equations
Carcass physical composition (Marcondes et al., in press)	
Muscle	$M_{Car}\ (\%) = 54.42 + 0.26 \times M_{Cor} - 1.28 \times VF$
Fat	$F_{Car}\ (\%) = 0.69 + 0.46 \times F_{Cor} + 1.18 \times VF$
Bone	$B_{Car}\ (\%) = 7.91 + 0.56 \times B_{Cor} - 0.24 \times VF$
Carcass physical composition (Hankins and Howe, 1946)	
Muscle	$M_{Car}\ (\%) = 15.56 + 0.81 \times M_{Cor}$
Fat	$F_{Car}\ (\%) = 3.06 + 0.82 \times F_{Cor}$
Bone	$B_{Car}\ (\%) = 4.30 + 0.61 \times B_{Cor}$
Carcass chemical composition (Marcondes et al., 2010)	
Crude protein (CP)	$CP_{Car}\ (\%) = 17.92 + 0.60 \times CP_{Cor} - 0.17 \times DP$
Ether extract (EE)	$EE_{Car}\ (\%) = 4.31 + 0.31 \times EE_{Cor} + 1.37 \times VF$
Water (W)	$W_{Car}\ (\%) = 48.74 + 0.28 \times W_{Cor} - 0.017 \times EBW$
Carcass chemical composition (Valadares Filho et al., 2006)	
Crude protein	$CP_{Car}\ (\%) = 4.05 + 0.78 \times CP_{Cor}$
Ether extract	$EE_{Car}\ (\%) = 4.96 + 0.54 \times EE_{Cor}$
Water	$W_{Car}\ (\%) = 34.97 + 0.45 \times W_{Cor}$
Carcass chemical composition (Hankins & Howe, 1946)	
Crude protein	$CP_{Car}\ (\%) = 5.98 + 0.66 \times CP_{Cor}$
Ether extract	$EE_{Car}\ (\%) = 2.82 + 0.77 \times EE_{Cor}$
Water	$W_{Car}\ (\%) = 14.90 + 0.78 \times W_{Cor}$
Empty body chemical composition (Valadares Filho et al., 2006)	
Crude protein	$CP_{EBW}\ (\%) = 4.96 + 0.76 \times CP_{Cor}$
Ether extract	$EE_{EBW}\ (\%) = 4.56 + 0.60 \times EE_{Cor}$
Water	$W_{EBW}\ (\%) = 31.42 + 0.51 \times W_{Cor}$
Empty body chemical composition (Marcondes et al., 2010)	
Crude protein	$CP_{EBW}\ (\%) = 10.78 + 0.47 \times CP_{Cor} - 0.21 \times VF$
Ether extract	$EE_{EBW}\ (\%) = 2.75 + 0.33 \times EE_{Cor} + 1.80 \times VF$
Water	$W_{EBW}\ (\%) = 38.31 + 0.33 \times W_{Cor} - 1.09 \times VF + 0.50 \times OV$

M_{Car}: carcass muscle; M_{Cor}: rib cut muscle; F_{Car}: carcass fat; F_{Cor}: rib cut fat; B_{Car}: carcass bone; B_{Cor}: rib cut bone; CP_{Car}: carcass CP; CP_{Cor}: rib cut CP; DP: dressing percentage; EE_{Car}: carcass EE; EE_{Cor}: rib cut EE; EBW: empty body weight; VF: visceral fat percentage that included renal, pelvic, cardiac and mesentery fat in EBW; OV: organs and viscera percentage; W_{Car}: carcass water; W_{Cor}: rib cut water; CP_{EBW}: empty body CP; EE_{EBW}: empty body EE; W_{EBW}: empty body water.

noncarcass component chemical composition in Nellore bulls.

2. Materials and methods

2.1. Location

The experiment was conducted on the Experimental Feedlot of Animal Science Department, in Viçosa, Brazil. Laboratory analyses were done at the Ruminant Nutrition Laboratory of the Animal Science Department at the Federal University of Viçosa (UFV) in Viçosa, MG, Brazil. The procedures for the care and management of the bulls followed the guidelines of the Federal University of Viçosa.

The data of this study were not part of the database used to adjust any of the equations tested.

2.2. Animal resource and study design

Thirty-seven Nellore bulls with initial body weight of 259 ± 24.9 kg and an initial age of 14 months were used. Five bulls were randomly assigned to the reference group, four bulls were fed at maintenance level (1.1% of BW) and twenty-eight bulls were fed *ad libitum*. The bulls fed *ad libitum* were randomly separated into four groups (seven bulls per group), which were slaughtered at different times (42, 84, 126 and 168 days). One bull from the maintenance group was slaughtered at each slaughter. The reference group was slaughtered in the beginning of the experiment. Sixteen bulls were housed in a feedlot using a Tie Stall system with an automatic water bowl and an individual concentrate bin; the other twelve bulls were fed *ad libitum* and the maintenance bulls were kept in collective stalls with concrete floors and individual feeders (electronic gates) with a total area of 50 m^2. At the beginning of the experiment, all the bulls were identified, weighed and treated against ecto- and endo-parasites.

2.3. Diets and feed composition

The diet was formulated according to Valadares Filho et al. (2010) to allow a weight gain of 1.3 kg daily. The diet was composed of 55% of corn silage and 45% of concentrate on the dry matter (*DM*) basis. The concentrate contained corn, soybean meal, urea, ammonium sulfate, sodium chloride, limestone and mineral mix (Table 1).

The feed was provided twice daily as total mixed ration, and it was adjusted to maintain orts of 5–10% on fed basis and water was permanently available.

2.4. Slaughter and samplings

Before the slaughter, the bulls fasted for 16 h to get the shrunk body weight. The bulls were killed by stunning them and then cutting their jugular vein for total bleeding. After the bloodletting, the gastrointestinal tract (*i.e.*, the rumen, reticulum, omasum, abomasum and small and large intestines) was washed. The weights of the heart, lungs, liver, spleen, kidneys, KPH fat, industrial meat, mesentery, tails, trimmings and washed gastrointestinal tract were added to the other parts of the body (*i.e.*, carcasses, head, hide, limbs and blood) to determine the empty body weight (*EBW*).

Samples of the heads and posterior and anterior limbs of the maintenance bulls and two bulls fed *ad libitum* were removed in each slaughter and were subsequently divided into soft tissue, bone and hide. These samples were freeze-dried and ground for further laboratory analysis.

After the slaughter, the carcass of each animal was separated into two half-carcasses, which were chilled at 4 °C for 18 h. After the 18-h period, the half-carcasses were weighed again. In the left half-carcass, the 9–10–11th rib cut section was removed for dissection as recommended by Hankins and Howe (1946).

The left half-carcass was completely separated into muscle, fat and bone. Muscle and fat were ground separately after proportionally pooling a sample based on the amounts in the carcass. The bones were separated into long bones, vertebrae and ribs, which were sampled that a pooled sample of bones was created based on the relative proportions of the carcass. To evaluate the muscle, fat and bone composition of the left half carcass, the tissue amounts of the 9–10–11th rib cut section components were included in the calculations of the left half-carcass composition.

The rumen, reticulum, omasum, abomasum, small and large intestines, internal fat, mesentery, liver, heart, kidneys, lung, tongue, spleen, industrial meat and parings (esophagus, trachea and reproductive) were ground in an industrial cutter for 20 min to give a homogeneous sample of organs and viscera. The hide was sampled as a 25 × 25 cm^2 from the left croup of each animal and this sample was considered as representative of the whole hide.

With exception of blood, the samples of the organs and viscera, muscle and fat, bone, hide, head, limbs, soft tissue

Table 3
Equations used to estimate the noncarcass components of Zebu.

Item	Equations
Blood and leather	
Crude protein	CP_{BL} (%): 24.895
Ether extract	EE_{BL} (%): $-14.383+0.019 \times CCW+1.480 \times L_{EBW}$
Water	W_{BL} (%): $59.243+2.468 \times B_{EBW}$
Ash	A_{BL} (%): $1.148-0.002 \times DP-0.036 \times L_{EBW}$
Head and limbs	
Crude protein	CP_{HL} (%): $9.930+0.0014 \times EBW$
Ether extract	EE_{HL} (%): $6.550+0.993 \times VF$
Water	W_{HL} (%): $57.475-1.094 \times VF$
Ash	A_{HM}: 15.121
Organs and viscera	
Crude protein	CP_{OV}: 12.015
Ether extract	EE_{OV}: $9.370+5.000 \times VF$
Water	W_{OV}: $77.217-5.212 \times VF$
Ash	A_{OV}: $2.693-0.039 \times OV_{EBW}-0.022 \times DP$

CP_{BL}: blood and leather CP; EE_{BL}: blood and leather EE; CCW: cold carcass weight; EBW: empty body weight; L_{EBW}: EBW leather percentage; W_{BL}: blood and leather water; B_{EBW}: EBW blood percentage; A_{BL}: blood and leather ash; DP: dressing percentage; CP_{HL}: head and limbs CP; EE_{HL}: head and limbs EE; EBW: empty body weight; VF: visceral fat percentage that included renal, pelvic, cardiac and mesentery fat in EBW; W_{HL}: head and limbs water; A_{HM}: head and limbs ash; CP_{OV}: organs and viscera CP; EE_{OV}: organs and viscera EE; W_{OV}: organs and viscera water; A_{OV}: organs and viscera ash; OV_{EBW}=EBW organs and viscera percentage.

and bone were freeze-dried to evaluate the fat dry matter content. The samples were partly defatted through two successive washes with petroleum ether using a Soxhlet extractor to determine the partly defatted dry matter. After this process, the samples were ground in a ball mill for later laboratory analysis. The removed fat from the extraction was calculated as the difference between the fat dry matter and partly defatted dry matter. The result was added to the value of residual ether extract in partly defatted dry matter to determine the total fat content.

The samples were analyzed for DM, ash, total nitrogen and ether extract (*EE*) as described by AOAC (2000).

Table 4
Variable description used to estimate the physical and chemical carcass composition and chemical empty body composition and noncarcass components.

Item	Mean	*s*	Maximum	Minimum
Empty body weight (kg)	343.92	0.29	548.62	192.09
Cold carcass weight (kg)	218.12	0.32	352.20	117.05
Organs and viscera (% EBW)	14.74	0.08	17.10	12.26
Visceral fat (% EBW)	4.29	0.34	7.36	1.70
Dressing percentage (%)	57.38	0.04	60.96	52.39
Leather (% EBW)	10.67	0.08	12.92	8.96
Blood (% EBW)	3.80	0.14	4.90	2.98
Rib cut section ether extract (%)	23.06	0.37	37.74	9.07
Rib cut section crude protein (%)	15.54	0.07	18.63	13.24
Rib cut section water (%)	54.94	0.11	66.62	43.70
Rib cut section adipose tissue (%)	24.54	0.38	39.00	7.38
Rib cut section muscle tissue (%)	53.70	0.09	63.61	45.32
Rib cut section bone tissue (%)	21.76	0.25	33.88	13.68

2.5. Equations evaluated

The data of this experiment were used to evaluate the equations developed by Hankins and Howe (1946), Marcondes et al. (2010, in press) and Valadares Filho et al. (2006). Thus, the equations developed by Hankins and Howe (1946) and Marcondes et al. (in press) were used to estimate the carcass physical composition while the equations developed by Hankins and Howe (1946), Marcondes et al. (2010) and Valadares Filho et al. (2006) were used to estimate the carcass chemical composition. In addition, the equations developed by Marcondes et al. (2010) and Valadares Filho et al. (2006) were used to evaluate the empty body chemical composition using the 9–10–11th rib cut section and other variables (Table 2). Then, the equations developed by Marcondes et al. (2010) were also used to estimate the chemical composition of noncarcass components (blood and hide; head and limbs; organs and viscera, Table 3).

Table 5
Mean (kg) and descriptive statistic of relationship among the observed and predicted values of physical carcass composition.

Item	Muscle			Adipose			Bone		
	OBS[a]	HH	M11	OBS[a]	HH	M11	OBS[a]	HH	M11
Mean	138.33	126.81	133.78	41.10	55.23	40.76	37.73	36.37	38.30
Standard deviation	39.10	34.69	37.56	24.02	31.63	23.94	6.76	6.52	6.93
Maximum	209.92	198.82	205.64	95.76	116.67	85.57	53.21	53.39	53.20
Minimum	75.23	74.09	77.23	8.80	10.88	7.59	28.36	25.58	26.82
R	–	0.99	0.99	–	0.98	0.98	–	0.96	0.95
CCC[b]	–	0.94	0.98	–	0.83	0.98	–	0.94	0.94
Regression									
Intercept									
Estimate	–	−3.20	0.64	–	0.19	1.12	–	1.45	2.34
Standard error	–	3.50	3.68	–	1.78	1.67	–	1.76	2.07
P-value[c]	–	0.37	0.86	–	0.92	0.51	–	0.42	0.27
Inclination									
Estimate	–	1.12	1.03	–	0.74	0.98	–	1.00	0.92
Standard error	–	0.03	0.03	–	0.03	0.04	–	0.05	0.05
P-value[d]	–	<0.001	0.28	–	<0.001	0.60	–	0.96	0.16
AEP[e]	–	−11.52	−4.54	–	14.13	−0.34	–	−1.37	0.57
MSEP[f]	–	177.47	55.48	–	291.89	24.91	–	5.15	5.23
SB	–	132.65	20.60	–	199.66	0.12	–	1.86	0.32
MaF	–	18.92	2.31	–	56.48	0.01	–	0.06	0.03
MoF	–	25.90	32.57	–	35.75	24.78	–	3.22	4.88
RMSEP[g]									
kg		13.32	7.45		17.08	4.99		2.27	2.29
%		9.63	5.38		41.57	12.14		6.01	6.06

[a] OBS—observed values; HH—predicted values in Hankins and Howe (1946) method; M11—predicted values in Marcondes et al. (in press) method.

[b] CCC—correlation and concordance coefficient.

[c] H_0: $\beta_0=0$.

[d] H_0: $\beta_1=1$.

[e] AEP=average error of prediction.

[f] MSEP=mean square error of prediction; SB=square bias; MaF=magnitude of random fluctuation; MoF=model of random fluctuation.

[g] RMSEP=root mean square error of prediction, in kg or percentage of the average observed value.

2.6. Statistics analyses

The body components estimated by equations proposed by Marcondes et al. (2010), Hankins and Howe (1946) and Valadares Filho et al. (2006) were compared with the observed values using the following regression model:

$$y=\beta_0+\beta_1\times x,$$

where x=predicted values; y=observed values; β_0 and β_1=intercept and slope, respectively.

The regression was evaluated according to the following statistical hypothesis:

$$H_0:\beta_0=0 \quad \text{and} \quad H_0:\beta_1=1 \quad \text{and} \quad H_a:\text{not } H_0$$

If the null hypotheses were not rejected, it could be concluded that the equations accurately estimate the body components of Nellore bulls. The inclination and the intercept were evaluated separately to observe where the equations have possible errors.

Estimates were evaluated using the estimate value of the mean square error of the prediction and its components (Kobayashi and Salam, 2000):

$$\mathrm{MSEP}=\mathrm{SB}+\mathrm{MaF}+\mathrm{MoF}=1/n \quad \sum\nolimits_{i=1}(x_i-y_i)^2,$$

$$\mathrm{SB}=(x-y)^2,$$

$$\mathrm{MaF}=(s_x-s_y)^2,$$

$$\mathrm{MoF}=2s_xs_y(1-r),$$

where x are predicted values; y are observed values; MSEP is the mean squared error of prediction; SB is the squared bias; MaF is the component relative to the magnitude of random fluctuation; MoF is the component relative to the model of random fluctuation; s_x and s_y are the standard deviations of the predicted and observed values, respectively and r is the Pearson linear correlation between the predicted and observed values.

For all calculations of variance and covariance, the total number of observations was used as a divisor because it was an estimate of the prediction error (Kobayashi and Salam, 2000).

The prediction of efficiency was determined by estimating the correlation and concordance coefficient (*CCC*) or reproducibility index described by Tedeschi (2006).

The parameters β_0 and β_1 were evaluated separately to have an idea if the bias was represented by a constant (it was evaluated by the intercept difference of parametric value zero) or by a tendency of percentage bias (it was evaluated by the slope deviation of parametric value 1). The CCC indicates models with good accuracy and precision (when close to 1.0) or models with problem of reproducibility (when close to 0.0). The smallest mean square error of prediction indicates the best model in the evaluation. In this study, it can indicate that the model error is associated with the squared bias (*SB*) or errors related to the high dispersion of data around the mean (*MaF*) or systematic errors concerning the direction of the curve predicted (*MoF*).

For all comparisons, the level of 0.05 was established as the critical level of probability for type I error.

3. Results

3.1. Data used in the experiment

All the comparisons between the observed values and predict values by proposed equations were calculated using the mass (kg) for the evaluated components (Table 4). It can be seen for the extent when the mass

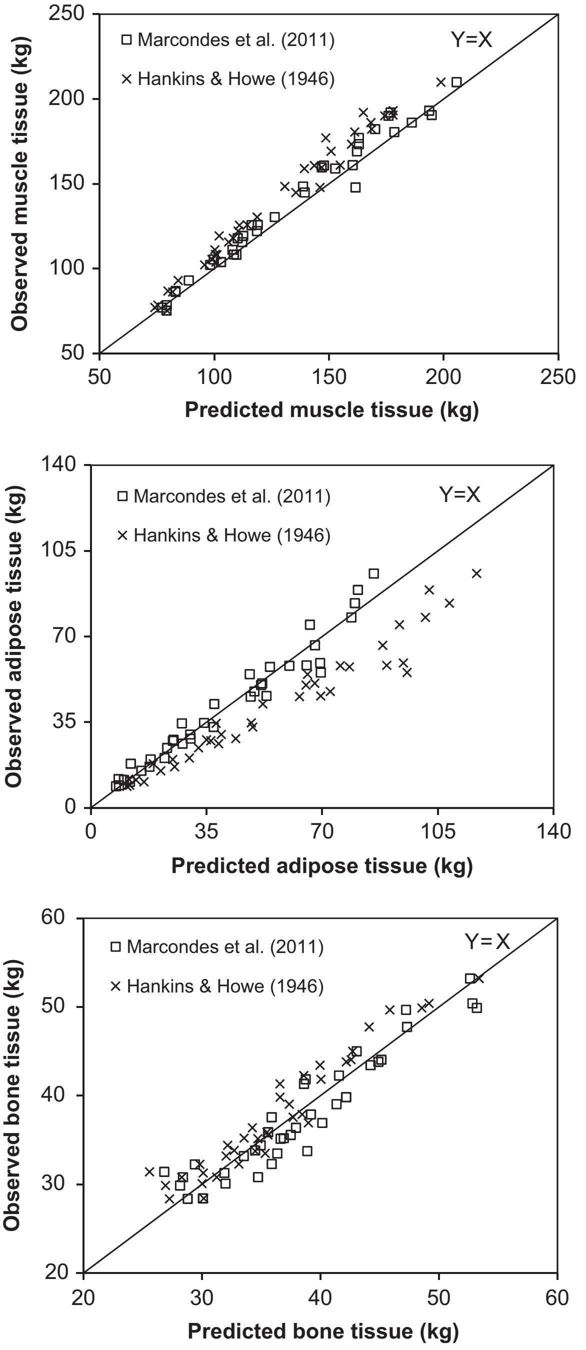

Fig. 1. Relationship among the observed and predicted values to physical carcass composition estimated according to Hankins and Howe (1946) and Marcondes et al. (in press).

was considered while the extent of components percentage was very small. Therefore, the use of the comparisons, using the mass (kg), is more recommended.

3.2. Carcass physical composition

Hankins and Howe (1946) equations had the worst estimate for the muscle and the adipose tissue than compared with Marcondes et al. (in press) when the CCC was observed (Table 5 and Fig. 1). As well as the equations of Hankins and Howe (1946) also presented problems with the inclination ($P < 0.05$) while Marcondes et al. (in press) estimate correctly for intercept and inclination. That equation presented the largest SB and it had a smaller capacity to simulate the variation around the mean (largest MaF) than the Marcondes et al. (in press) equation. However, the equations developed by both Hankins and Howe (1946) and Marcondes et al. (in press) accurately estimated the proportion of bones in the carcass ($P > 0.05$).

3.3. Carcass chemical composition

The equations developed by Hankins and Howe (1946) and Valadares Filho et al. (2006) did not estimate correctly any of the carcass chemical contents values because the CCC was not closer to 1 (Table 6 and Fig. 2) and all of the equations have problems with intercept and inclination ($P < 0.05$), but not to ether extract where these equations did not have problems in relation with intercept ($P > 0.05$).

Moreover, the equations predicted by Hankins and Howe (1946) and Valadares Filho et al. (2006) presented a larger SB than that proposed by Marcondes et al. (2010) to all carcass chemical contents.

The equation developed by Marcondes et al. (2010) did not estimate correctly the carcass water because the intercept and the slope did not present good estimate ($P < 0.05$). However, when evaluated other parameters, this equation had the CCC values closest to one and the smallest values for MSEP (Table 6 and Fig. 2). Probably, this fact can be explained for the water that was calculated by difference from the measurements of other constituents and it is therefore, subject to accumulated errors.

The empty body chemical composition is more important than the carcass chemical composition because the carcass is associated only with the edible parts of the animal. To evaluate the empty body chemical composition, knowledge about both the carcass and noncarcass composition is necessary. In studies of carcass composition, the noncarcass composition can be estimated using equations. Therefore, the comparison between observed and predicted values using Marcondes et al. (2010) equations was evaluated.

Table 6
Mean (kg) and descriptive statistics for relationship among the observed and predicted values to chemical carcass composition.

Item	Crude protein				Ether extract				Water[a]			
	OBS[a]	HH	*V*	M10	OBS[a]	HH	*V*	M10	OBS[a]	HH	*V*	M10
Mean	35.33	27.95	30.01	36.28	42.29	45.42	34.83	41.05	129.10	105.59	87.29	126.39
SD	10.89	5.96	7.04	10.30	24.31	26.17	18.35	22.05	32.74	20.87	12.04	34.51
Maximum	54.54	38.39	42.35	55.52	89.14	95.48	69.94	86.00	192.29	143.35	109.08	189.63
Minimum	18.24	18.67	19.05	20.51	9.67	11.33	10.93	11.92	77.34	71.27	67.49	73.56
R	–	0.96	0.98	0.96	–	0.98	0.98	0.98	–	0.99	0.99	0.99
CCC[b]	–	0.61	0.75	0.96	–	0.97	0.88	0.98	–	0.66	0.26	0.99
Regression												
Intercept												
Estimate	–	−15.36	−10.74	−1.54	–	1.06	−2.80	−2.26	–	−34.37	−105.14	9.96
SE[c]	–	1.89	1.73	1.84	–	1.75	1.88	1.54	–	4.57	6.49	2.34
P-value[d]	–	< 0.001	< 0.001	0.41	–	0.55	0.15	0.15	–	< 0.001	< 0.001	< 0.001
Inclination												
Estimate	–	1.81	1.53	1.02	–	0.91	1.29	1.09	–	1.55	2.68	0.94
SE[c]	–	0.07	0.06	0.05	–	0.03	0.05	0.03	–	0.04	0.07	0.02
P-value[e]	–	< 0.001	< 0.001	0.74	–	0.01	< 0.001	0.15	–	< 0.001	< 0.001	0.00
AEP[f]	–	−7.39	−5.32	0.60	–	3.13	−7.45	−1.21	–	−23.51	−41.81	−2.62
MSEP[g]	–	81.78	46.70	9.51	–	41.76	110.17	23.22	–	706.68	2174.3	24.07
AS	–	53.87	27.84	0.89	–	9.82	55.52	1.54	–	552.55	1747.70	7.32
MaF	–	25.09	15.54	0.33	–	3.34	34.60	5.00	–	136.94	416.67	3.07
MoF	–	2.81	3.33	8.29	–	28.60	20.06	16.69	–	17.19	9.92	13.67
RMSEP[h]												
kg		8.98	6.98	3.07		6.46	10.50	4.78		26.58	46.63	4.87
%		25.41	19.76	8.69		15.28	24.82	11.30		20.59	36.12	3.77

[a] OBS—observed values; HH—predicted values in Hankins and Howe (1946) method; *V*—predicted values in Valadares Filho et al. (2006) method; M10—predicted values in Marcondes et al. (2010) method.

[b] CCC = correlation and concordance coefficient.

[c] SE = standard error.

[d] H_0: $\beta_0 = 0$.

[e] H_0: $\beta_1 = 1$.

[f] AEP = average error of prediction.

[g] MSEP = mean square error of prediction; SA = square addition; MaF = magnitude of random fluctuation; MoF = model of random fluctuation.

[h] RMSEP = root mean square error of prediction, in kg or percentage of average observed value.

3.4. Noncarcass chemical composition

In blood and hide, the equations correctly estimated only crude protein to intercept and slope ($P > 0.05$) and the CCC was closer to 1 (Table 7 and Fig. 3). The ether extract and ash have problems with reproducibility because of the low CCC and in relation with intercept and slope ($P < 0.05$) to ether extract and in relation with slope to ash. For water, the equation presented good accuracy and prediction but it has problem with intercept and slope ($P < 0.05$).

In relation with head and limbs, none of the equations correctly estimated any of the evaluated chemical components because they have problems with the intercept and the slope ($P < 0.05$). For crude protein and water, the equations presented problems with reproducibility due low CCC.

In the organs and viscera, only ether extract was correctly estimated when the intercept and the slope were considered ($P > 0.05$). For crude protein and water, the equation have problems in relation with intercept and slope ($P < 0.05$) while for ash, the equation also have problem of reproducibility (low CCC).

For all noncarcass chemical composition, the equations developed by Marcondes et al. (2010) had the MSEP closest to zero in spite of the RMSEP presented high variation.

3.5. Empty body chemical composition

The empty body chemical composition was obtained by adding the noncarcass chemical composition to the carcass chemical composition (Table 8 and Fig. 4).

All the equations developed by Valadares Filho et al. (2006) presented problems of reproducibility due low CCC and in relation with the intercept and slope ($P < 0.05$). Therefore, the equations developed by Valadares Filho et al. (2006) did not correctly estimate any of the empty body chemical components ($P < 0.05$). The equations developed by Marcondes et al. (2010) correctly estimated the empty body constituents except for water ($P > 0.05$), which has problem in relation with intercept ($P < 0.05$). Thus, these equations presented the smaller SB and MaF values compared to equations developed by Valadares Filho et al. (2010).

4. Discussion

4.1. Carcass physical composition

The problem to estimate the adipose tissue may be due to the use of only heifers and steers during the development of the original equation developed by Hankins and Howe (1946). These genders exhibit an earlier degree of finishing and the largest amounts of adipose tissue and could result in equations that overestimate the adipose tissue. Some authors (Lana, 1988; Paulino et al., 2005; Silva, 2001) verified that the adipose tissue of carcass exhibits large variation and that the application of equations developed by Hankins and Howe (1946) to zebu beef cattle overestimates this tissue.

The equations developed by Hankins and Howe (1946) and Marcondes et al. (in press) accurately estimated bone tissue. Thus, these equations can be recommended to be used in Nellore bulls.

The most accurate estimates of the carcass tissues were obtained by the Marcondes et al. (in press) equations (Fig. 1). This high accuracy can be explained by the large database of Brazilian bulls that was used to develop these equations. The increase in labor required by these

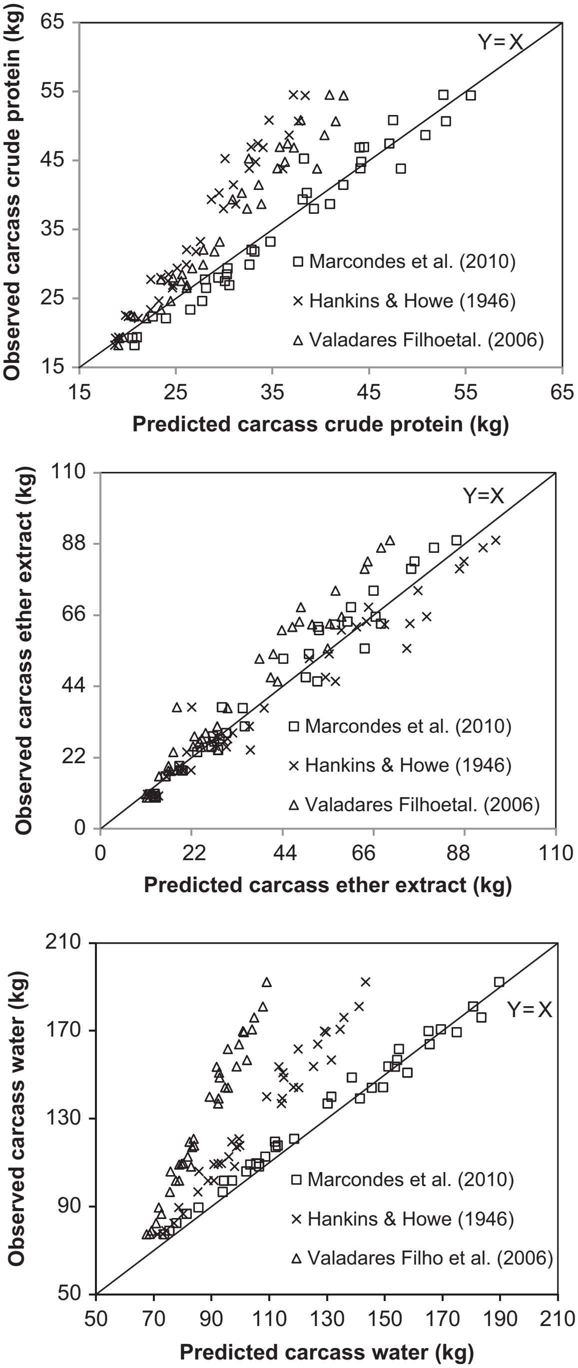

Fig. 2. Relationship among the observed and predicted values to chemical carcass composition estimated according to Hankins and Howe (1946), Marcondes et al. (2010) and Valadares Filho et al. (2006).

Table 7

Mean (kg) e descriptive statistic for the relationship among the observed and predicted values to noncarcass chemical composition.

Item	Blood and leather								Head and limbs								Organs and víscera							
	CP		EE		MM		WaterCP		CP		EE		MM		Water		CP		EE		MM		Water	
	Obs	M10	Obs	M10	Obs	M10	Obs	M10	Obs	M10	Obs	M10	Obs	M10	Obs	M10	Obs	M10	Obs	M10	Obs	M10	Obs	M10
Mean	11.73	12.23	5.93	2.81	0.27	0.38	31.14	33.65	3.92	2.43	2.75	2.56	3.25	3.53	10.87	12.28	5.81	6.18	16.25	16.98	0.37	0.37	28.84	27.00
SD	3.10	3.01	3.82	1.13	0.09	0.10	5.93	8.00	0.57	0.40	0.58	0.66	0.68	0.53	1.33	1.63	1.85	2.07	10.05	9.03	0.14	0.10	5.96	6.06
Maximum	18.35	17.72	13.90	5.31	0.47	0.57	41.67	47.64	5.16	3.33	4.03	4.05	4.76	4.71	13.82	15.68	12.33	10.91	39.36	37.99	0.80	0.58	40.54	39.19
Minimum	6.06	6.92	0.92	0.81	0.12	0.21	19.01	19.19	2.98	1.75	1.80	1.52	2.01	2.60	8.41	9.46	2.91	2.88	2.16	4.57	0.15	0.21	17.87	16.12
r	–	0.94	–	0.88	–	0.82	–	0.96	–	0.99	–	0.89	–	1.00	–	0.98	–	0.84	–	0.98	–	0.76	–	0.97
CCC[b]	–	0.92	–	0.30	–	0.50	–	0.87	–	0.16	–	0.80	–	0.75	–	0.59	–	0.86	–	0.97	–	0.10	–	0.92
Regression																								
Intercept																								
Estimate	–	−0.08	–	−2.36	–	−0.00	–	7.08	–	0.48	–	0.75	–	−1.25	–	1.04	–	1.19	–	−2.17	–	−0.02	–	3.19
SE[c]	–	0.77	–	0.84	–	0.03	–	1.16	–	0.07	–	0.18	–	0.05	–	0.35	–	0.54	–	0.81	–	0.06	–	1.19
P-value[d]	–	0.92	–	0.01	–	0.98	–	< 0.001	–	< 0.001	–	< 0.001	–	< 0.001	–	0.01	–	0.00	–	0.02	–	0.79	–	0.01
Inclination																								
Estimate	–	0.97	–	2.95	–	0.72	–	0.72	–	1.41	–	0.79	–	1.28	–	0.80	–	0.75	–	1.08	–	1.04	–	0.95
SE	–	0.06	–	0.28	–	0.09	–	0.03	–	0.03	–	0.07	–	0.01	–	0.03	–	0.08	–	0.04	–	0.15	–	0.04
P-value[e]	–	0.57	–	< 0.001	–	< 0.003	–	< 0.001	–	< 0.001	–	0.00	–	< 0.001	–	< 0.001	–	0.01	–	0.05	–	0.80	–	0.26
AEP[f]	–	0.50	–	−3.12	–	0.11	–	2.51	–	−1.49	–	–0.19	–	0.28	–	1.39	–	0.37	–	0.73	–	0.00	–	−1.84
MSEP[g]	–	1.40	–	17.83	–	0.014	–	13.81	–	2.23	–	0.13	–	0.098	–	2.14	–	1.40	–	2.45	–	0.01	–	5.81
SB	–	0.25	–	9.74	–	0.01	–	6.31	–	2.20	–	0.04	–	0.075	–	1.97	–	0.13	–	0.53	–	0.00	–	3.41
MaF	–	0.01	–	7.0	–	0.00	–	4.14	–	0.03	–	0.01	–	0.021	–	0.09	–	0.05	–	1.01	–	0.00	–	0.01
MoF	–	1.14	–	1.06	–	0.00	–	3.36	–	0.00	–	0.08	–	0.00	–	0.09	–	1.22	–	4.47	–	0.01	–	2.39
RMSEP[h]																								
kg		1.20		4.22		0.12		3.70		1.83		0.45		0.44		1.76		0.96		2.13		0.76		2.38
%		10.25		71.23		31.69		11.00		73.52		16.98		12.22		14.01		15.59		12.57		70.96		8.80

[a] OBS—observed values; M10—predicted values in Marcondes et al. (2010) method.

[b] CCC = correlation and concordance coefficient.

[c] SE = standard error.

[d] H_0: $\beta_0 = 0$.

[e] H_0: $\beta_1 = 1$.

[f] AEP = average error of prediction.

[g] MSEP = mean square error of prediction; SB = square bias; MaF = magnitude of random fluctuation; MoF = model of random fluctuation.

[h] RMSEP = root mean square error of prediction, in kg or percentage of average observed value.

equations is offset by an increase in the model ability to make good predictions for the inclusion of visceral fat percentage, which is a component that exhibits large variation among bulls. This component represents the physical separation of mesentery fat added renal, pelvic and cardiac fats.

Due to the better precision and accuracy, the equations proposed by Marcondes et al. (in press) can be considered adequate to estimate the carcass physical composition and they are recommended to estimate the proportion of carcass tissue in Nellore bulls reared under Brazilian conditions.

4.2. *Carcass chemical composition*

Some studies (Ferreira et al., 2001; Jorge et al., 2000; Véras et al., 2001) realized in Brazil have predicted the carcass chemical composition of beef cattle by the chemical composition of the 9–10–11th rib cut section. These studies estimated the chemical composition of muscle, adipose and bone tissue of this section and extrapolated these results to the carcass chemical composition using the equations developed by Hankins and Howe (1946). Most of these studies concluded that the body chemical composition could be estimated by the section chemical

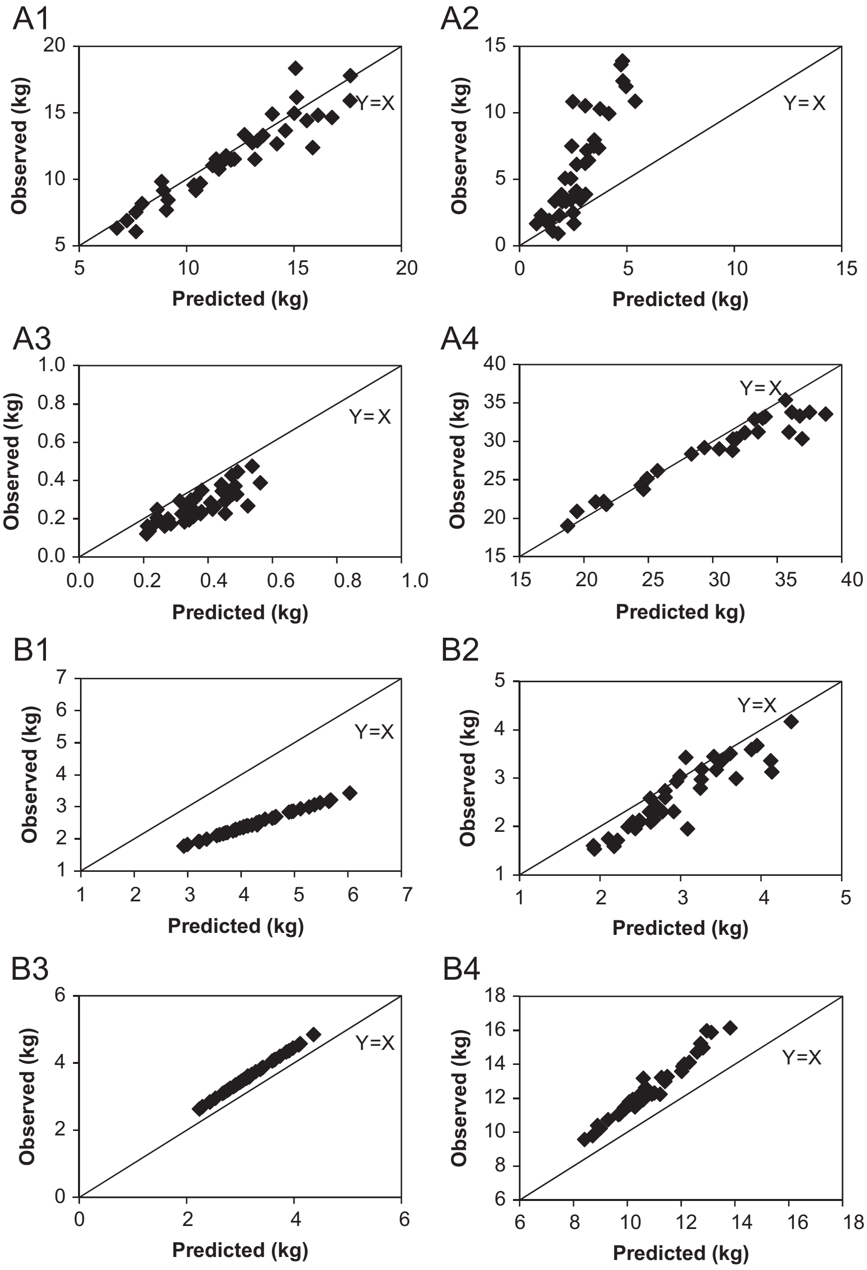

Fig. 3. Relationship among observed and predicted values to chemical noncarcass components estimated according to Marcondes et al. (2010) (A: blood and leather; B: head and limbs; C: organs and viscera; 1: crude protein; 2: ether extract; 3: ash and 4: water).

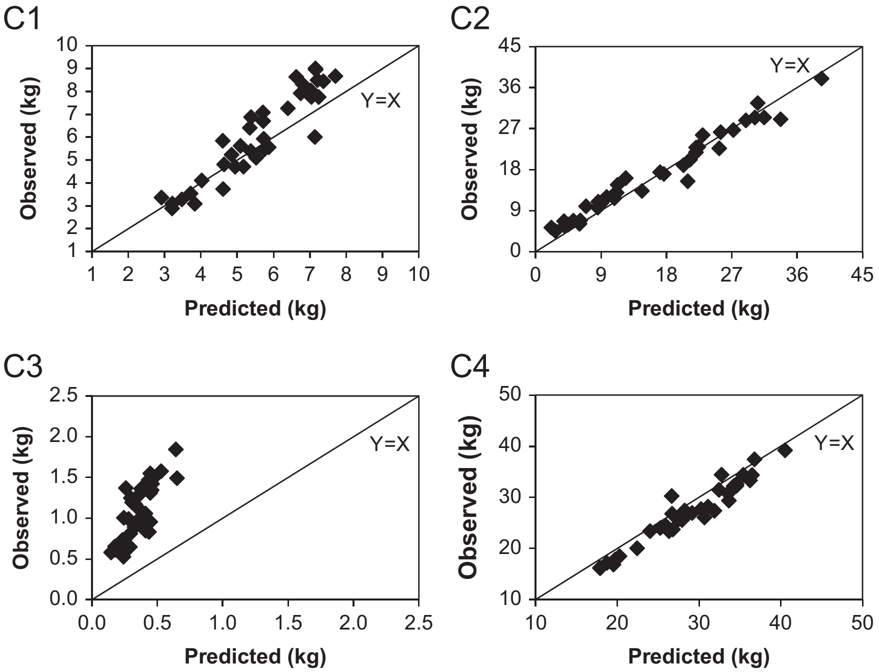

Fig. 3. Continued.

Table 8
Mean (kg) and descriptive statistics for the relationship among the observed and predicted values to chemical empty body composition.

Item	Crude protein			Ether extract			Water		
	OBS[a]	*V*	M10	OBS[a]	*V*	M10	OBS[a]	*V*	M10
Mean	53.85	45.66	59.03	63.91	56.49	66.86	213.20	125.16	201.12
SD	15.38	10.78	15.03	36.14	30.73	35.35	48.08	19.50	48.93
Maximum	82.06	72.19	86.81	140.01	117.03	139.89	307.96	162.25	298.29
Minimum	28.84	28.63	35.03	14.28	15.30	18.38	136.01	92.68	124.53
R	–	0.91	0.97	–	0.98	0.99	–	0.98	1.00
CCC[b]	–	0.71	0.93	–	0.94	0.98	–	0.18	0.97
Regression									
Intercept									
Estimate	–	−3.69	−3.90	–	−0.20	−3.42	–	−89.77	16.66
SE[c]	–	4.72	2.35	–	2.71	2.25	–	10.04	3.12
P-value[d]	–	0.44	0.11	–	0.94	0.14	–	<0.001	<0.001
Inclination									
Estimate	–	1.27	0.98	–	1.15	1.01	–	2.42	0.98
SE[c]	–	0.10	0.04	–	0.04	0.03	–	0.08	0.02
P-value[e]	–	0.01	0.61	–	0.00	0.82	–	<0.001	0.16
AEP[f]	–	−8.19	5.18	–	−7.42	2.95	–	−88.04	−12.08
MSEP[g]	–	119.72	37.36	–	144.64	46.68	–	8579.57	169.98
SB	–	71.64	25.81	–	67.03	8.69	–	7751.69	150.29
MaF	–	18.01	0.01	–	28.22	0.61	–	794.60	0.74
MoF	–	30.07	11.54	–	49.39	37.38	–	33.28	18.95
RMSEP[h]									
kg		10.90	5.92		11.66	6.65		92.63	12.96
%		20.18	10.96		18.17	10.37		43.44	6.08

[a] OBS—observed values; *V*—predicted values in Valadares Filho et al. (2006) method; M10=predicted values in Marcondes et al. (2010) method.
[b] CCC=correlation and concordance coefficient.
[c] SE=standard error.
[d] H_0: $\beta_0=0$.
[e] H_0: $\beta_1=1$.
[f] AEP=average error of prediction.
[g] MSEP=mean square error of prediction; SB=square bias; MaF=magnitude of random fluctuation; MoF=model of random fluctuation.
[h] RMSEP=root mean square error of prediction, in kg or percentage of average observed value.

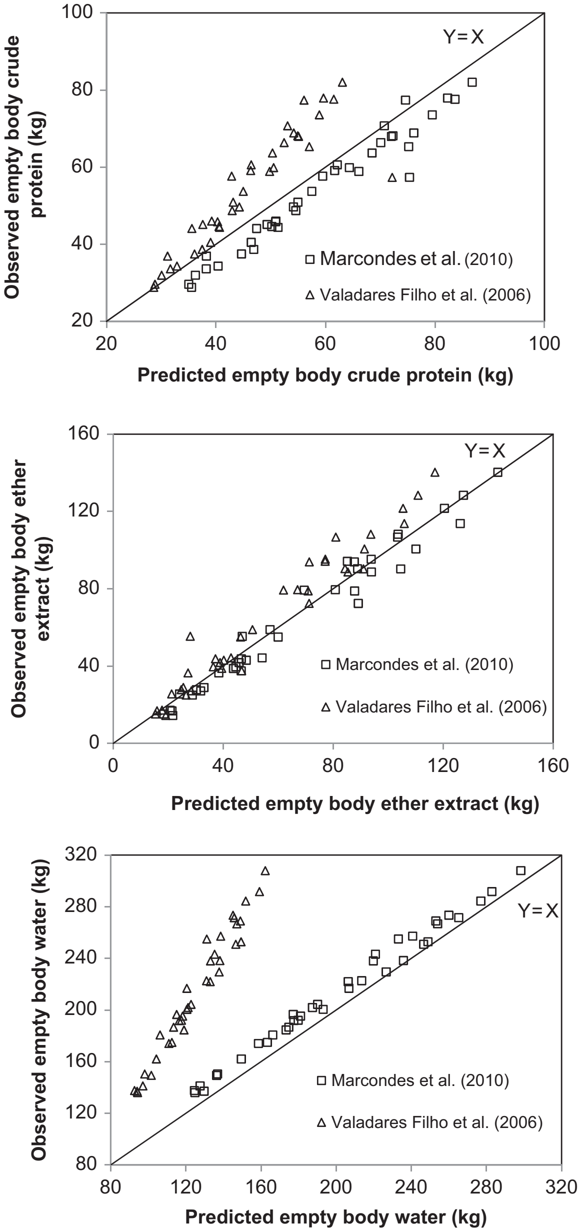

Fig. 4. Relationship among the observed and predicted values to chemical empty body composition estimated according to Marcondes et al. (2010) and Valadares Filho et al. (2006).

composition. However, another authors concluded that is not true for the ether extract composition of the carcass (Paulino et al., 2005; Silva, 2001).

The inclusion of additional variables, such as visceral fat, dressing percentage and EBW in the equations to estimate the carcass chemical composition gave better results (Table 3 and Fig. 2) (Marcondes et al., 2010).

However, the smaller database used to develop the equations by Marcondes et al. (2010) used bulls with low body weights, which probably resulted in incorrect estimates of crude protein and water in the carcasses (Fig. 2). Thus, experiments using bulls with lower body weights are needed and could verify the applicability of these equations to smaller bulls.

Therefore, the use of equations developed by Marcondes et al. (2010) to estimate the carcass chemical composition is recommended in Nellore bulls reared under Brazilian conditions.

4.3. *Noncarcass chemical composition*

Evaluating the noncarcass chemical composition requires more time, cost and labor. Moreover, the limbs and head dissection is a laborious procedure, which is dangerous and difficult to routinely measure. The head and limbs are constituents that exhibit little variation in their composition. Therefore, the adequacy of the equations is affected (Fig. 3). An increase in the number of observations and the adoption of other variables could be used to improve the estimates. Organs and viscera are the noncarcass components that are most influenced by age and weight gain (Marcondes et al., 2010).

An alternative to estimate noncarcass chemical composition could be the formulation of a composed sample of all the noncarcass components. This method could result in a decreased error and a lowered use of reagents. The use of only one equation to estimate all noncarcass components could be more practical and applicable for experiments that rely on this estimate.

4.4. *Empty body composition*

The best estimates of empty body chemical composition can be explained by the increased number of observations in the database used by Marcondes et al. (2010) in comparison with Valadares Filho et al. (2006) (329 *versus* 66) and by the inclusion of new variables in the models (Fig. 4). Visceral fat was an important variable used in all the equations. Visceral fat and organs and viscera percentage of the empty body weight may represent the best metabolic standard (Marcondes et al., 2010).

Some researchers (Ferrell et al., 1978; Williams et al., 1983; Nour and Thonney, 1994) have discussed the interactions between feeding level and body composition. Visceral fat could be one indicator of this relationship and underscores the importance of including this variable in equations that consider nutrition and body composition.

In the same way that carcass composition was estimated, some researchers (Ferreira et al., 2001; Jorge et al., 2000; Véras et al., 2001) have estimated empty body chemical composition using the 9–10–11th rib cut section composition, and the carcass physical using the equations developed by Hankins and Howe (1946). Because the carcass is the main constituent of the empty body mass, these researchers concluded that the empty body chemical composition can be estimated using the section chemical composition.

The equations developed by Marcondes et al. (2010) to estimate the carcass physical and chemical composition and empty body chemical composition exhibit both precision and accuracy and they represent an important advance in the prediction of body composition, thereby reducing experimental costs. Cost is one of the limiting factors in conducting some studies in this area because evaluating body composition requires a complete dissection of half carcass.

5. Conclusions

In Nellore bulls, the carcass physical composition is better estimated using the equations developed by Marcondes et al. (in press) while the carcass and empty body chemical composition are better estimated using equations developed by Marcondes et al. (2010). The use of these equations is recommended when it is necessary to estimate the empty body composition in Nellore bulls and it could result in a decrease in the cost and labor of experiments conducted to estimate the nutritional requirements in Nellore bulls. The use of the equations developed by Hankins and Howe (1946) and Valadares Filho et al. (2006) is not recommended to estimate the carcass composition in Nellore bulls.

Conflict of interest

The author and co-authors authorize the publication of the paper: "Evaluation of equations to predict body composition in Nellore bulls" at Livestock Science. This paper has not been sent to any other Journal before.

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