http://dx.doi.org/10.26626/978-85-8179-194-4.2023.C005.p.109-134

5

Prediction of body and carcass composition of beef cattle

Flávia Adriane de Sales Silva, Letícia Artuzo Godoi, Luiz Fernando Costa e Silva, Breno de Castro Silva, Marcos Inácio Marcondes, Mário Fonseca Paulino, Pedro del Bianco Benedeti, Mario Luiz Chizzotti, Sebastião de Campos Valadares Filho

INTRODUCTION

The nutrients required by cattle depend on the animals' body composition. The methods utilized to predict body composition can be classified as direct and indirect. Direct methods consist of separating and dissecting all body components and then quantifying physical and chemical components. Thereby, experiments conducted using direct methods become extremely laborious, slow, and expensive due to the loss of at least half of the carcass besides the number of people and laboratory analyses involved. However, indirect methods predict body composition from simple parameters without the need for carcass dissection.

Several indirect methods have been developed. A method used to estimate body water and ether extract (EE) from specific gravity was developed by Kraybill et al. (1952) and, during the 1990´s, it was used by researchers in Brazil (Gonçalves et al., 1991; Peron et al., 1993; Lanna et al., 1995; Alleoni et al., 1997). However, this method did not result in adequate estimates for animals raised under Brazilian conditions (Lanna et al., 1995; Alleoni et al., 1997). Other techniques utilizing tools such as antipyrine, titrated water, N-acetyl-amine-antipyrine (Panaretto and Till, 1963), urea dilution (Preston and Kock, 1973) and ^{40}K (Clark et al., 1976) were not widely used in Brazil due to their complexity, high cost, and lack of equipment and/or experienced people. In this context, the most utilized indirect method in Brazil is that first proposed by Hankins and Howe (1946), which equations were developed to estimate carcass and empty body composition based on the composition of the section between the 9th and 11th ribs. This technique is widely used due to its ease of use, reduced cost involved, and speed of the process. Several groups reported positive results when this technique was used (Silva, 2001; Henrique et al., 2003; Paulino et al., 2005a).

THE USE OF THE SECTION BETWEEN THE 9th AND 11th RIBS

Studies during the 1920´s (Trowbridge and Haigh, 1921; Trowbridge and Haigh, 1922; Moulton, 1923; Lush, 1926) evaluated several carcass cuts to estimate carcass physical composition. It was concluded that the ribs region presented the best relationship with the carcass composition. Then, Hankins and Howe (1946) evaluated the use of different carcass cuts to predict the physical and chemical composition of cattle carcass and also developed a technique to obtain a carcass sample between the 9th and 11th ribs (HH section; Figure 5.1).

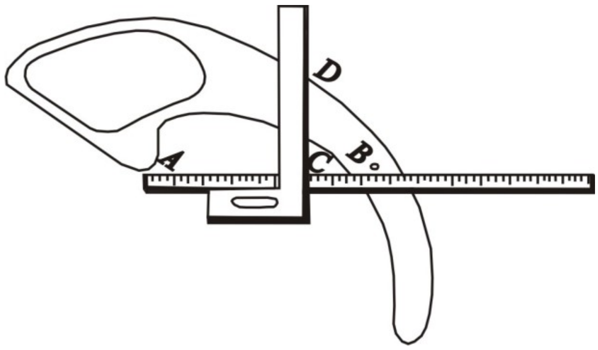

Figure 5.1 - Method developed by Hankins and Howe (1946) for collecting the section between the 9th and 11th ribs. The rib section can be obtained in carcasses hanging by transverse foramen located in the pelvis. First, a cut splitting the section between the 9th and 11th ribs is performed. Next, the distance between the split vertebra (point A) and the cartilage or "bottom" of the rib is measured (point B), and 61.5% of this distance is calculated (point C). Further, a perpendicular line is erected, and the separation is made where this line intersects the external circumference (point D).

CHEMICAL AND PHYSICAL COMPOSITION OF THE CARCASS AND EMPTY BODY CHEMICAL COMPOSITION

Prediction equations for carcass physical and chemical composition were first proposed by Hankins and Howe (1946) from the database of *Bos taurus taurus* steers and heifers. Thus, equations for each sex and a general equation were defined (Table 5.1).

Table 5.1 - Prediction equations for physical and chemical composition of carcass from the composition of the section between 9th and 11th ribs cut proposed by Hankins and Howe (1946)

Item	Sex	Equation[1]
Carcass physical composition		
Fat, %	General	$\% Fcarc = 3.06 + 0.82 \times \% F_{HH}$
	Steers	$\% Fcarc = 3.54 + 0.80 \times \% F_{HH}$
	Heifers	$\% Fcarc = 3.14 + 0.83 \times \% F_{HH}$
Muscle, %	General	$\% Mcarc = 15.56 + 0.81 \times \% M_{HH}$
	Steers	$\% Mcarc = 16.08 + 0.80 \times \% M_{HH}$
	Heifers	$\% Mcarc = 16.09 + 0.79 \times \% M_{HH}$
Bone, %	General	$\% Bcarc = 4.30 + 0.61 \times \% B_{HH}$
	Steers	$\% Bcarc = 5.52 + 0.57 \times \% B_{HH}$
	Heifers	$\% Bcarc = 6.88 + 0.44 \times \% B_{HH}$
Carcass chemical composition		
Ether extract, %	General	$\% EEcarc = 2.82 + 0.77 \times \% EE_{HH}$
	Steers	$\% EEcarc = 3.49 + 0.74 \times \% EE_{HH}$
	Heifers	$\% EEcarc = 2.73 + 0.78 \times \% EE_{HH}$
Crude protein, %	General	$\% CPcarc = 5.98 + 0.66 \times \% CP_{HH}$
	Steers	$\% CPcarc = 6.19 + 0.65 \times \% CP_{HH}$
	Heifers	$\% CPcarc = 5.64 + 0.69 \times \% CP_{HH}$
Water, %	General	$\% Wcarc = 14.90 + 0.78 \times \% W_{HH}$
	Steers	$\% Wcarc = 16.83 + 0.75 \times \% W_{HH}$
	Heifers	$\% Wcarc = 14.28 + 0.78 \times \% W_{HH}$

[1]Fcarc = fat in the carcass; F_{HH} = fat in the HH section; Mcarc = muscle in the carcass; M_{HH} = muscle in the HH section; Bcarc = bone in the carcass; B_{HH} = bone in the HH section; EEcarc = ether extract in the carcass; EE_{HH} = ether extract in the HH section; CPcarc = crude protein in the carcass; CP_{HH} = crude protein in the HH section; Wcarc = water in the carcass; W_{HH} = water in the HH section.

Hankins and Howe (1946) equations have been widely used due to the ease of obtaining the HH section. Some studies (Cole et al., 1962; Powell and Huffman, 1973; Crouse and Dikeman, 1974; Nour and Thonney, 1994) evaluated these equations, however, presented distinct results. These differences may be related to the fact that the carcass chemical composition equations were developed from the soft tissue composition, while the bone composition was not considered.

Some researchers have tried to predict the chemical composition of the carcass and empty body of beef cattle from the chemical composition of the whole HH section (Peron et al., 1993; Jorge et al., 2000; Ferreira et al., 2001; Véras et al., 2001). In this case, samples of muscle, adipose, and bone tissues from the dissection of HH section were chemically analyzed and used to estimate the carcass chemical composition. However, the carcass physical composition was estimated from the equations proposed by Hankins and Howe (1946). Thereby, carcass chemical composition was estimated from the chemical composition of HH section, while the empty body composition was determined by the sum of carcass and non-carcass compositions. As the carcass is the main quantitative component of the empty body, most of these studies concluded that the chemical composition of the empty body could be predicted from the chemical composition of HH section.

Nevertheless, other studies (Silva, 2001; Paulino et al., 2005a; Costa e Silva et al., 2013) reported that this premise could not be completely accurate, mainly regarding the carcass content of EE. Thus, considerable efforts were made to establish more accurate predictive equations for carcass and empty body composition of beef cattle in the previous editions of this publication.

Equations to predict carcass and empty body chemical composition based on the HH section composition were developed for Zebu cattle in the first edition of the BR-CORTE (BR-CORTE, 2006). For this, a database composed of the chemical composition of the 66 animals from two studies was used (Paulino, 2002; Paulino, 2006; Table 5.2).

Table 5.2 - Equations based on the 9th to 11th rib section composition for estimating the chemical composition of the carcass and empty body of Zebu cattle, adapted from BR-CORTE (2006)

Item	Equation[1]	Standard error	R^2
Carcass chemical composition			
Ether extract	$\% EEcarc = 4.96 + 0.54 \times\% EE_{HH}$	2.22	0.80
Crude protein	$\% CPcarc = 4.05 + 0.78 \times\% CP_{HH}$	1.00	0.72
Ash	$\% Acarc = 2.88 + 0.50 \times\% A_{HH}$	0.66	0.40
Water	$\% Wcarc = 34.97 + 0.45 \times\% W_{HH}$	1.94	0.66
Empty body chemical composition			
Ether extract	$\% EE_{EBW} = 4.56 + 0.60 \times\% EE_{HH}$	2.37	0.81
Crude protein	$\% CP_{EBW} = 4.96 + 0.76 \times\% CP_{HH}$	0.90	0.75
Ash	$\% A_{EBW} = 2.54 + 0.39 \times\% A_{HH}$	0.47	0.45
Water	$\% W_{EBW} = 31.42 + 0.51 \times\% W_{HH}$	1.94	0.71

[1]EEcarc = ether extract in the carcass; CPcarc = crude protein in the carcass; Acarc = ash in the carcass; Wcarc = water in the carcass; EE_{HH} = ether extract in the HH section; CP_{HH} = crude protein in the HH section; A_{HH} = ash in the HH section; W_{HH} = water in the HH section; EE_{EBW} = ether extract in the empty body composition; CP_{EBW} = crude protein in the empty body composition; A_{EBW} = ash in the empty body composition; W_{EBW} = water in the empty body composition.

Marcondes et al. (2010; 2012) developed equations to predict chemical and physical compositions of the carcass and the empty body using the composition of the 9th to 11th rib section and other measurements of purebred (Nellore) and crossbred (Nellore × Angus and Nellore × Simmental) Zebu cattle (Tables 5.3 and 5.4), which were previously described in the second edition of the BR-CORTE (BR-CORTE, 2010). The database comprised the body composition of 247 bulls, steers, and heifers from six experiments conducted in feedlot.

According to Marcondes et al. (2012), the use of additional variables in models, as well as considering the effect of genetic group and sex provided better estimates of carcass and empty body compositions. It is noteworthy that the proportion of visceral fat (VF; composed by the mesenteric, renal, pelvic, and cardiac fat) was significant to predict most of the carcass and empty body constituents.

Body composition, mainly the fat fraction, and growth development, vary according to several factors, such as feeding level, genetic group, and sex. Although the feeding level influences body composition and growth (Prior et al., 1977; Ferrell et al., 1978; Nour et al., 1981; Williams et al., 1983; Nour and Thonney, 1987), its inclusion in the predictive equations is difficult and this information is not always available. According to Butterfield (1966), VF is correlated with animal metabolism and is relatively constant even during feeding challenges. Hence, it probably best represents body fat content. Thus, the use of VF along with other predictive variables in the equations might be very important for their applicability.

Table 5.3 - Prediction equations for physical and chemical composition of the carcass and chemical composition of empty body of purebred and crossbred Zebu cattle, adapted from Marcondes et al. (2010; 2012)

Variable	GG/Sex[1]	Equation[2]	R^2	RSME[3]
Carcass physical composition				
Fat*	-	% Fcarc = a + 0.30 × % F_{HH} + b × % VF	0.79	3.01
Muscle	Nellore Nellore × Simmental	% Mcarc = 57.33 + 0.20 × % M_{HH} -1.39 × % VF	0.51	2.97
	Nellore × Angus	% Mcarc = 60.96 + 0.12 × % M_{HH} -1.39 × % VF		
Bone	Nellore Nellore × Simmental	% Bcarc = 29.26 + 0.30 × % B_{HH} - 0.21 × HCY - 0.95 × % VF	0.77	1.43
	Nellore × Angus	% Bcarc = 29.26 + 0.30 × % B_{HH} - 0.21 × HCY - 1.01 × % VF		
Carcass chemical composition				
EE	-	% EEcarc = 4.31 + 0.31 × % EE_{HH} + 1.37 × % VF	0.83	2.13
CP	-	% CPcarc = 17.92 + 0.60 × % CP_{HH} - 0.17 × HCY	0.50	1.26
Water	Nellore	% Wcarc = 48.74 + 0.28 × % W_{HH} - 0.017 × EBW	0.67	2.27
	Nellore × Angus	% Wcarc = 38.06 + 0.48 × % W_{HH} - 0.017 × EBW		
	Nellore × Simmental	% Wcarc = 46.69 + 0.32 × % W_{HH} - 0.017 × EBW		
Empty body chemical composition				
EE	Bulls	% EE_{EBW} = 2.75 + 0.33 × % EE_{HH} + 1.80 × % VF	0.89	1.97
	Steers**	% EE_{EBW} = 1.84 + 0.33 × % EE_{HH} + 1.91 × % VF		
	Heifers	% EE_{EBW} = 4.77 + 0.33 × % EE_{HH} + 1.28 × % VF		
CP	-	% CP_{EBW} = 10.78 + 0.47 × % CP_{HH} - 0.21 × % VF	0.59	1.03
Water	Bulls	% W_{EBW} = 38.31 + 0.33 × % A_{HH} - 1.09 × % VF + 0.50 × % OV	0.82	1.96
	Steers**	% W_{EBW} = 45.67 + 0.25 × % A_{HH} - 1.89 × % VF + 0.50 × % OV		
	Heifers	% W_{EBW} = 31.61 + 0.47 × % A_{HH} - 1.06 × % VF + 0.50 × % OV		

[1]GG = genetic group; [2]Fcarc = fat in the carcass; F_{HH} = fat in the HH section; Mcarc = muscle in the carcass; M_{HH} = muscle in the HH section; Bcarc = bone in the carcass; B_{HH} = bone in the HH section; EEcarc = ether extract in the carcass; EE_{HH} = ether extract in the HH section; EE_{EBW} = ether extract in the empty body; % VF = percentage of mesenteric fat plus renal, pelvic, and cardiac fat in the empty body; CPcarc = crude protein in the carcass; CP_{HH} = crude protein in the HH section; HCY = hot carcass yield (%); CP_{EBW} = crude protein in the empty body; Wcarc = water in the carcass; W_{HH} = water in the HH section; EBW = empty body weight; W_{EBW} = water in the empty body; % OV = percentage of organs and viscera in the empty body; [3]RSME = root square mean of error.
*There was effect of sex for the intercept while there was interaction between sex and breed for the coefficient related to %VF where the deployment of this interaction can be seen in Table 5.4.
**The new equations for Nellore x Angus steers are presented in the section "Evaluation of the equations proposed by Hankins and Howe (1946), BR-CORTE (2006) and BR-CORTE (2010)".

Table 5.4 - Deployment of the effect of sex on the intercept and interaction between sex and breed on the coefficient related to the percentage of mesenteric fat plus renal, pelvic, and cardiac fat (VF)

Sex	Genetic group	Intercept	Coefficient related to VF
Bulls	Nellore	0.689	1.18
	Nellore × Angus		1.20
Steers	Nellore	5.259	0.38
	Nellore × Angus		0.43
	Nellore × Simmental		0.74
Heifers	Nellore	0.471	1.53
	Nellore × Angus		1.98
	Nellore × Simmental		2.34

EVALUATION OF THE EQUATIONS PROPOSED BY HANKINS AND HOWE (1946), BR-CORTE (2006), AND BR-CORTE (2010)

Body composition of Zebu bulls and crossbred beef cattle (bulls and steers)

Costa e Silva et al. (2013) concluded that the equations proposed by Marcondes et al. (2012) adequately estimate the carcass physical composition of Nellore bulls. Likewise, Fonseca et al. (2014) concluded that the equations proposed by Marcondes et al. (2012) estimated adequately the muscle and adipose tissues of F1 Nellore × Angus bulls and steers. However, Costa e Silva et al. (2013) did not recommend any of the equations proposed by Hankins and Howe

(1946) for predicting the carcass physical composition, whereas Fonseca et al. (2014) reported that none of the equations proposed by Hankins and Howe (1946) or Marcondes et al. (2012) correctly estimated the amount of bones of F1 Nellore × Angus cattle.

Moreover, some early studies conducted in Brazil concluded that the equations developed by Hankins and Howe (1946) were not fully applicable to predict carcass and empty body chemical composition of purebred (*Bos taurus indicus*) and crossbred (*Bos taurus indicus* × *Bos taurus taurus*) cattle (Lana et al., 1995; Silva, 2001; Paulino et al., 2005b).

Likewise, Costa e Silva et al. (2013) and Fonseca et al. (2014) evaluated whether the equations proposed by Hankins and Howe (1946), BR-CORTE (2006) and Marcondes et al. (2012) correctly estimate the carcass and empty body chemical composition of Zebu cattle and their crosses. Costa e Silva et al. (2013) did not recommend the use of the equations proposed by the BR-CORTE (2006) or Hankins and Howe (1946) for predicting carcass and empty body chemical composition of Nellore bulls, while reported that the equations proposed by Marcondes et al. (2012) presented accurate estimates.

Fonseca et al. (2014), utilizing data from F1 Nellore × Angus bulls and steers, verified that the equations proposed by Marcondes et al. (2012) showed superior estimates for carcass and empty body chemical composition, except for the water content in the empty body. As water is calculated by difference, this component is susceptible to the accumulation of errors from other analyses (Costa e Silva et al., 2013).

Fonseca et al. (2014) also observed that the EE content in empty body was correctly predicted by Marcondes et al. (2012) equations only when bulls and steers were analyzed separately. Additional evaluation performed by these authors showed that the equation did not require any adjustment for predicting the EE content in the empty body of bulls, whereas a reparameterization with fatter steers would improve the predictions of the EE content in the empty body for such animals.

As the equations proposed by Marcondes et al. (2012) were not sufficiently adjusted to estimate the EE and water contents in the empty body of crossbred beef steers (Fonseca et al., 2014), new equations for predicting the EE and water contents in such animals were developed and evaluated in the last edition of this publication (BR-CORTE, 2016). For this, a new database was built utilizing data from Marcondes et al. (2012) and Fonseca et al. (2014) to estimate the EE content, whereas the new equation for predicting the water content was derived from the same data used by Marcondes et al. (2012). Thus, the estimates of EE and water contents in the empty body of crossbred beef steers were readjusted using the cross-validation procedure (Duchesne and MacGregor, 2001). Twenty percent of the data from each study were randomly separated for validation of the EE equation, while an independent experiment was utilized for validation of the water equation. The equations proposed and validated can be seem below:

$$\% EE_{EBW} = 2.797 + 0.289 \times \% EE_{HH} + 2.056 \times \% VF$$
$$(R^2 = 0.84; RSME = 2.51),$$

where EE_{EBW} = ether extract content in the empty body, EE_{HH} = ether extract content in the 9th to 11th rib section, and VF = visceral fat (mesenteric, renal, pelvic, and cardiac fat).

$$\% W_{EBW} = 30.77 + 0.48 \times \% W_{HH} - 1.07 \times \% VF + 0.50 \times \% OV$$
$$(R^2 = 0.88; RSME = 2.42)$$

where W_{EBW} = water content in the empty body, W_{HH} = water content in the 9th to 11th rib section, VF = visceral fat (mesenteric, renal, pelvic, and cardiac fat), and OV = organs and viscera content in the empty body.

The inclusion of new predictive variables such as VF and organs and viscera (OV) improved the estimates of carcass and empty body chemical composition of purebred Zebu bulls and crossbred Zebu bulls and steers. Thus, the carcass and empty body equations recommended in the third edition of BR-CORTE (BR-CORTE, 2016) were kept in the current edition. It may avoid the complete dissection of the half-carcass and decrease the costs and labor involved in studies of nutrient requirements for beef cattle (Costa e Silva et al., 2013).

Body composition of Zebu cattle (steers and heifers)

The goodness of fit of the prediction equations suggested by Hankins and Howe (1946), BR-CORTE (2006), and BR-CORTE (2010) to predict the carcass and empty body chemical composition of Zebu steer and heifers was evaluated in the last edition of this publication (BR-CORTE, 2016). For this, individual information of 32 Nellore heifers and 18 Nellore steers from a study by Costa e Silva (2015) was utilized (Table 5.5).

Table 5.5 - Description of data utilized to evaluate the equations for body composition of Nellore steers (n = 18) and heifers (n = 32)

Item	Mean	SD[1]	Maximum	Minimum
Steers				
Empty body weight, kg	168	39.5	260	109
Carcass weight, kg	101	24.5	160	65.4
Organs + viscera, % EBW	14.1	1.56	17.5	11.7
VF[2], % EBW	3.02	0.93	4.63	1.73
Ether extract in the EBW, %	9.83	1.60	12.7	7.52
Crude protein in the EBW, %	18.7	0.78	20.0	17.0
Water in the EBW, %	67.7	1.16	69.6	65.5
Ether extract in the carcass, %	10.6	1.55	13.4	7.55
Crude protein in the carcass, %	18.5	0.94	20.3	16.9
Water in the carcass, %	66.2	1.61	68.8	62.0
Ether extract in the HH section, %	12.2	2.69	17.4	6.06
Crude protein in the HH section, %	18.9	1.77	21.8	15.8
Water in the HH section, %	64.1	1.52	65.8	58.8
Heifers				
Empty body weight, kg	190	40.4	266	104
Carcass weight, kg	116	24.8	162	62.6
Organs + viscera, % EBW	14.8	0.99	16.81	13.1
VF[2], % EBW	3.93	0.88	5.83	1.65
Ether extract in the EBW, %	13.1	2.38	18.9	7.45
Crude protein in the EBW, %	18.5	0.75	20.4	17.1
Water in the EBW, %	64.9	2.49	70.0	60.4
Ether extract in the carcass, %	13.0	2.36	18.1	8.23
Crude protein in the carcass, %	18.5	0.90	21.3	16.6
Water in the carcass, %	64.3	2.59	69.0	59.5
Ether extract in the HH section, %	15.2	2.91	20.4	9.12
Crude protein in the HH section, %	17.5	1.52	20.1	14.3
Water in the HH section, %	62.7	1.73	67.1	59.9

[1]SD = standard deviation; [2]VF = mesenteric fat plus renal, pelvic, and cardiac fat.

Briefly, all equations correctly estimated the crude protein (CP) content in the carcass, whereas only the equations recommended by the BR-CORTE (2010) correctly estimated the carcass contents of EE and water of Zebu steers and heifers (Table 5.6).

Furthermore, the BR-CORTE (2010) equations accurately and precisely estimated all chemical contents in the empty body evaluated, whereas the equations proposed by BR-CORTE (2006) presented inconsistencies in the intercept and/or slope of the linear regression (Table 5.7). Therefore, the predictive equations of carcass and empty body chemical compositions of Zebu steers and heifers first described in the second edition of BR-CORTE (BR-CORTE, 2010) were recommended in the last edition of this publication and kept in the current edition.

Table 5.6 - Means (kg) and descriptive statistics of the relationship between observed and predicted values of the carcass chemical composition of growing Nellore steers and heifers

Item	Crude protein				Ether extract				Water			
	Obs[1]	HH	B06	B10	Obs	HH	B06	B10	Obs	HH	B06	B10
Mean	19.9	19.3	19.4	19.7	14.0	15.7	14.2	15.5	71.1	70.0	69.6	69.4
Standard deviation	4.36	3.79	3.75	3.78	5.61	5.47	4.57	5.41	14.9	15.43	15.6	15.0
Maximum	28.7	27.4	27.5	28.1	29.4	25.0	22.1	27.8	104	103	101	99.3
Minimum	11.9	11.8	11.8	12.0	4.94	6.19	6.28	5.93	42.9	41.7	40.8	41.2
R	-	0.94	0.92	0.95	-	0.92	0.93	0.94	-	0.99	0.99	0.99
CCC[2]	-	0.92	0.90	0.94	-	0.87	0.91	0.90	-	0.99	0.98	0.98
Regression												
Intercept												
Estimate	-	-0.96	-0.92	-1.75	-	-0.84	-2.29	-1.09	-	4.25	5.26	2.67
Standard error	-	1.17	1.33	1.05	-	0.97	0.96	0.86	-	1.47	1.39	1.43
P value[3]	-	0.42	0.49	0.10	-	0.39	0.02	0.21	-	0.006	0.0004	0.07
Slope												
Estimate	-	1.08	1.07	1.10	-	0.94	1.14	0.97	-	0.96	0.95	0.99
Standard error	-	0.06	0.07	0.05	-	0.06	0.06	0.05	-	0.02	0.02	0.02
P value[4]	-	0.19	0.29	0.07	-	0.32	0.03	0.58	-	0.04	0.008	0.49
MSE[5]	-	2.67	3.11	1.88	-	8.02	4.54	6.19	-	6.41	7.26	7.09
Mean bias	-	0.34	0.23	0.03	-	3.11	0.07	2.38	-	1.33	2.29	2.88
Systematic bias	-	0.09	0.07	0.13	-	0.10	0.42	0.02	-	0.46	0.69	0.04
Random error	-	2.24	2.80	1.71	-	4.81	4.05	3.79	-	4.62	4.27	4.17

[1]Obs – observed values; HH – values predicted by equations from Hankins and Howe (1946); B06 – values predicted by equations from BR-CORTE (2006); B10 – values predicted by equations from BR-CORTE (2010). [2]CCC – concordance correlation coefficient; [3]H_0: β_0=0. [4]H_0: β_1=1. [5]MSE = mean square error.

Table 5.7 - Means (kg) and descriptive statistics of the relationship between observed and predicted values of empty body chemical composition from growing Nellore steers and heifers

Item	Crude protein			Ether extract			Water		
	Obs[1]	B06	B10	Obs	B06	B10	Obs	B06	B10
Mean	33.7	33.7	33.4	22.1	24.0	25.2	117	113	113
Standard deviation	6.10	5.49	5.50	8.73	7.80	9.06	23.1	23.8	23.2
Maximum	46.8	45.9	45.7	41.6	37.5	42.6	171	165	158
Minimum	19.9	20.3	20.2	7.77	10.4	8.93	72.9	68.4	70.1
R	-	0.95	0.97	-	0.94	0.96	-	0.99	0.98
CCC[2]	-	0.94	0.96	-	0.91	0.91	-	0.98	0.97
Regression									
Intercept									
Estimate	-	-1.79	-2.24	-	-3.14	-1.34	-	8.25	6.69
Standard error	-	1.94	1.47	-	1.41	1.02	-	2.19	3.38
P value[3]	-	0.36	0.14	-	0.03	0.19	-	0.001	0.053
Slope									
Estimate	-	1.05	1.08	-	1.05	0.93	-	0.96	0.98
Standard error	-	0.06	0.04	-	0.06	0.04	-	0.02	0.03
P value[4]	-	0.35	0.09	-	0.36	0.06	-	0.06	0.40
MSE[5]	-	3.79	2.43	-	12.6	16.0	-	26.8	35.7
Mean bias	-	0.0002	0.08	-	3.65	10.1	-	17.1	15.0
Systematic bias	-	0.08	0.17	-	0.16	0.42	-	0.74	0.33
Random error	-	3.70	2.17	-	8.75	5.44	-	9.04	20.4

[1]Obs – observed values; B06 – values predicted by the equations from BR-CORTE (2006); B10 – values predicted by the equations from BR-CORTE (2010). [2]CCC – concordance correlation coefficient; [3]H_0: β_0=0. [4]H_0: β_1=1. [5]MSE = mean square error.

CHEMICAL COMPOSITION OF CARCASS AND EMPTY BODY OF CROSSBRED DAIRY CATTLE

The carcass and empty body chemical composition described in the first and second editions of this publication (BR-CORTE, 2006 and 2010) were obtained from a database of Zebu (mainly Nellore) and beef crossbred cattle (Nellore × *Bos taurus taurus*), respectively.

Prados (2012), evaluating the suitability of these equations for predicting the body composition of crossbred dairy cattle (¼ Holstein × ¾ Zebu bulls), verified that the CP content in the empty body was adequately estimated by the BR-CORTE (2010) equation, whereas the equations proposed by the BR-CORTE (2006) correctly estimated the EE and water contents in the empty body. Likewise, Neves (2013) observed that the equations proposed by Hankins and Howe (1946) accurately estimated the CP content in the carcass and the CP and water contents in the empty body of Holstein × Zebu bulls. Also, this author concluded that equations proposed by the BR-CORTE (2010) were not adequate to estimate the carcass and empty body chemical composition of Holstein × Zebu bulls.

The presence of the Holstein breed in the genotype of the animals used in these studies, may have resulted in a different growth and conformation pattern when compared to breeds selected for beef production and their crossbreds. Thus, the prediction equations of carcass and empty body compositions presented reduced goodness of fit.

In this context, new predictive equations of body composition of crossbred dairy cattle were proposed in the last edition of this publication (BR-CORTE, 2016). For this, a database comprising individual information of 80 bulls, 56 steers, and 44 heifers from five experiments (Prados, 2012; Neves, 2013; Zanetti, 2014; Rodrigues, 2014; Silva, 2015) was utilized (Table 5.8).

Table 5.8 - Description of data used to generate equation for body composition for crossbred dairy cattle from the composition of the section between the 9th and the 11th rib cut

Item	Mean	SD[1]	Maximum	Minimum
Empty body weight, kg	311	82.5	529	118
Carcass weight, kg	188	51.8	345	68.3
Non-carcass component weight, kg	117	29.4	224	50.0
Organs and viscera, kg	59.3	21.0	124	20.9
VF[2], kg	16.4	7.59	46.2	2.25
Crude protein in the HH section, %	17.2	2.22	25.5	8.70
Ether extract in the HH section, %	19.8	6.54	36.5	3.01
Ash in the HH section, %	5.24	2.36	10.9	0.68
Water in the HH section, %	57.4	6.13	74.3	42.3
Crude protein in the carcass, %	17.3	1.96	21.7	12.1
Ether extract in the carcass, %	16.5	4.24	30.6	7.47
Ash in the carcass, %	4.43	1.27	7.90	1.60
Water in the carcass, %	61.7	3.45	69.6	54.6
Crude protein in the empty body, %	17.8	1.63	21.5	14.7
Ether extract in the empty body, %	16.1	4.27	28.0	4.84
Ash in the empty body, %	3.90	1.11	6.47	1.51
Water in the empty body, %	62.0	3.75	71.8	52.7

[1]SD = standard deviation; [2]VF = mesenteric fat plus renal, pelvic, and cardiac fat.

Using the *cross-validation* procedure (Duchesne and MacGregor, 2001), the effect of animal was considered in the statistical analyses which allowed the generation of a single equation for each component evaluated (CP, EE, and water). The equations developed are described in Table 5.9.

Table 5.9 - Prediction equations for carcass and empty body chemical composition for crossbred dairy cattle

Item	Equations[1]	R^2
Carcass chemical composition		
Ether extract	$\% EEcarc = 4.54 + 0.48 \times \% EE_{HH} + 0.12 \times \% OV$	0.66
Crude protein	$\% CPcarc = 18.38 + 0.16 \times \% CP_{HH} - 0.20 \times \% OV$	0.53
Water	$\% Wcarc = 55.67 + 0.21 \times \% W_{HH} - 0.021 \times EBW$	0.40
Empty body chemical composition		
Ether extract	$\% EE_{EBW} = 3.53 + 0.34 \times \% EE_{HH} + 0.80 \times \% VF + 0.10 \times \% OV$	0.73
Crude protein	$\% CP_{EBW} = 19.92 + 0.086 \times \% CP_{HH} - 0.19 \times \% OV$	0.58
Water	$\% W_{EBW} = 53.02 + 0.17 \times \% W_{HH} - 1.28 \times \% VF + 0.27 \times \% OV$	0.47

[1]EEcarc = ether extract in the carcass; EE_{HH} = ether extract in the HH section; OV = percentage of organs and viscera in the empty body; CPcarc = crude protein in the carcass; VF = percentage of mesenteric fat plus renal, pelvic, and cardiac fat in the empty body; CP_{HH} = crude protein in the HH section; Wcarc = water in the carcass; W_{HH} = water in the HH section; EBW = empty body weight, kg; EE_{EBW} = ether extract in the empty body; CP_{EBW} = crude protein in the empty body; W_{EBW} = water in the empty body.

Silva et al. (2021) evaluated the goodness of fit of the prediction equations developed by Hankins and Howe (1946) and the BR-CORTE (2016) to predict the carcass and empty body chemical composition of crossbred dairy cattle. An independent database composed by 33 Holstein × Zebu steers were utilized. Briefly, CP and EE chemical contents in the carcass, and all chemical components in the empty body were precisely and accurately estimated by the BR-CORTE (2016) equations. However, water content in the carcass was better predicted by Hankins and Howe (1946) equation.

The BR-CORTE (2016) equations were developed using a database composed by Holstein × Zebu animals, which probably resulted in the best goodness of fit for CP and EE content in the carcass and the correct estimation of all chemical components in the empty body. Therefore, the BR-CORTE (2016) equations can be used to predict CP and EE in the carcass, as well as all chemical components in the empty body of Holstein × Zebu steers.

PREDICTION OF BODY MINERAL COMPOSITION

The equations recommended in the second edition of BR-CORTE (BR-CORTE, 2010) for predicting empty body mineral composition were based on Marcondes et al. (2009) study in which the mineral composition (calcium, phosphorus, sodium, potassium, and magnesium) of the section between the 9th and the 11th ribs was utilized as the predictive variable (Table 5.10).

Marcondes et al. (2009) verified a high correlation coefficient between the mineral composition of the HH section and the empty body (Table 5.10). However, Costa e Silva (2012) observed that the equations generated by Marcondes et al. (2009) did not correctly estimate the body macromineral composition (Ca, P, Mg, Na, and K) of Nellore bulls (Table 5.11).

In this way, a new database was developed in the last edition of this publication (BR-CORTE, 2016) aiming to develop new predictive equations of the mineral composition of the empty body of beef cattle (Table 5.12). Individual data of Zebu cattle were obtained from Marcondes et al. (2009) and Costa e Silva (2015), whereas the mineral composition of crossbred beef cattle were taken from Marcondes (2010) and Souza (2010) studies. Data from Rodrigues (2014) and Zanetti (2014) were utilized to estimate mineral composition for crossbred dairy cattle.

A meta-analysis was performed to develop equations for predicting the body macromineral composition (Ca, P, Mg, Na, and K) of Zebu, crossbred beef and dairy cattle (Table 5.13).

Table 5.10 - Prediction equations of macromineral composition in the empty body for beef cattle from the mineral composition of the section between the 9th and the 11th ribs (Adapted from Marcondes et al., 2009)

Item	Equation[1]	R^2
Calcium	$\% Ca_{EBW} = 0.7334 + 0.5029 \times \% Ca_{HH}$	0.71
Phosphorus	$\% P_{EBW} = 0.3822 + 0.4241 \times \% P_{HH}$	0.70
Magnesium	$\% Mg_{EBW} = 0.0096 + 0.6260 \times \% Mg_{HH}$	0.73
Sodium	$\% Na_{EBW} = 0.1111 + 0.2886 \times \% Na_{HH}$	0.31
Potassium	$\% K_{EBW} = 0.0357 + 0.6732 \times \% K_{HH}$	0.60

[1]Ca_{EBW} = calcium in the empty body; Ca_{HH} = calcium in the HH section; P_{EBW} = phosphorus in the empty body; P_{HH} = phosphorus in the HH section; Mg_{EBW} = magnesium in empty body; Mg_{HH} = magnesium in the HH section; Na_{EBW} = sodium in the empty body; Na_{HH} = sodium in the HH section; K_{EBW} = potassium in the empty body; K_{HH} = potassium in the HH section.

Table 5.11 - Means (kg) and descriptive statistics of the relationship between the observed and predicted values of mineral composition in the empty body of Nellore bulls

Item	Calcium		Phosphorus		Magnesium		Sodium		Potassium	
	Obs[1]	Predicted	Obs	Predicted	Obs	Predicted	Obs	Predicted	Obs	Predicted
Mean	4.37	3.00	2.83	2.91	0.12	0.14	0.42	0.39	0.60	0.41
Standard deviation	1.03	0.67	0.60	0.80	0.03	0.03	0.09	0.12	0.16	0.13
Maximum	7.15	4.66	4.25	5.47	0.17	0.20	0.61	0.68	0.90	0.71
Minimum	2.24	1.93	1.91	1.77	0.06	0.08	0.28	0.18	0.33	0.22
r	-	0.76	-	0.67	-	0.75	-	0.68	-	0.85
CCC[2]	-	0.31	-	0.64	-	0.62	-	0.62	-	0.46
Regression										
Intercept										
Estimate	-	0.85	-	1.35	-	0.03	-	0.22	-	0.19
Standard error	-	0.52	-	0.28	-	0.01	-	0.04	-	0.04
P-value[3]	-	0.11	-	< 0.001	-	0.03	-	< 0.001	-	< 0.001
Slope										
Estimate	-	1.17	-	0.51	-	0.63	-	0.53	-	1.01
Standard error	-	0.17	-	0.09	-	0.09	-	0.10	-	0.10
P-value[4]	-	0.32	-	< 0.001	-	< 0.001	-	< 0.001	-	0.92
MSE[5]	-	2.31	-	0.35	-	< 0.001	-	0.009	-	0.043
Mean bias	-	1.86	-	0.01	-	< 0.001	-	0.001	-	0.037
Systematic error	-	0.01	-	0.15	-	< 0.001	-	0.003	-	0.001
Random error	-	0.44	-	0.19	-	< 0.001	-	0.005	-	0.007

[1]Obs – observed values; [2]CCC – concordance correlation coefficient; [3]H_0: β_0=0. [4]H_0: β_1=1. [5]MSE = mean standard error.

Table 5.12 - Description of data used to generate equations to predict mineral composition of Zebu, crossbred beef and dairy cattle

Item	Mean	SD[1]	Maximum	Minimum
Zebu cattle (n=133)				
Empty body weight, kg	272	102	549	104
Ash in the HH section, %	5.56	1.63	10.3	2.74
Calcium in the empty body, %	2.23	0.90	4.75	0.89
Phosphorus in the empty body, %	0.77	0.18	1.26	0.41
Magnesium in the empty body, %	0.04	0.01	0.08	0.02
Sodium in the empty body, %	0.12	0.02	0.18	0.08
Potassium in the empty body, %	0.17	0.02	0.26	0.10
Crossbred beef cattle (n=117)				
Empty body weight, kg	344	82.6	506	192
Ash in the HH section, %	6.29	1.29	9.68	1.79
Calcium in the empty body, %	1.51	0.29	3.19	1.04
Phosphorus in the empty body, %	0.72	0.12	0.98	0.48
Magnesium in the empty body, %	0.04	0.01	0.07	0.03
Sodium in the empty body, %	0.13	0.03	0.21	0.08
Potassium in the empty body, %	0.21	0.03	0.41	0.14
Crossbred dairy cattle (n=80)				
Empty body weight, kg	318	67.9	510	195
Ash in the HH section, %	3.90	2.55	8.06	0.68
Calcium in the empty body, %	1.32	0.25	1.77	0.59
Phosphorus in the empty body, %	0.71	0.18	1.10	0.20
Magnesium in the empty body, %	0.03	0.01	0.05	0.02
Sodium in the empty body, %	0.14	0.02	0.17	0.10
Potassium in the empty body, %	0.20	0.05	0.28	0.11

Table 5.13 - Prediction equations for macromineral composition (Ca, P, Mg, Na, and K) in the empty body for Zebu, crossbred beef and dairy cattle

Item	Equation[1]	R^2
Zebu cattle		
Calcium	$\% Ca_{EBW} = 1.4557 + 0.2362 \times \% ASH_{HH} - 0.00223 \times EBW$	0.80
Phosphorus	$\% P_{EBW} = 1.0068 - 0.00099 \times EBW$	0.10
Magnesium	$\% Mg_{EBW} = 0.02859 + 0.001721 \times \% ASH_{HH} - 0.00001 \times EBW$	0.54
Sodium	$\% Na_{EBW} = 0.1213 + 0.002116 \times \% ASH_{HH} - 0.00002 \times EBW$	0.51
Potassium	$\% K_{EBW} = 0.1942 + 0.000833 \times \% ASH_{HH} - 0.0001 \times EBW$	0.22
Crossbred beef cattle		
Calcium	$\% Ca_{EBW} = 1.7028 + 0.04638 \times \% ASH_{HH} - 0.00142 \times EBW$	0.52
Phosphorus	$\% P_{EBW} = 0.4619 - 0.0404 \times \% ASH_{HH}$	0.49
Magnesium	$\% Mg_{EBW} = 0.02418 + 0.00196 \times \% ASH_{HH}$	0.34
Sodium	$\% Na_{EBW} = 0.1205 + 0.002747 \times \% ASH_{HH} - 0.00002 \times EBW$	0.56
Potassium	$\% K_{EBW} = 0.1636 + 0.007102 \times \% ASH_{HH}$	0.35
Crossbred dairy cattle		
Calcium	$\% Ca_{EBW} = 1.2445 + 0.0506 \times \% ASH_{HH} - 0.00035 \times EBW$	0.58
Phosphorus	$\% P_{EBW} = 0.7279 + 0.0333 \times \% ASH_{HH} - 0.00048 \times EBW$	0.58
Magnesium	$\% Mg_{EBW} = 0.0406 - 0.00106 \times \% ASH_{HH}$	0.06
Sodium	$\% Na_{EBW} = 0.1454 + 0.00064 \times \% ASH_{HH}$	0.05
Potassium	$\% K_{EBW} = 0.1411 + 0.01478 \times \% ASH_{HH}$	0.79

[1]Ca_{EBW} = calcium in the empty body; ASH_{HH} = ash in the HH section; EBW = empty body weight (kg); P_{EBW} = phosphorus in the empty body; Mg_{EBW} = magnesium in the empty body; Na_{EBW} = sodium in the empty body; K_{EBW} = potassium in the empty body.

The R^2 estimates for most minerals as a function of genetic group were considered satisfactory. However, the estimates of R^2 were close to zero for phosphorus and potassium in Zebu cattle, magnesium and potassium in crossbred beef cattle, and magnesium and sodium in crossbred dairy cattle, indicating that there is a tendency of constancy of these minerals in the empty body of such animals. However, it is important to highlight that these equations still need to be evaluated with an independent database to properly evaluate the effect of genetic group.

NON-CARCASS CHEMICAL COMPOSITION

As previously described, the prediction equations based on the composition of the 9th to 11th rib section for empty body chemical composition presented a better adjustment when compared with those for carcass chemical composition (Table 5.4). However, if the researcher utilizes the equations of carcass chemical composition or if the determination of the real carcass composition by dissection is required, the composition of the remaining body components (blood, hide, limbs, head, organs, and viscera) will need to be determined to ascertain the empty body chemical composition.

The determination of non-carcass chemical composition implicates, necessarily, in greater cost, time, and labor, once there are at least 4 more samples to be chemically analyzed (blood, hide, limbs + head, and organs + viscera) per animal. Carcass yield may range from 60 to 65% of the empty body weight (EBW; Costa et al., 2005; Missio et al., 2009). Thus, all non-carcass components would represent from 35 to 40% of the EBW. Hence, knowing the non-carcass chemical composition is important due to its contribution to the EBW composition.

In this context, Costa e Silva et al. (2012), aiming to reduce labor and experimental costs, developed predictive equations of the chemical composition of non-carcass components (blood, hide, limbs + head, and organs + viscera). A database composed of individual information of 335 Zebu, crossbred beef and dairy cattle were utilized. The study effect was accounted for, as well as the effects of genetic group and sex on the non-carcass components composition were evaluated during the statistical analysis.

Costa e Silva et al. (2012) observed that an adjustment for predicting the chemical composition of each non-carcass component (blood, hide, limbs, head, organs, and viscera) was necessary, and it would consequently result in too many predictive equations. Thus, to reduce the number of equations generated and simplify the estimates, the non-carcass components were grouped as head + limbs, hide + blood, and organs + viscera and new equations were generated, and previously described in the second edition of BR-CORTE (BR-CORTE, 2010).

The goodness of fit of prediction equations described by BR-CORTE (2010) were evaluated by Costa e Silva et al. (2013). These authors verified that the CP content of hide + blood was correctly estimated, whereas the EE and water equations presented adjustment problems (reproducibility and precision). In relation to head + limbs, the equations accurately estimated all chemical contents evaluated. Also, only the EE content in organs + viscera was correctly estimated. Thus, it was concluded that new equations should be developed, or so, instead of dividing the non-carcass components in three groups (hide + blood, head + limbs, and organs + viscera), a composite sample could be analyzed and generate a single equation for each chemical constituent.

In this sense, a database (Table 5.14) composed by the composition of non-carcass of 231 Zebu, 94 beef crossbred, and 180 dairy crossbred cattle (bulls, steers, and heifers) obtained from 19 thesis and dissertations (Moraes, 2006; Souza, 2009; Marcondes, 2007; Marcondes, 2010; Chizzotti, 2007; Porto, 2009; Gionbelli, 2010; Paixão, 2008; Paulino, 2006; Machado, 2009; Costa e Silva, 2011; Costa e Silva, 2015; Valente, 2013; Fonseca, 2013; Silva, 2015; Prados, 2012; Rodrigues, 2014; Zanetti, 2014; Neves, 2013) was utilized for developing new non-carcass equations in the last edition of this publication (BR-CORTE, 2016).

Table 5.14 - Description of data used to generate equations to predict non-carcass chemical composition of Zebu, crossbred beef and dairy cattle (n = 505)

Item[1]	Mean	SD[2]	Maximum	Minimum
Empty body weight, kg	302	92.2	549	80.7
Non-carcass component weight (NC), kg	112	34.0	224	31.6
Crude protein in the NC, kg	20.7	7.42	53.3	4.42
Ether extract in the NC, kg	20.4	12.5	69.9	1.89
Water in the NC, kg	65.4	17.5	134	22.5
Calcium in the NC, kg	0.80	0.62	3.57	0.04
Phosphorus in the NC, kg	0.31	0.26	1.76	0.02
Magnesium in the NC, g	16.5	8.28	50.0	2.37
Sodium in the NC, g	149	79.3	426	36.8
Potassium in the NC, g	134	62.8	324	31.4

[1]NC = non-carcass; [2]SD = standard deviation.

The prediction equations of non-carcass chemical composition were generated from the meta-analysis using the NLMIXED procedure, in which the dependent variables were regressed as a function of EBW. Also, the effects of sex and genetic group were tested, where only sex was significant for all constituents, except phosphorus and magnesium (Tables 5.15 and 5.16).

Nevertheless, they still need to be evaluated with an independent database to be widely and reliably adopted for predicting the non-carcass chemical composition for Zebu, crossbred beef and dairy cattle.

Table 5.15 - Prediction equations for non-carcass chemical composition for Zebu, crossbred beef and dairy cattle

Item	Sex	Equations[1]
Crude protein	Bulls	$CP_{NC} = 0.1675 \times EBW^{0.8434}$
	Steers	$CP_{NC} = 0.5263 \times EBW^{0.6452}$
	Heifers	$CP_{NC} = 1.2411 \times EBW^{0.4921}$
Ether extract	Bulls	$EE_{NC} = 3.7171 \times \exp^{(0.004936 \times EBW)}$
	Steers	$EE_{NC} = 4.8911 \times \exp^{(0.004671 \times EBW)}$
	Heifers	$EE_{NC} = 3.5533 \times \exp^{(0.006199 \times EBW)}$
Water	Bulls	$W_{NC} = 1.5768 \times EBW^{0.6547}$
	Steers	$W_{NC} = 3.1486 \times EBW^{0.5242}$
	Heifers	$W_{NC} = 7.3003 \times EBW^{0.3865}$

[1]CP_{NC} = crude protein in the non-carcass components (kg); EBW = empty body weight (kg); EE_{NC} = ether extract in the non-carcass components (kg); W_{NC} = water in the non-carcass components (kg).

Table 5.16 - Prediction equations for macromineral composition of non-carcass components for Zebu, crossbred beef and dairy cattle

Item	Sex	Equations
Calcium	Bulls	$Ca_{NC} = 43.71 \times EBW^{0.3510}$
	Steers	$Ca_{NC} = 5.176 \times EBW^{0.8772}$
	Heifers	$Ca_{NC} = 69.36 \times EBW^{0.4342}$
Phosphorus	-	$P_{NC} = 2.262 \times EBW^{0.4522}$
Magnesium	-	$Mg_{NC} = 10.99 \times EBW^{0.1736}$
Sodium	Bulls	$Na_{NC} = 73.65 \times EBW^{0.1181}$
	Steers	$Na_{NC} = 3.264 \times EBW^{0.6916}$
	Heifers	$Na_{NC} = 23.04 \times EBW^{0.3544}$
Potassium	Bulls	$K_{NC} = 96.43 \times EBW^{0.0673}$
	Steers	$K_{NC} = 5.147 \times EBW^{0.5781}$
	Heifers	$K_{NC} = 31.54 \times EBW^{0.2821}$

[1]Ca_{NC} = calcium in the non-carcass components (g); EBW = empty body weight (kg); P_{NC} = phosphorus in the non-carcass components (g); Mg_{NC} = magnesium in the non-carcass components (g); Na_{NC} = sodium in the non-carcass components (g); K_{NC} = potassium in the non-carcass components (g).

RELATIONSHIP BETWEEN FAT-FREE DRY MATTER AND BODY COMPOSITION

Reid et al. (1955) suggested that body EE content could be estimated from the body water content. The authors also indicated that the protein to ash ratio (protein:ash) in the body would be constant in the fat-free dry matter, being only influenced by the animal age. In this context, Marcondes et al. (2010) studied the relationship between fat-free dry matter and EBW composition utilizing a database with 272 cattle. As there were no effects of genetic group or sex on the regression parameters, Marcondes et al. (2010) proposed the following equation to estimate EE in the empty body based on water content:

$$\%EE_{EBW} = 236.21 - 126.25 \times \log(W_{EBW}) + 1.114 \times \%VF$$
$$(R^2 = 0.96; RSME = 1.26),$$

where EE_{EBW} = ether extract content in the empty body, W_{EBW} = water content in the empty body, VF = mesenteric fat, plus renal, pelvic, and cardiac fat content in the empty body.

Knowing the proportion of fat in the empty body, the protein concentration in the fat-free dry matter can be estimated as a function of the empty body mass. However, differently to Reid et al. (1955) that correlated protein:ash with age, Marcondes et al. (2010) correlated protein:ash with EBW. This happened because age can be a relative measurement of body composition, as different nutritional plans can result in different body composition at the same age. Thus, the following equation suggested by Marcondes et al. (2010) can alternatively be utilized:

$$\%CPFFDM_{EBW} = 74.09 + 0.0098 \times EBW,$$

where $CPFFDM_{EBW}$ = crude protein content in the empty body on a fat-free dry matter basis and EBW = empty body weight (kg). The ash content (%) in the empty body on a fat-free dry matter basis can be estimated as 100 – CP.

NEW METHODS TO PREDICT BODY COMPOSITION OF CATTLE

Techniques that do not require slaughtering the animal to obtain its body composition have been studied. Such techniques may be useful for cattle sorting in feedlots, reducing differences within pens regarding nutrient requirements or carcass standard, as well as to define the best time for slaughter.

Composition obtained from DXA

The use of dual energy X-ray absorptiometry (DXA) is an alternative technique to indirectly determine cattle body composition. Its application is common in human medicine aiming to evaluate the mineral composition of bone as well as fat and muscle mass. Thus, some studies have evaluated its usefulness for indirect determination of cattle carcasses composition.

In this way, Prados et al. (2016), utilizing a database with 116 observations (96 Nellore bulls and 20 Nellore × Angus bulls), developed equations (Table 5.17) to estimate the composition of the section between the 9^{th} and the 11^{th} ribs based on DXA measurements (GE Lunar Prodigy Advance Dxa System, GE Healthcare, Madison, Wisconsin, USA). After scanning, the rib sections were dissected, and their chemical compositions were compared to the DXA parameters.

Table 5.17 - Prediction equations of the chemical composition of the section between the 9^{th} and the 11^{th} ribs using dual-energy X-ray absorptiometry (DXA)

Variable[1]	Equations[2]	R^2
Ether extract	$EE_{HH} = 122.40 + 1.12 \times F_{DXA}$	0.86
Fat free tissue	$FF_{HH} = 103.22 + 0.87 \times FF_{DXA}$	0.93
Lean tissue	$LT_{HH} = 37.08 + 0.91 \times LT_{DXA}$	0.95
Ash	$A_{HH} = 18.72 + 1.02 \times BMC_{DXA}$	0.39

[1]EE_{HH} = ether extract in the HH section; F_{DXA} = fat measured by DXA; Fat free tissue = lean tissue added with ash content in the bone, FF_{HH} = fat free in the HH section (water + protein + ash); FF_{DXA} = fat free measured by DXA (LT_{DXA} + BMC_{DXA}); LT_{HH} = lean tissue in the HH section; LT_{DXA} = lean tissue measured by DXA; A_{HH} = ash in the HH section; BMC_{DXA} = bone mineral content measured by DXA; [2]All variables in grams. (Adapted from Prados et al., 2016).

Prados et al. (2016) concluded that the equations generated were accurate and are recommended for predicting the chemical composition of the section between the 9th and the11th ribs of Nellore and Nellore × Angus cattle. However, the authors also highlighted that more studies would be needed to evaluate the use of DXA to estimate carcass composition.

More recently, Godoi (2021) developed equations for predicting carcass and empty body composition based on the composition of different carcass sections and DXA measurements. For this, the half-carcass of 15 Nellore heifers was divided into seven sections (S1 to S7): S1 - longitudinal cut after the second rib; S2 - longitudinal cut after the section eighth rib; S3 - section between the 9th and 11th ribs (Hankins and Howe, 1946); S4 - the remaining section after the removal of S3; S5 - twelfth rib; S6 - longitudinal cut after the sacrum; and S7 - the remaining section after the removal of S1 to S6 (Figure 5.1).

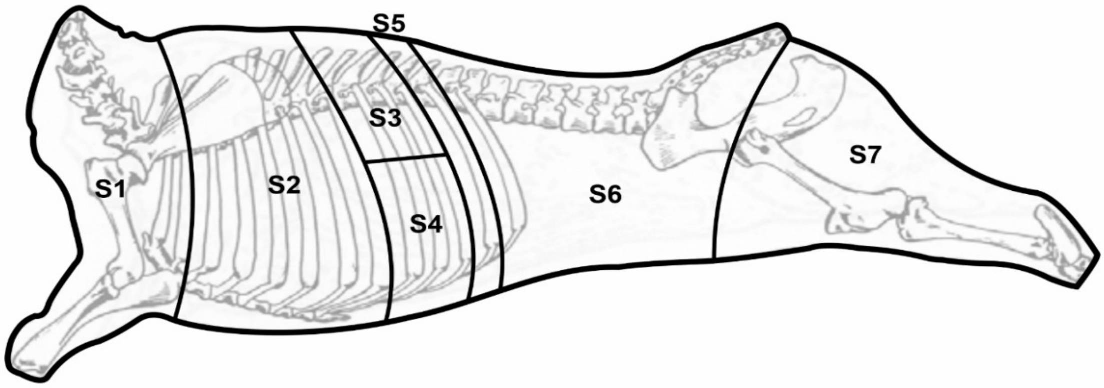

Figure 5.1 - Description of the carcass sections evaluated for predicting carcass and empty body composition of Nellore heifers, adapted from Godoi (2021).

After the scanning and obtention of DXA parameters (DXA lean mass, DXA fat mass, and DXA bone mineral content (BMC), each section was dissected into muscle, fat, and bones, and its physical composition was recorded. The muscle, fat and bones of all sections were summed to obtain the carcass physical composition. The muscle + fat and bone samples of each section were analyzed for CP, EE, and MM to obtain their chemical composition. After that, the full carcass chemical composition was calculated based on the chemical composition of each section and its relative proportions on each carcass. Samples of non-carcass components were obtained and chemically analyzed to, along with the carcass chemical composition, determine the empty body chemical composition.

Statistical procedures were performed using the SAS (Inst. Inc., Cary, NC), with the animal being the experimental unit. The physical and chemical composition of each carcass section (S1 to S7), as well as their DXA parameters (DXA lean mass, DXA fat mass, and DXA BMC) were used to predict the physical and chemical composition of the carcass and the chemical composition of the body. The Akaike's information criterion (AIC), and Swarz Bayesian information criteria (BIC) were used to determine the predictive variables that would be included in the prediction equation. The leave-one-out cross-validation method was used to develop linear predictive equations using PROC REG in the SAS (9.4) software. More details can be obtained in Godoi (2021).

The prediction equations proposed by Godoi (2021) to get the carcass physical composition of Nellore heifers using the physical composition of carcass sections are presented in Table 5.18, whereas the predictive equations of carcass physical composition based on DXA measurements can be seen in Table 5.19. S2 and S6 equations for fat content, S6 and S7 equations for muscle content, and S2 and S7 equations for bone content have shown AIC and BIC lower than the prediction equations based on other sections.

Table 5.18 - Prediction equations for the carcass physical composition of Nellore heifers using the physical composition of carcass sections, adapted from Godoi (2021)

Variable	Section	Equation[1]	R^2	RMSE[2]	AIC[3]	BIC[4]
Fat, kg	1	$Fat_{carc} = -1.599 + 4.227 \times Fat_S$	0.93	1.87	20.6	22.9
	2	$Fat_{carc} = 1.936 + 4.792 \times Fat_S$	0.97	1.22	7.72	9.67
	3	$Fat_{carc} = 3.999 + 16.96 \times Fat_S$	0.91	2.14	24.7	27.5
	4	$Fat_{carc} = 4.181 + 14.18 \times Fat_S$	0.84	2.88	33.6	36.2
	5	$Fat_{carc} = 5.013 + 20.646 \times Fat_S$	0.88	2.51	29.4	32.4
	6	$Fat_{carc} = 1.728 + 4.004 \times Fat_S$	0.98	0.91	-0.85	0.34
	7	$Fat_{carc} = -1.139 + 5.448 \times Fat_S$	0.95	1.64	16.7	19.7
Muscle, kg	1	$Musc_{carc} = -1.386 + 3.897 \times Musc_S$	0.92	2.98	34.6	36.7
	2	$Musc_{carc} = 8.867 + 4.74 \times Musc_S$	0.95	2.29	26.7	28.8
	3	$Musc_{carc} = 13.171 + 23.029 \times Musc_S$	0.79	4.86	49.3	51.6
	4	$Musc_{carc} = 14.893 + 24.93 \times Musc_S$	0.76	5.19	51.3	51.7
	5	$Musc_{carc} = 16.261 + 34.558 \times Musc_S$	0.84	4.19	44.8	47.4
	6	$Musc_{carc} = 2.775 + 5.452 \times Musc_S$	0.98	1.54	14.7	17.8
	7	$Musc_{carc} = -3.064 + 3.35 \times Musc_S$	0.99	1.22	7.83	10.6
Bone, kg	1	$Bone_{carc} = 1.169 + 2.805 \times Bone_S$	0.84	0.77	-5.99	-7.35
	2	$Bone_{carc} = 3.585 + 3.941 \times Bone_S$	0.89	0.65	-11.3	-8.25
	3	$Bone_{carc} = 4.942 + 15.774 \times Bone_S$	0.66	1.13	5.51	7.65
	4	$Bone_{carc} = 6.544 + 20.665 \times Bone_S$	0.45	1.45	12.9	13.1
	5	$Bone_{carc} = 5.06 + 38.604 \times Bone_S$	0.65	1.14	5.79	6.84
	6	$Bone_{carc} = 3.453 + 5.652 \times Bone_S$	0.77	0.92	-0.64	0.54
	7	$Bone_{carc} = -1.385 + 3.659 \times Bone_S$	0.94	0.47	-21.1	-18.6

[1]Fat_{carc}= fat in half carcass (kg); Fat_S = fat in each section (kg); $Musc_{carc}$= muscle in half carcass (kg); $Musc_S$ = Muscle in each section; $Bone_{carc}$= bones in half carcass (kg); $Bone_S$ = Bone in each section (kg);
[2]RMSE = root mean square error.
[3]AIC = Akaike's information criterion.
[4]BIC = Swarz Bayesian information criteria.

When DXA measurements were used to estimate the physical composition of the carcass, the S1 and S7 equations for fat and bone contents showed lower AIC and BIC values than those equations based on the other sections evaluated. Nevertheless, lower AIC and BIC values were observed for S2 and S7 equations for muscle content when compared to the predictive equations based on other sections. Furthermore, is it noteworthy that S7 equations presented the lowest predictive errors (RMSE) for all physical constituents evaluated using both techniques (physical composition of carcass sections and DXA measurements), except for the bone predictive equation based on the DXA measurements.

Therefore, results suggested that the carcass physical composition (fat, muscle, and bone contents) of Nellore heifers were generally better predicted by S7 equations whether by the physical composition or DXA measurements of carcass sections.

Table 5.19- Prediction equations for carcass physical composition of Nellore heifers using dual energy X-ray absorptiometry (DXA) of carcass sections, adapted from Godoi (2021)

Variable	Section	Equation[1]	R^2	RMSE[2]	AIC[3]	BIC[4]
Fat, kg	1	$Fat_{carc} = 1.954 + 4.571 \times DXAFat_S$	0.96	1.52	14.5	16.5
	2	$Fat_{carc} = 4.931 + 4.262 \times DXAFat_S$	0.91	2.19	25.4	25.6
	3	$Fat_{carc} = 3.644 + 11.983 \times DXAFat_S$	0.80	3.30	37.7	38.6
	4	$Fat_{carc} = 2.521 + 14.995 \times DXAFat_S$	0.82	3.11	35.9	37.1
	5	$Fat_{carc} = 6.801 + 13.269 \times DXAFat_S$	0.69	4.09	44.1	44.5
	6	$Fat_{carc} = 3.061 + 3.471 \times DXAFat_S$	0.91	2.15	24.8	24.9
	7	$Fat_{carc} = -1.345 + 5.148 \times DXAFat_S$	0.98	0.94	-0.10	1.84
Muscle, kg	1	$Muscle_{carc} = -7.294 + 3.374 \times DXALean_S$	0.92	3.03	35.1	37.7
	2	$Muscle_{carc} = 6.226 + 4.089 \times DXALean_S$	0.95	2.44	28.6	28.9
	3	$Muscle_{carc} = 19.313 + 21.106 \times DXALean_S$	0.44	7.96	64.1	62.7
	4	$Muscle_{carc} = 20.758 + 18.033 \times DXALean_S$	0.72	5.62	53.7	53.3
	5	$Muscle_{carc} = 26.373 + 26.327 \times DXALean_S$	0.54	7.17	60.9	59.6
	6	$Muscle_{carc} = 5.431 + 4.661 \times DXALean_S$	0.87	3.74	41.4	40.4
	7	$Muscle_{carc} = -6.644 +3.129 \times DXALean_S$	0.96	1.99	22.5	24.6
Bone, kg	1	$Bone_{car}c = 2.956 +8.865 \times DXABMC_S$	0.90	0.61	-12.8	-11.1
	2	$Bone_{carc} = 5.339 + 12.375 \times DXABMC_S$	0.81	0.85	-2.98	-0.32
	3	$Bone_{carc} = 7.718 + 23.153 \times DXABMC_S$	0.58	1.27	9.10	11.2
	4	$Bone_{carc} = 7.933 + 56.493 \times DXABMC_S$	0.43	1.48	13.5	13.7
	5	$Bone_{carc} = 8.107 + 55.587 \times DXABMC_S$	0.52	1.29	9.41	10.1
	6	$Bone_{carc} = 6.817 + 11.219 \times DXABMC_S$	0.66	1.12	5.26	6.46
	7	$Bone_{carc} = 2.518 + 9.267 \times DXABMC_S$	0.81	0.85	-3.17	-0.74

[1]Fat_{carc}= fat in half carcass (kg); $DXAFat_S$ = fat mass in each section; $Muscle_{carc}$= muscle in half carcass (kg); $DXALean_S$ = Lean mass in each section; $Bone_{carc}$= bones in half carcass (kg); $DXABMC_S$ = Bone mineral content in each section.
[2]RMSE = root mean square error.
[3]AIC = Akaike's information criterion.
[4]BIC = Swarz Bayesian information criteria.

The predictive equations of the carcass chemical composition (EE, CP, and ash) based on the chemical composition of carcass sections of Nellore heifers proposed by Godoi (2021) are shown in Table 5.20.

S1 and S2 equations for EE and CP and S1 and S7 equations for ash have shown lower values of AIC and BIC when compared to the equations based on the other sections compositions.

Table 5.20 - Prediction equations for the carcass chemical composition of Nellore heifers using the chemical composition of carcass sections, adapted from Godoi (2021)

Variable	Section	Equation[1]	R^2	RMSE[2]	AIC[3]	BIC[4]
Ether extract, kg	1	$EE_{carc} = -1.596 + 4.309 \times EE_S$	0.98	0.99	1.47	4.48
	2	$EE_{carc} = 1.372 + 4.686 \times EE_S$	0.97	1.16	6.20	8.75
	3	$EE_{carc} = 2.899 + 17.82 \times EE_S$	0.95	1.49	13.7	16.2
	4	$EE_{carc} = 2.710 + 17.686 \times EE_S$	0.91	1.99	22.4	24.7
	5	$EE_{carc} = 4.134 + 22.946 \times EE_S$	0.92	1.77	19.0	21.9
	6	$EE_{carc} = 2.500 + 4.036 \times EE_S$	0.97	1.18	6.89	8.54
	7	$EE_{carc} = -1.989 + 5.227 \times EE_S$	0.95	1.46	13.2	16.1
Crude Protein, kg	1	$CP_{carc} = 0.216 + 3.562 \times CP_S$	0.91	0.82	-4.07	-3.64
	2	$CP_{carc} = 3.120 + 4.408 \times CP_S$	0.93	0.71	-8.31	-5.92
	3	$CP_{carc} = 3.993 + 20.311 \times CP_S$	0.73	1.39	11.8	13.6
	4	$CP_{carc} = 4.290 + 22.054 \times CP_S$	0.85	1.07	3.74	6.20
	5	$CP_{carc} = 4.857 + 30.464 \times CP_S$	0.87	0.92	-0.71	2.36
	6	$CP_{carc} = 2.720 + 4.533 \times CP_S$	0.88	0.94	-0.14	0.93
	7	$CP_{carc} = -0.433 + 3.478 \times CP_S$	0.83	1.12	5.30	4.57
Ash, kg	1	$Ash_{carc} = 0.359 + 3.010 \times Ash_S$	0.88	0.28	-36.0	-35.3
	2	$Ash_{carc} = 0.871 + 4.586 \times Ash_S$	0.85	0.31	-33.4	-31.2
	3	$Ash_{carc} = 0.811 + 19.929 \times Ash_S$	0.61	0.50	-19.0	-17.3
	4	$Ash_{carc} = 1.152 + 31.700 \times Ash_S$	0.59	0.52	-18.0	-16.8
	5	$Ash_{carc} = 1.656 + 33.258 \times Ash_S$	0.51	0.55	-16.0	-15.8
	6	$Ash_{carc} = 0.957 + 5.617 \times Ash_S$	0.67	0.46	-21.6	-20.5
	7	$Ash_{carc} = 0.483 + 2.570 \times Ash_S$	0.87	0.29	-35.0	-35.9

[1]EE_{carc}= ether extract in half carcass (kg); EE_S = ether extract in each section (kg); CP_{carc}= crude protein in half carcass (kg); CP_S = crude protein in each section (kg); Ash_{carc}= Ash in half carcass (kg); Ash_S = ash in each section (kg).
[2]RMSE = root mean square error.
[3]AIC = Akaike's information criterion.
[4]BIC = Swarz Bayesian information criteria.

Similarly, the equations generated from S1 and S7 DXA measurements showed lower values of AIC and BIC for all chemical constituents evaluated (EE, CP, and ash) in relation to those equations built from other sections of DXA data (Table 5.21). Moreover, it is important to highlight that S1 equations presented the lowest RMSE for all carcass chemical constituents evaluated using both techniques (chemical composition of carcass sections or DXA measurements), except for the CP equation based on the chemical composition of its section and EE equation based on DXA measurements.

Table 5.21 - Prediction equations for carcass chemical composition of Nellore heifers using dual energy X-ray absorptiometry (DXA) of carcass sections, adapted from Godoi (2021)

Variable	Section	Equation[1]	R^2	RMSE[2]	AIC[3]	BIC[4]
Ether extract, kg	1	$EE_{carc} = 1.406 + 4.08 \times DXAFat_S$	0.95	1.51	14.3	17.0
	2	$EE_{carc} = 3.997 + 3.825 \times DXAFat_S$	0.91	1.95	21.9	21.9
	3	$EE_{carc} = 2.679 + 10.888 \times DXAFat_S$	0.81	2.83	33.0	33.6
	4	$EE_{carc} = 1.722 + 13.534 \times DXAFat_S$	0.83	2.69	31.5	32.6
	5	$EE_{carc} = 5.474 + 12.146 \times DXAFat_S$	0.71	3.50	39.4	40.1
	6	$EE_{carc} = 2.121 + 3.159 \times DXAFat_S$	0.94	1.59	15.8	14.9
	7	$EE_{carc} = -1.533 + 4.593 \times DXAFat_S$	0.97	1.08	4.05	6.98
Crude protein, kg	1	$CP_{carc} = -0.886 + 0.872 \times DXALean_S$	0.93	0.70	-8.98	-6.57
	2	$CP_{carc} = 3.144 + 1.000 \times DXALean_S$	0.86	1.01	2.01	0.69
	3	$CP_{carc} = 6.307 + 5.193 \times DXALean_S$	0.40	2.09	24.0	22.8
	4	$CP_{carc} = 6.793 + 4.337 \times DXALean_S$	0.63	1.64	16.7	16.0
	5	$CP_{carc} = 7.771 + 6.875 \times DXALean_S$	0.56	1.80	19.4	16.7
	6	$CP_{carc} = 2.916 + 1.144 \times DXALean_S$	0.80	1.21	7.46	6.26
	7	$CP_{carc} = -0.226 + 0.779 \times DXALean_S$	0.91	0.81	-4.49	-4.21
Ash, kg	1	$Ash_{carc} = -0.162 + 3.635 \times DXABMC_S$	0.89	0.27	-37.8	-35.9
	2	$Ash_{carc} = 0.703 + 5.29 \times DXABMC_S$	0.86	0.30	-34.6	-32.7
	3	$Ash_{carc} = 1.717 + 9.917 \times DXABMC_S$	0.62	0.50	-19.2	-17.7
	4	$Ash_{carc} = 1.778 + 24.665 \times DXABMC_S$	0.48	0.59	-14.6	-14.7
	5	$Ash_{carc} = 1.900 + 23.564 \times DXABMC_S$	0.55	0.54	-16.9	-16.9
	6	$Ash_{carc} = 1.426 + 4.591 \times DXABMC_S$	0.65	0.48	-20.4	-19.8
	7	$Ash_{carc} = -0.499 + 3.598 \times DXABMC_S$	0.87	0.29	-35.5	-32.9

[1]EE_{carc}= ether extract in half carcass (kg); $DXAFat_S$ = fat mass in each section; CP_{carc}= crude protein in half carcass (kg); $DXALean_S$ = Lean mass in each section; Ash_{carc}= ash in half carcass (kg); $DXABMC_S$ = Bone mineral content in each section.
[2]RMSE = root mean square error.
[3]AIC = Akaike's information criterion.
[4]BIC = Swarz Bayesian information criteria.

The prediction equations proposed by Godoi (2021) for the empty body chemical composition of Nellore heifers using the chemical composition of carcass sections or DXA measurements are presented in Table 5.22 and 5.23, respectively. The lowest values of AIC and BIC were observed for S1 and S2 equations when using the chemical composition of carcass sections for predicting the contents of EE, CP, and ash in the empty body, whereas S1 and S7 presented the lowest AIC and BIC values when DXA measurements were used for predicting the same chemical components in the empty body.

Table 5.22 - Prediction equations for the empty body chemical composition of Nellore heifers using the chemical composition of carcass sections, adapted from Godoi (2021)

Variable	Section	Equation[1]	R^2	RMSE[2]	AIC[3]	BIC[4]
Ether extract, kg	1	$EE_{EBW} = 0.249 + 12.717 \times EE_S$	0.94	4.75	48.6	51.4
	2	$EE_{EBW} = 8.089 + 14.122 \times EE_S$	0.97	3.22	36.9	38.3
	3	$EE_{EBW} = 13.562 + 52.524 \times EE_S$	0.91	5.91	55.2	57.0
	4	$EE_{EBW} = 12.12 + 53.302 \times EE_S$	0.91	5.79	54.5	57.7
	5	$EE_{EBW} = 17.113 + 67.93 \times EE_S$	0.90	6.33	57.2	59.6
	6	$EE_{EBW} = 12.239 + 11.938 \times EE_S$	0.94	4.99	50.0	52.2
	7	$EE_{EBW} = -0.978 + 15.444 \times EE_S$	0.92	5.66	53.8	56.3
Crude Protein, kg	1	$CP_{EBW} = -2.258 + 12.68 \times CP_S$	0.86	3.73	41.3	42.7
	2	$CP_{EBW} = 7.967 + 15.744 \times CP_S$	0.88	3.41	38.6	39.6
	3	$CP_{EBW} = 10.124 + 74.84 \times CP_S$	0.74	4.98	50.0	51.8
	4	$CP_{EBW} = 12.648 + 77.433 \times CP_S$	0.78	4.51	47.1	49.7
	5	$CP_{EBW} = 14.32 + 108.439 \times CP_S$	0.81	4.29	45.5	48.4
	6	$CP_{EBW} = 6.473 + 16.221 \times CP_S$	0.84	3.95	43.1	44.3
	7	$CP_{EBW} = -3.991 + 12.225 \times CP_S$	0.76	4.84	49.2	47.0
Ash, kg	1	$Ash_{EBW} = 4.198 + 6.238 \times Ash_S$	0.70	1.01	2.10	3.14
	2	$Ash_{EBW} = 5.134 + 9.726 \times Ash_S$	0.72	0.97	1.08	3.47
	3	$Ash_{EBW} = 4.67 + 44.782 \times Ash_S$	0.58	1.18	6.83	9.12
	4	$Ash_{EBW} = 5.594 + 69.094 \times Ash_S$	0.52	1.18	6.88	8.85
	5	$Ash_{EBW} = 6.359 + 78.81 \times Ash_S$	0.52	1.27	9.09	9.66
	6	$Ash_{EBW} = 5.076 + 12.45 \times Ash_S$	0.62	1.15	6.07	7.14
	7	$Ash_{EBW} = 4.51 + 5.279 \times Ash_S$	0.69	1.04	2.94	2.62

[1]EE_{EBW}= ether extract in empty body (kg); EE_S = ether extract in each section (kg); CP_{EBW}= crude protein in empty body (kg); CP_S = crude protein in each section (kg); Ash_{EBW}= ash in empty body (kg); Ash_S = ash in each section (kg).
[2]RMSE = root mean square error.
[3]AIC = Akaike's information criterion.
[4]BIC = Swarz Bayesian information criteria.

Therefore, the results of Godoi (2021) suggested that S1 equations, built from the chemical composition and DXA measurements of carcass section, generally better estimated all chemical components of the carcass and the empty body of Nellore heifers when compared to the other sections evaluated.

Although S1 equations did not exhibit the lowest values of AIC and BIC for most of carcass physical components among the other sections evaluated, they have shown good precision with values of R^2 between 84.3% and 95.6%, suggesting that perhaps it would also be reasonable to estimate the carcass physical composition of Nellore heifers through this section equations.

Table 5.23 - Prediction equations for the empty body chemical composition of Nellore heifers using dual energy X-ray absorptiometry (DXA) of carcass sections, adapted from Godoi (2021)

Variable	Section	Equation[1]	R^2	RMSE[2]	AIC[3]	BIC[4]
Ether extract, kg	1	$EE_{EBW} = 8.305 + 12.264 \times DXAFat_S$	0.95	4.57	47.4	49.7
	2	$EE_{EBW} = 16.301 + 11.431 \times DXAFat_S$	0.90	6.21	56.6	55.0
	3	$EE_{EBW} = 11.804 + 32.993 \times DXAFat_S$	0.83	8.22	65.1	65.4
	4	$EE_{EBW} = 8.974 + 40.948 \times DXAFat_S$	0.84	7.79	63.4	63.4
	5	$EE_{EBW} = 21.198 + 35.742 \times DXAFat_S$	0.68	11.0	73.8	73.8
	6	$EE_{EBW} = 11.311 + 9.301 \times DXAFat_S$	0.90	6.16	56.4	54.5
	7	$EE_{EBW} = -0.462 + 13.789 \times DXAFat_S$	0.97	3.41	38.6	40.7
Crude protein, kg	1	$CP_{EBW} = -8.92 + 3.283 \times DXALean_S$	0.99	1.23	8.07	10.8
	2	$CP_{EBW} = 7.014 + 3.683 \times DXALean_S$	0.87	3.57	30.0	39.9
	3	$CP_{EBW} = 16.539 + 20.902 \times DXALean_S$	0.48	7.12	60.7	59.8
	4	$CP_{EBW} = 19.301 + 16.844 \times DXALean_S$	0.71	5.36	52.2	52.1
	5	$CP_{EBW} = 24.387 + 24.845 \times DXALean_S$	0.54	6.68	58.8	57.3
	6	$CP_{EBW} = 5.163 + 4.333 \times DXALean_S$	0.86	3.75	41.5	41.1
	7	$CP_{EBW} = -5.5946 + 2.88 \times DXALean_S$	0.93	2.70	31.7	32.2
Ash, kg	1	$Ash_{EBW} = 2.252 + 8.403 \times DXABMC_S$	0.89	0.61	-13.0	-10.0
	2	$Ash_{EBW} = 4.478 + 11.793 \times DXABMC_S$	0.81	0.82	-4.19	-1.77
	3	$Ash_{EBW} = 6.946 + 20.936 \times DXABMC_S$	0.52	1.27	9.04	10.5
	4	$Ash_{EBW} = 6.202 + 64.855 \times DXABMC_S$	0.62	1.12	5.15	6.79
	5	$Ash_{EBW} = 7.075 + 53.605 \times DXABMC_S$	0.54	1.21	7.56	7.08
	6	$Ash_{EBW} = 5.694 + 11.129 \times DXABMC_S$	0.71	0.97	1.01	2.82
	7	$Ash_{carc} = 1.216 + 9.407 \times DXABMC_S$	0.92	0.50	-18.8	-15.9

[1] EE_{EBW}= ether extract in empty body (kg); $DXAFat_S$ = fat mass in each section; CP_{EBW}= crude protein in empty body (kg); $DXALean_S$ = Lean mass in each section; Ash_{EBW}= ash in empty body (kg); $DXABMC_S$ = Bone mineral content in each section.
[2] RMSE = root mean square error.
[3] AIC = Akaike's information criterion.
[4] BIC = Swarz Bayesian information criteria.

Nevertheless, it is important to highlight that most of the predictive equations generated for the physical and chemical composition of the carcass and chemical composition of the empty body presented high R^2 values whether built from carcass sections compositions or DXA measurements. Thus, based on the R^2 values, the physical and chemical composition of the carcass and the empty body chemical composition could be estimated by any of the evaluated carcass sections (S1 to S7), allowing the choice of the section according to the needs of each study. However, it is worth mentioning that the precision and accuracy of the estimates may vary depending on the carcass section chosen.

FINAL CONSIDERATIONS

The equations proposed in the last editions of this publication (BR-CORTE, 2010; BR-CORTE, 2016) were validated, and thus, are recommended for predicting the carcass and empty body composition of Zebu and crossbred beef and dairy cattle as a replacement for carcass dissection, resulting in reduced costs and labor.

Furthermore, the use of prediction equations for non-carcass components seems to be an accurate approach. Also, new methods, such as DXA, represent promising alternatives to predict body composition of cattle. However, more studies should be conducted to increase accuracy and to evaluate these equations using an independent database before being widely and reliably adopted.

REFERENCES

Alleoni, G. F.; Boin, C.; Leme, P. R.; Vieira, P. F.; Nardon, R. F.; Demarchi, J. J. A. A.; Otsuk, I. P.; Avaliação da gravidade específica e de outras medidas corporais e da carcaça para estimar a composição corporal de novilhos Nelore. *Revista Brasileira de Zootecnia*, 26:375-381, 1997.

BR-CORTE. Valadares Filho, S. C.; Costa e Silva, L. F., Gionbelli, M. P., Rotta, P. P., Marcondes, M. I., Chizzotti, M. L. *Nutrient Requirements of Zebu Beef Cattle – BR-CORTE*, 3 ed. – Viçosa: UFV, DZO. 193 p. 2016.

BR-CORTE. Valadares Filho, S. C.; Marcondes, M. I.; Chizzotti, M. L.; Paulino, P. V. R. *Nutrient Requirements of Zebu and crossbred cattle – BR-CORTE*, 2 ed. – Viçosa: UFV, DZO. 193 p. 2010.

BR-CORTE. Valadares Filho, S. C.; Paulino, P. V. R.; Magalhães, K. A. *Exigências Nutricionais de Zebuínos e Tabelas de Composição de Alimentos – BR-CORTE*. 1. ed. – Viçosa: UFV, DZO. 142p. 2006.

Butterfield, R. M., & Berg, R. T. (1966). A classification of bovine muscles, based on their relative growth patterns. *Research in Veterinary Science*, 7(3), 326-332.

Chizzotti, M. L. *Exigências nutriticionais de animais Nelore, puros e cruzados, de diferentes classes*. 2007. Tese (Doutorado em Zootecnia) Universidade Federal de Viçosa, Viçosa-MG. 101p. 2007.

Cole, J. W.; Ramsey, C. B.; Epley, R. H. Simplified method for predicting pounds of lean in beef carcasses. *Journal of Animal Science*, 21:355-361, 1962.

Costa E Silva L. F.; Marcondes, M. I.; Valadares Filho, S. C.; Ribeiro, A. M. F.; Prados, L. F.; Nascimento, F. B.; Gionbelli, M. P.; Santos. R. M. Prediction of non-carcass components in cattle. *Revista Brasileira de Zootecnia*, 41:907-1914, 2012.

Costa E Silva L. F.; Valadares Filho, S. C.; Detmann, E.; Marcondes, M. I.; Rotta, P. P.; Prados, L. F.; Zanetti, D. Evaluation of equations to predict body composition in Nellore bulls. *Livestock Science*, 151:46–57, 2013.

Costa E Silva, L.F. 2015. *Mineral requirements for Nellore cattle and equations to predict milk yield and dry matter intake for lactating Nellore cows and suckling Nellore calves*. 2015. Tese (Doutorado em Zootecnia) – Universidade Federal de Vicosa, Vicosa, MG. 2015.

Costa e Silva, L.F. *Exigências nutricionais, validação de equações para a estimação da composição do corpo vazio e uso da creatinina para estimar a proporção de tecido muscular em bovinos Nelore*. Dissertação (Mestrado em Zootecnia) – Universidade Federal de Viçosa, 126p, 2011.

Costa, M. A. L; Valadares Filho, S. C.; Paulino, M. F.; Valadares, R. F. D.; Cecon, P. R.; Paulino, P. V. R.; Moraes, E. H. B. K.; Magalhães K. A. Desempenho, digestibilidade e características de carcaça de novilhos Zebuínos alimentados com dietas contendo diferentes níveis de concentrado. *Revista Brasileira de Zootecnia*, 34:268-279, 2005.

Clark, J. L.; Hedrick, H. B.; Thompson. G. B. Determination of body composition of steers by ^{40}K. *Journal of Animal Science,* 42:352-356, 1976.

Crouse, J. D.; Dikeman, M. E. Methods of estimating beef carcass chemical composition. *Journal of Animal Science*, v.38, n.6, p.1190-1196, 1974.

Duchesne, C.; Macgregor, J. F. Jackknife and bootstrap methods in the identification of dynamic models. *Journal of Process Control*, 11:553–564, 2001.

Ferreira, M. A.; Valadares Filho, S. C.; Veras, A. S. C.; Araújo, G. G. L.; Signoretti, R. D. Predição da composição corporal por intermédio de método indireto. *Revista Brasileira de Zootecnia,* 30:242-246, 2001.

Ferrell, C. L.; Kohlmeier, R. H.; Crouse, J. D.; Glimp, H. Influence of dietary energy and protein biological type of steer upon rate of gain and carcass characteristics. *Journal of Animal Science,* 46:255-270, 1978.

Fonseca, M. A.; Valadares Filho, S. C.; Tedeschi, L. O.; Chizzotti, M. L.; Machado, M. G.; Abreu, D. C. 2014. Evaluation of predictive equations developed to assess body composition of F1 Nellore x Angus bulls and steers. *Animal Production Science*.

Gionbelli, M. P. (2010). *Desempenho produtivo e exigências nutricionais de fêmeas Nelore em crescimento.* Dissertação (Mestrado em Zootecnia) – Universidade Federal de Viçosa, 106 p, 2010.

Godoi, L. A. *Corn processing in feedlot diets for Nellore cattle: intake, digestion sites and different techniques to estimate digestibility; and nutritional requirements and body composition of Nellore heifers by dual-energy X-ray absorptiometry or by carcass sections*. 2021. Tese (Doutorado em Zootecnia) – Universidade Federal de Vicosa, Vicosa, MG. 2021.

Gonçalves, L. C.; Silva, J. F. C.; Oliveira, A. I. G.; Castro, A. C. G. Métodos para determinação da composição corporal e estudo da área corporal de novilhos. *Revista Brasileira de Zootecnia,* 20:405-412, 1991.

Hankins, O. G.; Howe, P. E. *Estimation of the composition of beef carcasses and cuts*. USDA, p. 1-20 (Technical Bulletin). 1946.

Henrique, W.; Sampaio, A. A. M.; Leme, P. R.; Alleoni, G. F.; Lanna, D. P. D. Estimativa da composição química corporal de tourinhos Santa Gertrudis a partir da composição química e física das 9-10-11ª costelas. *Revista Brasileira de Zootecnia*, 32:709-718, 2003.

Jorge, A. M.; Fontes, C. A. A.; Paulino, M. F.; Gomes Junior, P. Utilização de método indireto para predição da composição química corporal de zebuínos. *Revista Brasileira de Zootecnia,* 29:1862-1867, 2000.

Kraybill, H. F.; Bitter, H. L.; Hankins, O. G. Body composition of cattle. II. Determination of fat and water content from measurement of body specific gravity. *Journal of Applied Physiology*, 4:575-583, 1952.

Lanna, D. P. D.; Boin, C.; Alleoni, G. F.; Leme, P. R. Estimativa da composição química corporal de tourinhos Nelore através da gravidade específica. *Revista Brasileira de Zootecnia,* 24:351-362, 1995.

Lush, J. L. 1926. Practical methods of estimating proportions of fat and bone in cattle slaughtered in commercial packing plants. *Journal of Agriculture Research,* 57:79-97.

Machado, P. A. S. *Desempenho produtivo e exigências nutricionais de bovinos de corte em pastagem de brachiaria decumbens, suplementados no período de transição águas-secas.* Tese (Doutorado em Zootecnia) – Universidade Federal de Viçosa, 73 p, 2009.

Marcondes, M. I. 2010. *Exigências nutricionais e predição da composição corporal de bovinos nelore puros e cruzados*. Tese (Doutorado em Zootecnia) - Universidade Federal de Viçosa, Viçosa, MG, Brazil. 248p.

Marcondes, M. I. *Desempenho de bovinos Nelore alimentados individualmente ou em grupo, exigências nutricionais e avaliação proteica de alimentos para ruminantes*. Dissertação (Mestrado em Zootecnia) – Universidade Federal de Viçosa, 36 p, 2007.

Marcondes, M. I.; Valadares Filho, S. C.; Paulino, P. V. R.; Detmann, E.; Valadares, R. F. D.; Santos, T. R.; Diniz, L. L. Predição da composição corporal e da carcaça a partir da seção entre a 9a e 11a costelas em bovinos Nelore. *Revista Brasileira de Zootecnia*, 38:1597–1604, 2009.

Marcondes, M. I.; Chizzotti, M. L.; Valadares Filho, S. C.; Tedeschi, L. O. 2010. Prediction of Nellore empty body composition using indirect measurements. In: SAUVANT, D.(Ed). *Proceedings of Modeling nutrient digestion and utilization in farm animals*. 1.ed. Paris, FR: EAAP Publisher.

Marcondes, M. I.; Tedeschi, L. O.; Valadares Filho, S. C.; Chizzotti, M. L. Prediction of physical and chemical body compositions of purebred and crossbred Nellore cattle using the composition of a rib section. *Journal of Animal Science,* 90:1280–1290, 2012.

Missio, R. L.; Brondani, I. L.; Restle, J.; Silva, J. H. S.; Silveira, M. F.; Silva, V. S. Partes não-integrantes da carcaça de tourinhos alimentados com diferentes níveis de concentrado na dieta. *Revista Brasileira de Zootecnia*, 38:906-915, 2009.

Moraes, E. H. B. K. D. (2006). *Desempenho e exigências de energia, proteína e minerais de bovinos de corte em pastejo, submetidos a diferentes estratégias de suplementação*. Tese (Doutorado em Zootecnia) - Universidade Federal de Viçosa, Viçosa - MG. 2006.

Moulton, C. R. 1923. Age and chemical development in mammals. *Journal of Biological Chemistry,* 57:79-97.

Neves, M. L. M. W. 2013. *Exigências nutricionais e componentes não carcaça de bovinos mestiços leiteiros*. Tese (Doutorado em Zootecnia) – Universidade Federal Rural de Pernambuco, Recife, PE, Brazil. 150p.

Nour, A. Y. M.; Thonney, M. L.; Stouffer, J. R.; White Jr, W. R. C. Muscle, fat and bone in serially slaughtered large dairy or small beef cattle fed corn or corn silage diets in one of two locations. *Journal of Animal Science,* 52:512-521. 1981.

Nour, A. Y. M.; Thonney, M. L. Carcass soft tissue and bone composition of early and late maturing steers fed two diets in two housing types and serially slaughtered over a wide weight range. *Journal of Agricultural Science,* 109:345-356, 1987.

Nour, A. Y. M.; Thonney, M. L. Technical Note: Chemical composition of Angus and Holstein carcasses predicted from rib section composition. *Journal of Animal Science*, 72:1239-1241, 1994.

Paixão, M. L. *Desempenho produtivo e exigências nutricionais de bovinos de corte em pastagens de brachiaria decumbens com suplementação proteica*. Tese (Doutorado em Zootecnia) – Universidade Federal de Viçosa, 110p, 2008.

Panaretto, B. A.; Till, A. R. Body composition in vivo. II. The composition of mature goats and its relationship to the antiprine, tritiated water, and N-acetyl-4-aminoantipyrine spaces. *Australian Journal of Agricultural Reseach*, 14:926-943, 1963.

Paulino, P. V. R. 2002. *Exigências nutricionais e validação da seção HH para predição da composição corporal de zebuínos*. 2002. 150p. Dissertação (Mestrado em Zootecnia) – Universidade Federal de Viçosa, Viçosa-MG.

Paulino, P. V. R.; Costa, M. A. L.; Valadares Filho, S. C.; Paulino, M. F.; Valadares, R. F. D.; Magalhães, K. A.; Detmann, E.; Porto, M. O.; Moraes, K. A. K. Validação das equações desenvolvidas por Hankins e Howe para predição da composição da carcaça de Zebuínos e desenvolvimento de equações para estimativa da composição corporal. *Revista Brasileira de Zootecnia*, 34:327-339, 2005a.

Paulino, P. V. R.; Valadares Filho, S. C.; Costa, M. A. L.; Paulino, M. F.; Magalhães, K. A.; Detmann, E.; Valadares, R. F. D.; Porto, M. O.; Moraes, K. A. K. Validation of the 9-11th rib cut to estimate the chemical composition of the dressed carcass and of the whole empty body of Zebu cattle. *Livestock Production Science*, 93:245-253, 2005b.

Paulino, P. V. R. 2006. *Desempenho, composição corporal e exigências nutricionais de bovinos Nelore de diferentes classes sexuais*. Viçosa. Universidade Federal de Viçosa, 159p. Tese (Doutorado em zootecnia).

Prados, L. F., Zanetti, D., Amaral, P. M., Mariz, L. D. S., Sathler, D. F. T., Valadares Filho, S. C., Silva, F. F., Silva, B. C., Pacheco, M. C., Meneguelli, H. A., Chizzotti, M. L. Techinical note: Prediction of chemical rib section composition by dual energy x-ray absorptiometry in Zebu beef cattle. *Journal of Animal Science*, 94:2479-2484, 2016.

Peron, A. J.; Fontes, C. A. A.; Lana, R. P.; Queiroz, A. C.; Silva, D. J.; Freitas, J. A. Predição da composição corporal e da carcaça de bovinos através de métodos indiretos. *Revista Brasileira de Zootecnia*, 22:227-237, 1993.

Porto, M. O. *Multiples supplements to beef cattle in calves, growing and finishing, in pasture of Brachiaria decumbens.* Tese (Doutorado em Zootecnia) – Universidade Federal de Viçosa, 159 p, 2009.

Powell, W. E.; Huffman, D. L. Predicting chemical composition of beef carcasses from easily obtainable carcass variables. *Journal of Animal Science*, 36:1069-1076, 1973.

Prados, L. F. 2012. *Desempenho e exigências nutricionais de bovinos alimentados com dietas contendo diferentes níveis de cálcio e fósforo.* Dissertação (Mestrado em Zootecnia) – Universidade Federal de Viçosa, Viçosa, MG, Brazil. 97p.

Preston, R. L.; Kock, S. W. *In vivo prediction of body composition in cattle from urea space measurements*. In: Proceedings of the society for experimental biology and medicine, 1057-1061, 1973.

Prior, R. L.; Kohlmeier, R. H.; Cundiff, L. V.; Dikeman, M. E.; Crouse, J. D. Influence of dietary energy and protein on growth and carcass composition in different biological types of cattle. *Journal of Animal Science*, 45:132-146, 1977.

Reid, J. T.; Wellington, G. H.; Dunn, H. O. Some relationships among the major chemical components of the bovine body and their application to nutritional investigations. *Journal of Dairy Science,* 38:1344-1359, 1955.

Rodrigues, F. C. 2014. *Turnover proteíco, avaliação e predição da composição química e do corpo vazio de bovinos ¾ Zebu x ¼ Holandês*. Dissertação (Mestrado em Zootecnia) – Universidade Federal de Viçosa, Viçosa, MG, Brazil. 44p.

Silva, F. F. 2001. *Desempenho, características de carcaça, composição corporal e exigências nutricionais (de energia, proteína, aminoácidos e macrominerais) de novilhos Nelore, nas fases de recria e engorda, recebendo diferentes níveis de concentrado e proteína*. 2001. (Dissertação) – Universidade Federal de Viçosa, Viçosa, MG.

Silva, F. A. S. 2015. *Desempenho, produção de metano entérico, eficiência de utilização da energia, metabolismo protéico muscular e exigências nutricionais de novilhas Holandês x Zebu alimentadas com silagem de milho ou cana-de-açúcar em duas proporções*. Dissertação (Mestrado em Zootecnia) – Universidade Federal de Viçosa, Viçosa, MG, Brazil. 82p.

Silva F. A. S, Valadares Filho S. C., Costa e Silva L. F., Fernandes J. G., Lage B. C., Chizzotti M. L., Felix T. L. Nutrient requirements and evaluation of equations to predict chemical body composition of dairy crossbred steers. *Animal Bioscience*, 34:558-566, 2021. doi: 10.5713/ajas.19.0829.

Souza, E. J. 2010. *Desempenho e exigências nutricionais de fêmeas Nelore, F1 Nagus x Nelore e F1 Simental × Nelore em dietas contendo alto e baixo nível de concentrado.* Tese (Doutorado em Zootecnia) – Universidade Federal Rural de Pernambuco, Pernambuco, 2010.

Trowbridge, P. F.; Haigh, L. D. Studies in animal nutrition. I. *Changes in form and weight on different planes of nutrition.* Montana Agriculture Experimental Station. 111p. (Research Bulletin, 54). 1921.

Trowbridge, P. F., Haigh, L. D. Studies in animal nutrition. II. Changes in *proportions of carcass and offal on different planes of nutrition.* Montana Agriculture Experimental Station. 111p. (Research Bulletin, 43). 1922.

Valente, E. E. L. *Suplementação de bovinos de corte em pastejo com diferentes relações proteína:carboidrato da fase de amamentação ao abate*. Tese (Doutorado em Zootecnia) – Universidade Federal de Vicosa, Vicosa, MG, 2012.

Véras, A. S. C.; Valadares Filho, S. C.; Silva, J. F. C.; Paulino, M. F.; Cecon, P. R.; Valadares, R. F. D.; Ferreira, M. A.; Silva, C. M.; Silva, B. C. Predição da composição química corporal de bovinos Nelore e F1 Simental × Nelore a partir da composição química da seção Hankins e Howe (seção HH). *Revista Brasileira de Zootecnia*, 30:1112-1119, 2001.

Williams, J. E.; Wagner, D. G.; Walters, L. E.; Horn, G.W.; Waller, G. R.; Sims, P. L.; Guenther, J. J. Effect of production systems on performance, body composition and lipid and mineral profiles of soft tissue in cattle. *Journal of Animal Science*, 57:1020-1028, 1983.

Zanetti, D. 2014. *Exigências nutricionais, frequência de alimentação e níveis de cálcio e fósforo para bovinos Holandês x Zebu em confinamento.* Dissertação (Mestrado em Zootecnia) – Universidade Federal de Viçosa, Viçosa, MG, Brazil. 78p.