http://dx.doi.org/10.26626/978-85-8179-194-4.2023.C006.p.135-158

6

Prediction of carcass weight, backfat thickness, and body weight loss during the transport of beef cattle

Flávia Adriane de Sales Silva, Pedro del Bianco Benedeti, Breno de Castro Silva, Gutierrez José de Freitas Assis, Débora Evelyn de Freitas Assis, Victor Graciliano Luccas da Fonseca , Dhones Rodrigues de Andrade, Sebastião de Campos Valadares Filho, Mario Luiz Chizzotti

INTRODUCTION

Regardless of the type of operation (cow-calf, stocker/backgrounding, finishing, or whole production cycle), the beef cattle producer's ultimate goal is meat production. Thus, their participation in the beef supply chain usually ends when the animal is slaughtered, with payment based on carcass weight (CW). However, the expected carcass yield (CY) often generates disagreements between producers and slaughterhouses.

Producers often complain about the large variations in CY observed for cattle of similar type that were weighted under the same conditions at the farm prior to transportation, as well as regarding the disparities in CY obtained in different slaughterhouses. For most producers, the lower CY obtained in some slaughterhouses would be related to carcass dressing practices and/or problems with carcass weighing. On the other hand, slaughterhouses argue that lower CY may be due to on-farm weighing errors, management, and transport problems (e.g., long distance transport and bruising), lower finishing grade (carcass backfat), and cattle type (e.g., dairy crossbred).

In general, the carcass consists of muscle, bone, and fat after the removal of the head, hide, internal organs, peri-renal and inguinal fat, legs, tail, genitals, mammary gland (females), tissue damaged by exsanguination, spinal cord, and diaphragm (Pascoal et al., 2011; MAPA, 1989). Moreover, in some slaughter plants, there is also the removal of other carcass constituents such as the hump (when present) and tissues associated to the penis insertion in males, influencing the final CW and, consequently, the CY. Thus, the large variations in CY reported by producers may also be related to specific dressing procedures performed at different slaughter plants. In this context, several factors can affect CY, such as genotype, gender, nutrition, slaughter body weight (BW), and pre-slaughter management and transportation.

Minimal requirements of slaughterhouses regarding carcass quality include CW above 180 kg for females and 225 kg for bulls and steers (Assis, 2021). Nevertheless, carcasses with better quality traits (e.g., greater finishing grade and marbling) may be directed to specific markets and generate greater remuneration to producers. In many countries, beef carcasses are usually commercialized based on CW and cattle genotype, gender, and age at slaughter. Other factors such as conformation, meat and fat color, finishing grade, marbling, and pH may also be considered when defining carcass quality and its respective remuneration (Costa et al., 2002; Arboitte et al., 2004; Gomide et al., 2014).

In this context, the backfat thickness (BFT), typically measured between the 12th and the 13th ribs, is an important indicator of carcass quality, and it is positively correlated with CY and carcass adiposity and fat finishing grade (Berg and Butterfield, 1976; Tarouco et al., 2005; Silva et al., 2006). Moreover, adequate BFT is necessary to prevent CW losses, fast drop in carcass temperature, and meat darkening during the chilling process, allowing a better visual presentation of meat cuts and their sensorial characteristics (Luchiari Filho, 2000; Vaz and Restle, 2000; Moreira et al., 2018). On the other hand, excess of backfat is also detrimental to carcass quality, as excessive backfat deposition is usually associated with reduced beef cuts yield and increased operational costs due to the severe trimming required (Abraham et al., 1968; Costa et al., 2002; Neto et al., 2010). Thus, BFT of 3 to 6 mm is usually required by slaughterhouses (Luchiari Filho, 2000). In general, beef carcasses that do not meet the required BFT may be subject to pricing penalties.

However, CW, and consequently CY, as well as BFT are usually measured after slaughtering the animals, not allowing management adjustments within the productive cycle. In this sense, providing alternative methods for predicting these characteristics *in vivo* may enable producers to better define management strategies and the correct slaughter point aiming to produce carcasses of greater quality and remuneration, as well as with reduced production costs. Therefore, the committee of the current edition of the BR-CORTE proposed a new chapter to discuss the main factors that influence cattle CY and composition. Subsequently, equations for predicting CW and BFT are presented, as well as a study regarding the body weight loss during transport of beef cattle.

FACTORS INFLUENCING CARCASS YIELD AND COMPOSITION

Genotype and gender

Cattle from different genotypes and genderes present differences regarding their potential for meat production, body weight at maturity (matBW), BW gain rate, and composition of weight gain (Berg and Butterfield, 1976; Valadares Filho et al., 2016). In general, continental *Bos taurus taurus* breeds (e.g., Simmental and Charolais) present large frame and mature size (late precocity), *Bos taurus indicus* breeds (e.g, Nellore) present medium frame size and intermediate precocity, and British *Bos taurus taurus* breeds (e.g, Angus and Hereford) present small frame size and early precocity.

At the same BW, late maturity-breed cattle usually present greater BW gain rates and proportionally deposit more muscle and less fat in the carcass compared to early maturity-breed cattle (Nour et al., 1983; Hassen et al., 1998; Williams et al., 2010). In this sense, differences in CY among genotypes are commonly observed when the time of slaughter is determined by the carcass finishing degree, as larger frame size cattle present desired finishing grade at higher BW and, consequently, have greater CY (Camfield et al., 1996; Euclides Filho et al., 1997; Clímaco et al., 2011).

In relation to the genetic composition, the breed can also interfere in CY. At the same BW, beef cattle carcasses (such as Angus) have greater soft tissue to bone ratio, and proportionally more fat than dairy cattle carcasses (such as Holstein; Nour et al., 1981; Nour et al., 1983). These differences are likely because genetic selection in dairy cattle has been focused on milk production rather than tissue deposition. Thus, cattle from breeds that were genetically selected for beef production, at same BW, have greater CY than those selected for milk production (Nour et al., 1981; Bertrand et al., 1983; Nour et al., 1983).

The association of desirable characteristics from two or more breeds (heterosis) through crossbreeding also modifies the growth and conformation pattern of crossbred cattle when compared to those from the purebreds. The benefits of crossing taurine and zebu beef purebreds have been reported in the literature (Fitzhugh et al., 1975; Gray et al., 1978; Williams et al., 2010) and include greater productive performance and better carcass traits.

In this context, greater CW and, sometimes CY, is expected in crossbred cattle (taurine and zebu beef breeds) when compared to zebu purebred cattle, as the presence of taurine breeds in the genotype of these crossbred animals usually result in greater BW gain rates and carcass fat deposition (Crouse et al., 1989; Plasse et al., 1995; Yar et al., 2022). Greater CW and backfat thickness have been reported in Simmental × Nellore e Angus × Nellore steers (Oliveira et al., 2011) and heifers (Lage et al., 2012) in relation to Nellore steers and heifers, respectively. Similarly, Amaral et al. (2018) have described greater carcass gain and subcutaneous fat thickness in Angus × Nellore bulls when compared to Nellore.

On the other hand, crossbred dairy cattle (Holstein × Zebu) are also commonly raised for beef production in Brazil. However, the presence of the Holstein breed in the genotype of the crossbred dairy animals usually lead to a different growth and conformation pattern when compared to breeds selected for beef production and their crossbreds. Several studies available in the literature described lower CY in crossbred dairy cattle in relation to those from breeds selected for beef production (e.g., Nellore and Angus) and their crossbreds (Jorge et al., 1999; Fernandes et al., 2004; Rocha Junior et al., 2010). Nonetheless, some studies did not find differences in CY of dairy crossbred (Holstein × Zebu) and Zebu beef breeds cattle (Alves et al., 2004; Costa et al., 2007).

Gender also influences the weight gain rate, composition of gain, and consequently, body composition and carcass traits (Berg and Butterfield, 1976; Valadares Filho et al., 2016). Bulls usually present greater growth rate, with higher protein and less fat content in the gain when compared to steers and heifers within a contemporary group (Berg and Butterfield, 1976; Fortin et al., 1980; Paulino et al., 2009).

However, females deposit more udder and internal organs fat (Paulino et al., 2009). Moreover, steers typically deposit more abdominal and renal fat than bulls at similar BW (Paulino et al., 2009). Therefore, at the same BW, the CW, and frequently the CY, are greater in bulls and lower in heifers, whereas steers usually present intermediate values (Hassen et al., 1998; Vittori et al., 2006; Paulino et al., 2008). Vaz et al. (2010) reported that, even at young ages, steers present greater CY when compared to heifers, as heifers have greater weight of the digestive tract.

Slaughter body weight

Slaughter BW is an important factor to determine CW and CY of cattle. Body weight is positively correlated to CW (Lôbo et al., 2002; Silva et al., 2003; Cruz et al., 2004). Furthermore, CY linearly increases with increasing slaughter BW (May et al., 1992; Bruns et al., 2004; Restle et al., 2005). Carcass yield increases with increasing BW due to the increased carcass fat deposition and reduced proportion of BW that consists of the digestive tract and its content (Berg and Butterfield, 1976; Waldo et al., 1990; Owens et al., 1993). May et al. (1992), evaluating the carcass traits of Angus × Hereford steers serially slaughtered 0 to 196 d on feed, and Arboitte et al. (2004) assessing the carcass traits of 5/8 Nellore × 3/8 Charolais steers finished in feedlot and slaughtered at 425, 467, and 510 kg, observed a linear increase in CY and BFT of such animals. In addition, Restle et al. (2005) observed a decreasing contribution of internal organs to slaughter BW (kg/100 kg slaughter BW) as the slaughter BW of 5/8 Nellore × 3/8 Charolais steers increased from 425 to 510 kg.

Nonetheless, Hicks et al. (1987) and Bruns et al. (2004) have reported a quadratic increase in BFT with increasing BW at slaughter. Differences regarding the duration of studies and, consequently, the BW range evaluated may be responsible for the different patterns of BFT deposition in the carcass described among the studies.

Nutritional strategies

The diet offered to cattle may affect their CY (Berg and Butterfield, 1976; Owens et al., 1993). The gastrointestinal tract content and the relative weight of its compartments is greater when forage diets are fed to cattle in relation to concentrate diets (ARC, 1980; Owens et al., 1993; Véras et al., 2001). In addition, the greater nutrient supply (and energy) obtained from concentrate diets usually results in greater weight gain and carcass rates, carcass fat deposition, and CW (Nour et al., 1983; Oliveira et al., 2009; Marcondes et al., 2011). Several studies have demonstrated that CY linearly increases with increasing diet concentrate content (Gesualdi Júnior et al., 2000; Ribeiro et al., 2001; Leme et al., 2003; Oliveira et al., 2011). In this context, the greater the diet concentrate content, the greater the expected CY.

Transport and management

Beef cattle are transported at least once in their lives when they are shipped for slaughter. Handling, loading/unloading, commingling, vehicle accelerations and vibrations, exposure to new environments, and extreme temperatures during transportation can cause stress (Schwartzkopf-Genswein et al., 2016). As a result, animals often experience BW loss (shrink), carcass injuries, and alteration of meat quality (Bhatt et al., 2021).

In Brazil, BW loss may be the most important economic effect, because of BW or CW- based trading of cattle. This effect usually occurs mostly due to the lack of feed and water (Marques et al., 2012), but also because of increased transpiration, defecation, and urination. However, Schwartzkopf-Genswein et al. (2016) reported in a review that transportation related to BW loss was not only attributed to loss of gut fill but also to tissue loss, which can exceed 60% of BW losses depending on the length of the fasting period. Jones et al. (1988), evaluating the effects of fasting, mixing, transportation, and resting, mimicking what cattle would be exposed to during specific transport scenarios, concluded that the main effect of fasting and transportation in beef cattle was a loss in CW and gut fill, which was greater for a 72-hour journey compared to a 48-hour journey. Also, high ambient temperature and extra and rough handling of cattle usually increase weight loss (Coffey et al., 2001; González et al., 2012; van Engen and Coetzee, 2018).

Poor cattle management, especially pre-slaughter handling process, can also cause bruises and limit cattle well-being (Paranhos da Costa et al., 2012; Mendonça et al., 2019). Bruising can be defined as a tissue injury with rupture of blood vessels and accumulation of blood and serum beneath the skin (Strappini et al., 2012), which usually depreciates the commercial value of carcasses as the affected parts may need to be discarded. Bruises can cause carcass loss and consequently, negatively affect CY and the economic output.

Two studies conducted in Uruguay (Huertas et al., 2010; Huertas et al., 2015) found that 60% of the total beef carcass assessed had at least one bruise. Moreover, the occurrence of bruises on the carcasses resulted in an average removal of 2.0 and 1.6 kg of meat per lesion in the studies of Huertas et al. (2010) and Huertas et al. (2015), respectively. However, Zanardi et al. (2022) and Strappini et al. (2010) observed a relatively low prevalence of bruises in slaughterhouses in Italy and Chile slaughterhouses, where approximately 20% of cattle presented at least one bruise.

Several studies have been performed to evaluate the effects of pre-slaughter management (e.g, handling procedures and duration of transportation and vehicle type), genotype and gender predispositions to bruises occurrence (Strappini et al., 2010; Mendonça et al., 2016; Bethancourt-Garcia et al., 2019; Mendonça et al., 2019). Results from these studies have indicated that the occurrence of bruises on cattle carcasses are related to the distance traveled, where cattle transported for long distances presented more bruises than those transported for shorter journeys. Also, trucks with larger load capacities caused a greater number of severe bruises. Furthermore, carcass bruises were greater for females (cows, mainly) when compared to male cattle, as well as the presence of horned animals within cattle groups increased the risk of bruising.

Dressing procedure

The CW utilized for calculating the CY in commercial slaughterhouses is usually obtained after the slaughter, dressing, and cleaning processes, which differ among countries and slaughter plants. In this context, whether the carcass is weighed hot (hot carcass weight; HCW) or after cooling (cold carcass weight; CCW), is washed or not, and contains or not the kidneys attached will affect the CW obtained. Moreover, the removal of bruises, abscesses (e.g., resulted from vaccination against foot and mouth disease), or fat excess , known as trimming, may also decrease CW and, consequently, the CY.

In 2014, a survey performed in 28 Brazilian slaughter plants (Scot Consultoria company) showed mean CY values of 52 and 54% for male cattle raised in pasture and feedlots, respectively, and values between 48 and 49% for cows. In addition, mean values of CY of 50 e 51% were reported for heifers raised in pasture and feedlots, respectively. However, experimental results from comparative slaughter trials, in which carcasses were not trimmed, often describe greater CY, reach about 60%.

Differences between experimental and commercial CY may be also related to the experimental fasting period of 12 to 16 h to obtain the shrunk body weight (SBW) in trials, while in farming conditions normally they weight the animals without a fasting period, recording the full BW of animals. .

Comparisons between experimental and commercial CY values may often lead to producers distrust regarding the procedures for obtaining the CY by the slaughterhouses.

Thus, CY obtained in experiments should not be compared with those observed in commercial conditions without adjustments. In this sense, to compare experimental and commercial data, it would be necessary to establish the fasting effect and the dressing/trimming effect on CY.

In addition, the biological efficiency has been currently used as an indicator of feedlot production efficiency. This indicator is calculated as the amount of feed necessary to produce 1 or 15 kg of carcass (15 kg of carcass is a metric for CW called "*arroba*" utilized in Brazil). In this case, the production process efficiency is calculated after slaughtering the animals, which do not allow adjustments or modifications during the productive cycle. Therefore, estimating the CW from cattle's BW would enable nutritionists to make more precise adjustments on nutrition and management during the production cycle, as well as to assist on the definition of the best time for slaughter. Hence, linear and non-linear equations to predict CW from BW will be proposed.

ESTIMATION OF CARCASS WEIGHT

Linear equations

In a recent study, Benedeti et al. (2021) proposed a linear equation to predict CW of feedlot cattle according to the variables slaughter condition, gender, genotype, and shrunk body weight (SBW). A database composed by 1112 animals (Table 6.1) encompassing bulls, steers, and heifers of different genotype (Zebu, beef crossbred, and dairy crossbred), and slaughtered at two types of slaughter procedure (experimental and commercial) was used to develop a linear CW predictive equation (Eq.6.1).

Table 6.1 - Descriptive statistics of the data used to develop the linear model to predict carcass weight of beef cattle, adapted from Benedeti et al. (2021)

Item	n	Shrunk body weight, kg	Carcass weight, kg
Studies	30		
Animals	1112	429	234
Gender			
Bull	785	462	255
Steer	186	393	215
Heifer	141	297	158
Genotype			
Zebu	776	433	235
Crossbred beef cattle	164	419	230
Crossbred dairy cattle	171	423	234
*Slaughter procedure**			
Commercial	636	503**	280
Experimental	476	374	208

*Experimental = data from animals slaughtered in an experimental procedure without dressing or trimming the carcasses; Commercial = data from animals slaughtered in a commercial slaughter house.
**Shrunk body weight of commercial animals was estimated according to Gionbelli et al. (2016); SBW = 0.880 × $BW^{1.0175}$.

Authors found significant effects ($P < 0.05$) of the slaughter procedure only on the intercept and significant effects ($P < 0.05$) of gender, genotype, and SBW on the slope of the linear regression of the CW; thus, the following CW predictive equation was suggested:

$$CW\ (kg) = -11.03 + P + (0.6094 + G + B) \times SBW \quad \text{Eq.6.1,}$$

where CW = carcass weight (kg), P = slaughter procedure (if commercial = -10.98, if experimental = 0), G = gender effect (if steer = 0, if bull = 0.008169, and if heifer = -0.00612), B = genotype effect (if Zebu = 0, if crossbred beef cattle = -0.01595, and if crossbred dairy cattle = -0.03301), and SBW = shrunk body weight (kg).

Therefore, at the same SBW, greater CW estimations will be observed for cattle slaughtered in experimental when compared to commercial conditions, due to the absence of dressing or trimming process, which decrease CY. Furthermore, the estimated CW will be heavier for bulls, followed by steers and heifers, respectively, when considering animals with the same SBW. Regarding the genotype effect, the dairy crossbred, and beef crossbred decreases the CW estimation in relation to Zebu genotype, probably reflecting a greater dry matter intake of the crossbred cattle.

The validation analysis of the linear CW equation was performed using an independent database containing cattle slaughtered in experimental and commercial slaughter plants (Table 6.2). The experimental data set was composed by 70 observations, encompassing only bulls from two genotypes (Zebu and beef crossbred). Commercial data set was composed by 10 means from 746 cattle, encompassing Zebu and crossbred beef bulls and heifers.

Table 6.2 - Descriptive statistics of the data used to validate the linear model (Eq. 6.1) to predict carcass weight of Zebu beef cattle, adapted from Benedeti et al. (2021)

Item	Dataset*	
	Experimental	Commercial
Studies, n	2	-
Animals, n	70	10**
Gender, %		
Bull	100	92.2
Heifer	-	7.77
Genotype, %		
Zebu	65.7	79.4
Crossbred beef cattle	34.3	20.6
Shrunk body weight, kg	452 ± 67.4	471 ± 33.6***

*Experimental = independent data from animals slaughtered in an experimental plant; Commercial = independent data from animals slaughtered in a commercial abattoir.
**10 means from 746 animals.
***Shrunk body weight of commercial animals was estimated according to Gionbelli et al. (2016); SBW = 0.8800 × $BW^{1.0175}$.

The observed and predicted values were compared based on the following regression model: Y = β0 + β1 × X, where X = predicted values, Y = observed values, β0 = intercept of the equation, and β1 = slope of the equation. The regression was evaluated according to the following statistical hypothesis: H0: β0 = 0 and H0: β1 = 1, and Ha: not H0. If the null hypothesis was not rejected, it was concluded that the linear equation accurately and precisely estimated CW of feedlot cattle. Estimates were also evaluated using the mean squared error of prediction (MSEP), and its components (Bibby and Toutenburg, 1977): MSEP = SB + MaF + MoF = $1/n \sum_{i=1}(x_i - y_i)^2$; SB = $(x_i - y_i)^2$; MaF = $(s_x - s_y)^2$; Mof = $2s_x s_y(1-r)$; where x are the predicted values; y are the observed values; MSEP is the mean squared error of prediction; SB is the squared bias; MoF is the component relative to the model of random fluctuation; MaF is the component relative to the magnitude 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 coefficient between the predicted and observed values. The prediction of efficiency was determined by estimating the correlation and concordance coefficient or reproducibility index (CCC), as described by Tedeschi (2006). All calculations were obtained using the Model Evaluation System (MES; Tedeschi, 2006). For comparisons, 0.05 was established as the critical level of probability for type I error. More details regarding this study can be found in Benedeti et al. (2021).

Briefly, the validation analysis demonstrated that the linear equation accurately and precisely estimated CW of beef cattle in either experimental or commercial slaughter conditions (Table 6.3), as the null hypothesis of a respective intercept and slope equal to 0 and 1 (P > 0.05) were not rejected; and CCC was close to 1 (CCC of 0.979 and 0.961 for experimental and commercial conditions, respectively). However, the commercial validation presented the lowest

MSEP. The MSEP partitioning showed that the proportions of SB were 12.7 and 78.2%, while proportions of MaF were 0.006, and 8.31% in the experimental and commercial evaluations, respectively.

Table 6.3 - Validation statistic of the relationship between the observed and predicted carcass weight* of Zebu beef cattle by the linear model, adapted from Benedeti et al. (2021)

Item**	Experimental***		Commercial***	
	Observed	Predicted	Observed	Predicted
Mean, kg	268	265	258	264
Standard deviation, kg	40.4	39.7	23.0	24.8
Maximum, kg	322	327	285	298
Minimum, kg	105	117	215	217
R	-	0.982	-	0.994
CCC	-	0.979	-	0.961
Regression				
Intercept				
Estimate	-	3.33	-	15.6
Standard error	-	6.23	-	9.75
P-value (H_0: a=0)	-	0.595	-	0.148
Slope				
Estimate	-	1.00	-	0.919
Standard error	-	0.023	-	0.037
P-value (H_0: b=1)	-	0.943	-	0.058
MSEP	-	65.4	-	44.5
SB	-	8.32	-	34.8
MaF	-	0.004	-	3.68
MoF	-	57.1	-	6.01

*Developed equation: CW, kg = -11.03 + P + ((0.6094 + G + B) × SBW), R^2 = 0.98.
**P = Slaughter plant effect, if commercial = -10.98, if experimental =0; G = gender effect, if steer = 0, if bull = 0.008169 and if heifer = - 0.00612; B = genotype effect, if Zebu = 0, if Dairy crossbreds = -0.03301 and if Beef crossbreds = -0.01595; SBW = shrunk body weight; R = determination coefficient; CCC = correlation and concordance coefficient; MSEP = mean square error of prediction; SB = squared bias; MaF = magnitude of random fluctuation; MoF = model of random fluctuation.
***Experimental = independent data of animals slaughtered in an experimental plant; Commercial = independent data of animals slaughtered in a commercial slaughterhouse.

Thus, although experimental evaluation presented greater MSEP, it had the lowest SB, meaning that this validation analysis had a greater capacity to simulate variation around the mean. Such results may be related to differences on the validation experimental and commercial databases. Experimental data set had only bulls, while commercial had bulls and heifers. Nevertheless, the linear equation can be considered adequate to estimate CW of feedlot cattle due to its good precision and accuracy.

Non- linear equations

Carcass weight is affected by factors such as BW, weight gain rate and composition, body and carcass composition, and the contribution of the digestive tract size and fill to BW (Berg and Butterfield, 1976; Owens et al., 1993), as well as specific dressing procedures performed at different slaughter plants, which should be taken in account in predictive equations. Benedeti et al. (2021) have successfully considered such effects on CW when utilizing, besides the SBW, gender, genotype, and slaughter plant as dummy predictive variables in the linear equation described in the previous section. However, the consideration of many influencing factors may lead to overparameterization of CW prediction, increasing the complexity of calculations. In addition, Benedeti et al (2021) utilized a fixed adjustment factor for slaughter plant on CW prediction, not accounting for differences on dressing process among different animals and slaughterhouses.

Most of influencing factors (rate of gain and its composition, body composition, gut fill, etc.) of CW are correlated with BW and/or BW gain (Valadares Filho et al., 2016). Moreover, it is well known that the cattle growth curve, such as BW and tissues deposition, has been well described by simple non-linear models such as allometric equations (NASEM, 2016; Valadares Filho et al., 2016; Domínguez-Viveros et al., 2020), which could also be used to predict the optimal slaughter moment. Thus, aiming to provide a simpler and more accurate calculation of the CW for cattle of different genotype and gender, slaughtered at different conditions, authors conducted a study aiming: 1) to develop a non-linear equation to predict cattle experimental CW (eCW); 2) to evaluate the contribution of each component removed during the dressing procedure to obtain the commercial CW (cCW), as well as to develop a equation to predict cCW from eCW; and 3) to evaluate the goodness of fit of the equations generated to predict eCW and cCW of beef cattle.

Experimental carcass weight

A metanalysis was performed using data from 19 studies performed at the Universidade Federal de Viçosa (UFV), totalizing 682 feedlot cattle encompassing bulls, steers, and heifers of different genotypes (Zebu, beef crossbred, and dairy crossbred). The dataset contained individual information on SBW and CW of cattle obtained in experimental conditions (eCW), with no dressing procedures performed before weighing the carcass (Table 6.4).

Table 6.4 - Descriptive statistics of the data used to develop the non-linear model to predict experimental carcass weight of beef cattle

Item	n	Shrunk body weight, kg	Carcass weight, kg
Studies	19	-	-
Animals	682	380 ± 94.9	221 ± 58.9
Gender			
Bull	472	401 ± 83.9	237 ± 52.5
Steer	95	368 ± 103.6	204 ± 56.5
Heifer	115	303 ± 88.9	168 ± 50.3
Genotype			
Zebu	477	376 ± 93.3	222 ± 59.2
Crossbred beef cattle	52	397 ± 105.9	231 ± 65.7
Crossbred Dairy cattle	153	388 ± 95.4	214 ± 55

Before slaughter, animals were fasted for 12 to 16 h but with free access to water. Pre-boarding handling of animals was conducted in accordance with good animal welfare practices in Brazil. Experimental slaughter was performed via stunning and jugular cutting for total bleeding. Additional details regarding the experimental slaughter procedures can be obtained in Silva et al. (2021).

Data were coded for gender (bull, steer, and heifer) and genotype (Zebu, beef crossbred, and dairy crossbred). Initially, data were tested for normality. Further, a mixed model including the fixed effects of SBW, genotype, and gender, and random effects of study was used to evaluate linear and non-linear models with or without the intercept that best fits the relationship between eCW and SBW based on Akaike's Information Criteria (AIC). These analyses were performed with the MIXED procedure of the SAS (version 9.4, Inst. Inc., Cary, NC), and the 0.05 was established as the critical level of probability for a type I error.

A non-linear equation with intercept had the lowest AIC for predicting eCW. Moreover, there were significant effects ($P<0.05$) of genotype and gender on the exponent but not ($P>0.05$) on the intercept of the non-linear eCW model. Thus, the following non-linear equation to estimate experimental eCW was suggested:

$$\text{eCW (kg)} = 0.41764 \times \text{SBW}^{\beta 1} \qquad \text{Eq.6.2,}$$

where eCW = experimental carcass weight (kg); SBW = shrunk body weight (kg); β1 =

genotype and sex effect, if Zebu bull = 1.0583, if crossbred beef bull = 1.0561, if crossbred dairy bull = 1.0479, if Zebu steer = 1.0549, if crossbred beef steer = 1.0527, if crossbred dairy steer = 1.0445, if Zebu heifer = 1.0533, if crossbred beef heifer = 1.0511, and if crossbred dairy heifer = 1.0429 (Table 6.5).

Table 6.5 - Coefficients for the non-linear predictive equation of experimental carcass weight (Eq.6.2)

Genotype	Gender	β1
Zebu	Bull	1.0583
	Steer	1.0549
	Heifer	1.0533
Crossbred beef cattle	Bull	1.0561
	Steer	1.0527
	Heifer	1.0511
Crossbred Dairy cattle	Bull	1.0479
	Steer	1.0445
	Heifer	1.0429

The carcass gain rates according to genotype and gender can be accessed by the exponent (β1) of the generated equation to estimate eCW from SBW. The exponents greater than 1 observed in the current study indicated carcass gain in a greater rate than the cattle shrunk weight gain (SWG), regardless of cattle genotype and gender. However, values of β1 were greater for Zebu and lower for crossbred dairy cattle while crossbred beef cattle were intermediate within each gender. These results indicated that, within each gender, Zebu and crossbred dairy cattle presented the greatest and lowest proportions of SWG in carcass tissues, respectively, when compared to crossbred beef cattle.

In addition, estimated eCW will be higher for bulls, followed by steers and heifers respectively, when considering cattle with equal SBW within each genotype evaluated. As previously discussed, at the same SBW, bulls present greater proportion of protein and lower fat deposition than steers and heifers. Steers typically deposit more abdominal and renal fat than bulls at similar BW. Also, heifers tend to deposit more fat in udder and internal organs, which usually results in proportionally less deposition of carcass tissues in relation to bulls. Therefore, at the same BW, CW are greater in bulls and lower in heifers, whereas steers usually present intermediate CW.

These results corroborate with the discussion previously held, where: 1) purebred and crossbred beef cattle, at same SBW, usually present greater CW when compared to crossbred dairy cattle; e 2) At the same SBW, CW is usually greater in bulls and lower in heifers, whereas steers commonly stay in an intermediate position.

Commercial carcass weight

A database composed by 5 studies (Alhadas et al., 2021; Andrade, 2021; Lage, unpublished; Matos, unpublished; Pacheco, unpublished; Silva, unpublished) performed at UFV, totalizing 192 animals encompassing Zebu and crossbred beef bulls and heifers were utilized to evaluate the contribution of the dressing procedure on commercial CW (cCW), as well as to develop an equation for predicting cCW of beef cattle (Table 6.6) from eCW. Slaughter was performed similarly to that described previously for the estimative of eCW. Nevertheless, all carcasses were weighted before and after the dressing procedure, and the weight of each carcass constituent removed during this process was individually recorded. Thus, the dataset contained individual information on CW before (eCW) and after the dressing procedure (cCW), as well as the weight of each carcass component usually removed during the commercial dressing procedure, which were: the tissues damaged by exsanguination, nuchal ligament, lymph nodes, spinal cord, tissues associated to penis insertion (when present), and the trimming of fat excess and all damaged or contaminated parts (additional dressing). Further, the sum of all carcass components removed during the dressing procedure (total dressing) was calculated and included in the dataset.

Table 6.6 - Descriptive statistics of the data used to develop the equation to estimate the commercial carcass weight of beef cattle

Item	Total data set	Gender		Genotype	
		Bull	Heifer	Zebu	Crossbred beef
Studies, n	5	4	1	4	1
Animals, n	192	170	22	143	49
Shrunk body weight, kg	422 ± 85.5	424 ± 88.3	412 ± 60.1	400 ± 74.0	488 ± 83.6
Carcass weight before dressing, kg	252 ± 52.4	254 ± 53.7	237 ± 38.3	238 ± 45.2	292 ± 51.4
Carcass weight after dressing, kg	237 ± 49.8	239 ± 51.2	222 ± 34.7	223 ± 41.8	279 ± 48.6
Dressing					
Tissues damaged by exsanguination; kg	2.26 ± 1.162	2.22 ± 1.206	1.58 ± 0.669	2.59 ± 1.126	1.31 ± 0.613
Nuchal ligament, kg	0.63 ± 0.233	0.66 ± 0.233	0.44 ± 0.097	0.72 ± 0.193	0.37 ± 0.114
Lymph nodes, kg	0.95 ± 0.510	0.95 ± 0.527	0.90 ± 0.360	1.12 ± 0.480	0.45 ± 0.122
Spinal cord, kg	0.34 ± 0.136	0.34 ± 0.141	0.32 ± 0.088	0.38 ± 0.126	0.22 ± 0.086
Tissues associated to penis insertion, kg	0.48 ± 0.400	0.48 ± 0.400	-	0.51 ± 0.460	0.42 ± 0.161
Trimming*, kg	9.62 ± 3.488	9.49 ± 3.442	10.6 ± 3.76	9.35 ± 3.707	10.4 ± 2.63
Total dressing, kg	14.2 ± 4.33	14.1 ± 4.34	14.8 ± 4.31	14.6 ± 4.63	13.2 ± 3.10

*Trimming of fat excess and all damaged or contaminated parts.

Data were coded for genotype (Zebu and beef crossbred) and gender (bull and heifer). Initially, data were tested for normality. Subsequently, the fixed effects of genotype and gender on the total dressing (kg) were tested using a mixed model, accounting for the random variation among studies. Further, a mixed model including the fixed effects of genotype, and gender, and random effects of the study were used to evaluate linear (Eq.6.1) and non-linear (Eq.6.4) models with or without the intercept, that best fit the relationship between cCW and eCW based on Akaike's Information Criteria (AIC). These analyses were performed with the MIXED procedure of SAS (version 9.4, Inst. Inc., Cary, NC), and 0.05 was established as the critical level of probability for a type I error.

There were no effect of genotype or gender (P>0.05) on the total dressing (kg). In addition, a linear equation without intercept had the lowest AIC for predicting cCW from eCW. Further, no effect of genotype or gender (P>0.05) was observed on the slope of the equation. Therefore, the developed equation for estimating cCW was:

$$cCW\ (kg) = 0.9391 \times eCW \qquad \text{Eq.6.3,}$$

where cCW = commmercial carcass weight (kg) and eCW = experimental carcass weight (kg).

Thus, after replacing eCW in Eq.6.3, the cCW can be calculated as follows:

$$cCW\ (kg) = 0.9391 \times (0.41764 \times SBW^{\beta 1}) \qquad \text{Eq.6.4}$$

where cCW = commercial carcass weight (kg); SBW = shrunk body weight (kg); β1 = shown in Table 6.5.

The resulted cCW equation corroborate with the results on dressing procedure, where no effects of genotype or gender were observed for total dressing and slope of cCW equation. Although numerical differences in the contribution of some individual carcass component removed during the dressing procedure can be observed, Zebu and crossbred beef bulls and heifers presented similar total dressing in cCW (14.2 kg, on average).

Validation of the predictive equation of commercial carcass weight

An independent database containing cattle slaughtered in experimental and commercial conditions was used to validate the cCW equation (Table 6.7). The experimental data set was composed of 1196 observations from 10 studies, encompassing Zebu and crossbred beef bulls and heifers. In this case, the removal of the same carcass components described for the dressing procedure in the previous section was performed to obtain the observed cCW values at experimental conditions. Commercial data set was composed of 30 means from 1431 animals, encompassing Zebu and crossbred beef bulls, steers, and heifers. The data set used in the validation analysis was not included in the data set used to adjust the tested equation.

Table 6.7 - Descriptive statistics of the data used to validate the non-linear model to predict commercial carcass weight of beef cattle

Item	Data set	
	Experimental	Commercial
Studies, n	10	-
Animals, n	1196	1431
Gender, %		
Bull	99.0	70.4
Steer	-	4.2
Heifer	1.0	25.4
Genotype, %		
Zebu	90.7	47.9
Crossbred beef cattle	9.3	52.1
Shrunk body weight, kg	488 ± 53.5	454 ± 52.5

Validation analysis was performed as previously described for the evaluation of Eq.6.1.

Validation analysis demonstrated that Eq.6.4 accurately and precisely estimated the cCW, as the null hypothesis of a respective intercept, and slope equal to 0 and 1 were not rejected (P>0.05) and values of R and CCC were close to 1 for either experimental or commercial slaughter plants data sets (Table 6.8; Figure 6.1).

However, a superior goodness of fit was observed when cCW was validated with the experimental data set, which presented the greatest R^2 and CCC values and the lowest MSEP. Furthermore, the MSEP partitioning showed that the proportions of SB were 0.01 and 18.3%, whereas proportions of MoF were 99.8 and 67.9% in the experimental and commercial data set comparisons, respectively.

Table 6.8 - Validation statistics of the relationship between the observed and predicted commercial carcass weight of beef cattle by the non-linear model

Item*	Slaughter procedure			
	Experimental		Commercial	
	Observed	Predicted	Observed	Predicted
Mean, kg	275	274	254	250
Standard deviation, kg	33.6	32.8	20.6	21.1
Maximum, kg	378	373	278	291
Minimum, kg	138	138	215	205
R^2	-	0.94	-	0.89
CCC	-	0.97	-	0.92
Regression				
Intercept				
Estimate	-	1.64	-	23.7
Standard error	-	1.922	-	15.23
P-value	-	0.394	-	0.131
Slope				
Estimate	-	0.99	-	0.92
Standard error	-	0.007	-	0.061
P-value	-	0.424	-	0.212
MSEP	-	64.8	-	65.4
SB	-	0.01	-	18.3
MaF	-	0.03	-	2.59
MoF	-	64.7	-	44.4

*R^2 = determination coefficient; CCC = correlation and concordance coefficient; MSEP = mean square error of prediction; SB = squared bias; MaF = magnitude of random fluctuation; MoF = model of random fluctuation.

The greatest R^2 and CCC and the lowest MSEP indicated a superior accuracy and reproducibility in the experimental evaluation. Moreover, prediction errors for cCW were less associated with central tendency (SB) in experimental than commercial conditions.

Thus, prediction errors for cCW in experimental conditions had a lower proportion associated with the model than those for commercial conditions.

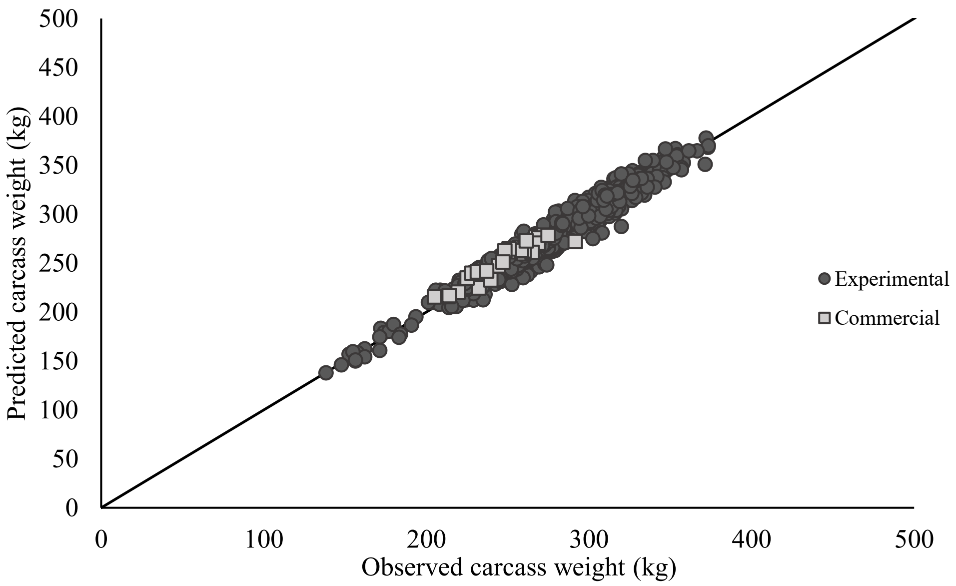

Figure 6.1 - Relationship between the observed and predicted commercial carcass weight of beef cattle by the non-linear model.

The goodness of fit of equations might be reduced when they are applied to estimate variables in different conditions than the ones used to generate the equation. Although the equation was proposed for predicting cCW, all data used to generate this equation was obtained in experimental conditions, in which the dressing procedure usually performed in commercial slaughter plants was reproduced to estimate cCW from eCW. Moreover, cattle were not transported, as the experimental slaughterhouse was located near the experimental feedlot. As previously discussed, there are differences on dressing procedures among different slaughterhouses, which might affect the CW. Unlike the dressing procedure performed in the current study, the hump muscle can also be removed during the dressing procedure of some slaughterhouses, for example. Moreover, cattle transport to commercial slaughter plants may lead to carcass losses due to bruising and/or shrink, whose incidence and/or severity seem to be dependent on the distance traveled, type of vehicle, animal genotype and gender (Schwartzkopf-Genswein et al., 2016). Thus, variations on the specific management and dressing procedure performed in commercial validation database and those in the database utilized for generating the equation could have contributed to reduced goodness of fit when predicting cCW in commercial conditions.

Furthermore, experimental database included bulls (99%) and heifers (1.0%), while the commercial included bulls (70.4%), steers (4.2%), and heifers (25.4%). Also, experimental database utilized in the validation was composed mostly by cattle from Zebu genotype (90.7%), whereas most cattle in the commercial database were beef crossbred (52.1%). This may also explain the better performance of the models for cattle slaughtered under experimental procedures, since bulls and Zebu cattle represented 88.5 and 74.5% of the data used to develop the proposed cCW equation, respectively. Moreover, there were no steers in the data set used to generate the cCW equation. Nevertheless, the cCW equation can be considered adequate to estimate cCW due to its good precision and accuracy in both experimental and commercial conditions.

ESTIMATION OF BACKFAT THICKNESS

Assis (2021) proposed an equation for predicting BFT of beef cattle. Then, a metanalysis was performed using data of 744 cattle from 21 studies encompassing bulls, steers, and heifers of different genotypes (Zebu, beef crossbred, and dairy crossbred), slaughtered in experimental and commercial conditions (Table 6.9). The database contained individual information on SBW, CW, BFT measured between the 12th and the 13th ribs, and average daily gain (ADG) during the finishing phase.

Table 6.9 - Descriptive statistics of the data used to develop a model to predict backfat thickness of beef cattle

Item	n	Carcass weight (kg)	Average daily gain (kg/d)	Backfat thickness (mm)
Studies	21	-	-	-
Animals	744	248 $\pm$ 64.0	1.10 $\pm$ 0.413	4.04 $\pm$ 2.073
Gender				
Bull	571	265 $\pm$ 53.9	1.18 $\pm$ 0.367	4.06 $\pm$ 1.949
Steer	95	217 $\pm$ 64.4	0.80 $\pm$ 0.370	4.12 $\pm$ 2.442
Heifer	78	162 $\pm$ 47.6	0.86 $\pm$ 0.532	3.73 $\pm$ 2.441
Genotype				
Zebu	589	257 $\pm$ 63.8	1.08 $\pm$ 0.398	4.27 $\pm$ 1.983
Crossbred beef cattle	41	209 $\pm$ 43.2	1.42 $\pm$ 0.331	5.16 $\pm$ 2.409
Crossbred dairy cattle	114	219 $\pm$ 57.7	1.15 $\pm$ 0.463	2.47 $\pm$ 1.583
Slaughter plant				
Commercial	342	288 $\pm$ 39.8	1.17 $\pm$ 0.361	4.88 $\pm$ 1.761
Experimental	402	215 $\pm$ 61.6	1.04 $\pm$0.453	3.32 $\pm$ 2.049

Thus, a mixed model including the fixed effects of genotype, gender, and slaughter conditions (commercial or experimental), and random effects of the study were tested for developing the BFT equation. The variance component structure was selected to determine the model with the best fit based on the AIC. These analyses were conducted with the MIXED procedure of SAS (version 9.4, Inst. Inc., Cary, NC), and 0.05 was established as the critical level of probability for a type I error. More details regarding this study can be found in Assis (2021).

A linear equation including intercept had the lowest AIC value (AIC = 2840) for predicting BFT from ADG and CW. Moreover, no effects of genotype, gender or slaughter condition were observed (P>0.05) on the intercept or the coefficient associated with the ADG predictive variable. However, interactions between genotype and gender were found for the coefficient associated with the CW predictive variable. Thus, Assis (2021) suggested the following BFT predictive equation:

$$\text{BFT (mm)} = -2.37 + 0.709 \times \text{ADG} + \text{CW} \times \text{G} \quad (R^2 = 0.49, \text{RMSE} = 1.67) \qquad \text{Eq.6.5,}$$

where BFT = backfat thickness (mm), ADG = average daily gain (kg/d), CW = carcass weight (kg), and G = interaction between genotype and gender effect (if Zebu bull = 0.0238, if Zebu steer = 0.03043, If Zebu heifer = 0.03545, if crossbred beef bull = 0.02705, if crossbred beef steer = 0.03368, if crossbred beef heifer = 0.03871, if crossbred dairy bull = 0.01770, if crossbred dairy steer = 0.02433, and if crossbred dairy heifer = 0.02935).

The model proposed adjusts the effect among genotype and gender, as well as the effect of gain rate; therefore, this equation indirectly accessed the effects of intake level and diet type on cattle CY and BFT. The ADG predictive variable explained most of BFT variations.

Validation of backfat thickness predictive equation

Brasileiro (2023) evaluated the goodness of fit of the BFT equation proposed by Assis (2021). Validation database was composed of 43 treatment means from 16 published studies (Table 6.10). The data set used in the validation analysis was not included in the data set used to adjust the BFT equation.

Table 6.10 - Descriptive statistics of the data used to validate the model to predict backfat thickness of beef cattle described on Eq.6.5

Item	n	Carcass weight, kg	Average daily gain, kg/d
Studies	16	-	-
Animals	1142	278 ± 30.2	1.36 ± 0.248
Gender			
Bull	1051	284 ± 24.5	1.38 ± 0.219
Steer	91	237 ± 40.8	1.21 ± 0.407
Genotype			
Zebu	939	276 ± 29.5	1.34 ± 0.249
Crossbred beef cattle	203	287 ± 34.9	1.49 ± 0.212

Validation analysis was performed as described in the previous sections of this Chapter. The Eq.6.5, proposed by Assis (2021), accurately predicted BFT of beef cattle (Table 6.11; Figure 6.2), as the null hypothesis of a respective intercept and slope equal to 0 and 1 (P > 0.05) was not rejected; and presented high CCC (CCC = 0.76). Moreover, the prediction errors for BFT were mostly (more than 71% of MSEP) associated with random error (MoF), rather than central tendency (SB), and due to linear regression or systematic bias (MaF).

Table 6.11 - Validation statistics of the relationship between the observed and predicted backfat thickness of beef cattle

Item*	Backfat thickness	
	Observed	Predicted
Mean, kg	5.18	5.53
Standard deviation, kg	0.98	0.903
Maximum, kg	7.55	7.61
Minimum, kg	3.04	3.49
R^2	-	0.65
CCC	-	0.76
Regression		
Intercept		
Estimate	-	0.29
Standard error	-	0.556
P-value	-	0.610
Slope		
Estimate	-	0.89
Standard error	-	0.099
P-value	-	0.256
MSEP	-	0.45
SB	-	0.12
MaF	-	0.01
MoF	-	0.32

*R^2 = determination coefficient; CCC = correlation and concordance coefficient; MSEP = mean square error of prediction; SB = squared bias; MaF = magnitude of random fluctuation; MoF = model of random fluctuation.

The equation proposed by Assis (2021), Eq.6.5, accurately and precisely estimated and, therefore, is recommended to estimate the BFT of Zebu and crossbred beef bulls and steers. The BFT equation may contribute for decision-making process in the beef cattle industry, allowing a more homogeneous carcass production. Nevertheless, further studies should be performed to evaluate the goodness of fit for predicting the BFT of other cattle categories, such as crossbred dairy cattle and Zebu and crossbred beef heifers.

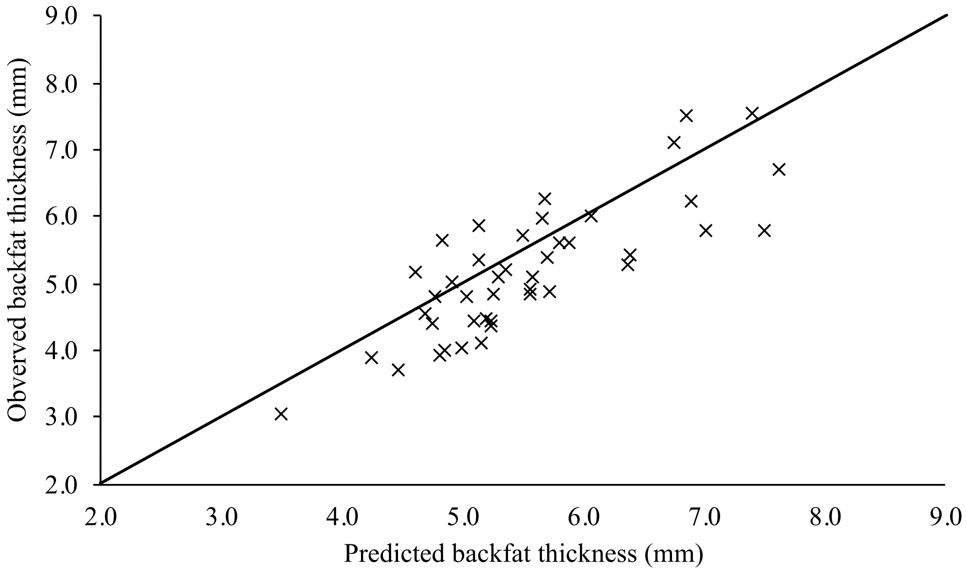

Figure 6.2 - Relationship between the observed and predicted backfat thickness of beef cattle.

WEIGHT LOSS DURING TRANSPORTATION

Andrade (2021) evaluated the effects of transportation on total BW (kg) and rate (kg/h) of BW loss, as well as the fractional rate of BW loss (% BW/h) of beef cattle in Brazilian conditions. Twenty Nellore growing bulls were used. Briefly, all animals were weighed (weight before transportation), transported for 8.45 h in a commercial livestock truck for 320.9 km, and weighed immediately after completing the journey (weight after transportation). Then, total weight loss (kg), weight loss as function of transport duration (kg/h), and the fractional weight loss rate (% BW/h) were calculated (Table 6.12).

Table 6.12 - Weight loss of beef cattle during transportation in Brazil, adapted from Andrade (2020)

Body weight		Weight loss		
Before transportation (kg)	After transportation (kg)	kg	kg/h	% BW/h
274	261	13.0	1.54	0.56
272	265	7.00	0.83	0.31
255	244	11.0	1.3	0.51
250	235	15.0	1.78	0.71
236	229	7.50	0.89	0.38
265	253	12.0	1.42	0.54
273	259	14.0	1.66	0.61
265	250	15.0	1.78	0.67
246	234	12.0	1.42	0.58
241	227	14.0	1.66	0.69
300	283	17.0	2.01	0.67
297	280	17.0	2.01	0.68
252	243	9.00	1.07	0.42
233	221	12.0	1.42	0.61
245	229	16.0	1.89	0.77
302	287	15.0	1.78	0.59
250	239	11.0	1.3	0.52
278	263	15.0	1.78	0.64
230	225	5.00	0.59	0.26
235	223	12.0	1.42	0.60
Average		12.5	1.48	0.57

On average, the weight loss experienced by cattle was: 12.5 kg, 1.48 kg/h, and 0.57 % BW/h. Considering the total duration of transportation (8.45 h), the growing Nellore bulls in Andrade (2021) study lost approximately 4.80 % BW, on average.

Schwartzkopf-Genswein and Grandin (2019) summarized studies conducted in North America evaluating the effects of transportation on productivity and health of cattle. Authors reported that transportation durations between 2 and 48 h resulted in weight loss values between 0 and 8% of BW. Many factors such as cattle category, handling at loading and unloading, drivers experience and training, loading density, environmental and vehicle conditions, and transportation distance and duration were associated with the severity of weight loss.

González et al. (2012), evaluating the factors affecting cattle shrink, reported BW loss from 4.90 to 7.94 % BW in cattle (calves, growing, finishing, and cull cattle) transported in long haul (> 400 km) from 11.6 to 14.9 h in Canada. Also, the authors found that calves, growing, and cull cattle as well as cattle loaded during afternoon and evening appeared to be more affected by transportation than finishing cattle and those loaded during the night and the morning, respectively, because of greater shrink.

Moreover, weight loss of 4.6, 6.5, and 7.0% of BW was observed in steers when transported for 5, 10, and 15 h, respectively (Warriss et al., 1995). Studies performed in Chile corroborate with the previous findings, where weight loss of about 3.5 and 12.5 % of BW were reported in weaned beef calves transported for short (3 h) and long (63 h) journeys, respectively (Werner et al., 2013; Bravo et al., 2018).

Thus, cattle will be subjected to weight loss when they are moved, however, the weight loss rate (% of BW/h) during transportation seems to be variable, and the greatest proportion of BW loss will occur during the early hours of feed and water deprivation (Knowles et al., 1999; Coffey et al., 2001). Weight loss rate calculated from Warriss et al. (1995) study was 0.92, 0.65, and 0.46 % of BW/h for steers transported for 5, 10, and 15 h, respectively, while Andrade (2021) reported an average BW loss rate of 0.57 % of BW/h for Nellore bulls that travelled for 8.45 h.

Studies evaluating the effects of transportation on the productive performance (specially BW loss) of beef cattle under Brazilian conditions are scarce. However, it seems that the results of Andrade (2021) corroborate with the discussion previously performed along this chapter. Nonetheless, caution must be taken when considering the results herein presented, as cattle weight loss due to transportation is dependent on other factors, such as cattle category, management, and environmental conditions.

FINAL CONSIDERATIONS

The equations presented in this chapter correctly estimated and, therefore, are recommended to estimate CW and BFT of beef cattle. We hope that these equations contribute for the production of more homogeneous carcasses and help the decision-making process in the beef cattle production system.

SUMMARY OF EQUATIONS AND PREDICTIONS

We suggest the use of the following equations described below to predict CW and BFT of beef cattle.

Carcass weight:

Eq. 6.1. Linear equation

$$cCW = -11.0 + P + ((0.6094 + G + B) \times SBW),$$

where

cCW = commercial carcass weight (kg); P = slaughter procedure effect (if commercial = -10.98, if experimental = 0), G = gender effect (if steer = 0, if bull = 0.008169, and if heifer = -0.00612), B = genotype effect (if Zebu = 0, if beef crossbred = -0.01595, and if dairy crossbred = -0.03301), and SBW = shrunk body weight (kg).

Eq. 6.4. Non-linear equation

$$cCW\ (kg) = 0.9391 \times (0.41764 \times SBW^{\beta 1})$$

where

cCW = commercial carcass weight (kg);; SBW = shrunk body weight (kg); β1 = genotype and gender effect, if Zebu bull = 1.0583, if crossbred beef bull = 1.0561, if crossbred dairy bull = 1.0479, if Zebu steer = 1.0549, if crossbred beef steer = 1.0527, if crossbred dairy steer = 1.0445, if Zebu heifer = 1.0533, if crossbred beef heifer = 1.0511, and if crossbred dairy heifer = 1.0429;

Eq. 6.5. Backfat thickness:

$$BFT = -2.37 + 0.709 \times ADG + cCW \times G,$$

where BFT = backfat thickness (mm), ADG = average daily gain (kg/d), cCW = commercial carcass weight (kg), and G = interaction between genotype and gender effect (if Zebu bull = 0.0238, if Zebu steer = 0.03043, If Zebu heifer = 0.03545, if crossbred beef bull = 0.02705, if crossbred beef steer = 0.03368, if crossbred beef heifer = 0.03871, if crossbred dairy bull = 0.01770, if crossbred dairy steer = 0.02433, and if crossbred dairy heifer = 0.02935.

In Tables 6.13 (linear CW equation, Eq. 6.1), 6.14 (non-linear CW equation, Eq. 6.4), and 6.15 (BFT equation, Eq. 6.5), predictions of CW and BFT for Zebu, crossbred, beef and dairy cattle are presented for different gender, slaughter in experimental and commercial conditions.

Table 6.13 - Carcass weight estimations[1] of beef cattle with different shrunk body weight (SBW), from Eq. 6.1, Benedeti et al. (2021)

Item	Experimental[2]			Commercial[2]		
	Zebu	Crossbred beef cattle	Crossbred dairy cattle	Zebu	Crossbred beef cattle	Crossbred dairy cattle
350 kg of SBW						
Heifer, kg	200	195	189	189	184	178
Steer, kg	202	197	191	191	186	180
Bull, kg	205	200	194	194	189	183
450 kg of SBW						
Heifer, kg	260	253	246	249	242	235
Steer, kg	263	256	248	252	245	237
Bull, kg	267	260	252	256	249	241
550 kg of SBW						
Heifer, kg	321	312	303	310	301	292
Steer, kg	324	315	306	313	304	295
Bull, kg	329	320	310	318	309	299

[1]Carcass weight (kg) = −11.03 + P + ((0.6094 + G + B) × SBW), where P = slaughter plant effect (if commercial = −10.98, if experimental =0), G = gender effect (if steer = 0, if bull = 0.008169 and if heifer = −0.00612), B = genotype effect (if Zebu = 0, if beef crossbreds = −0.01595, and if dairy crossbred = −0.03301), and SBW = shrunk BW (kg).
[2]Experimental = independent data of animals slaughtered in an experimental plant without carcass dressing/trimming; Commercial = independent data of animals slaughtered in a commercial abattoir.

Table 6.14 - Carcass weight estimations of beef cattle with different shrunk body weights (SBW), from Eq.6.2 and 6.3

Item	Experimental[1]			Commercial[2]		
	Zebu	Crossbred beef cattle	Crossbred dairy cattle	Zebu	Crossbred beef cattle	Crossbred dairy cattle
350 kg of SBW						
Heifer, kg	200	197	188	188	185	176
Steer, kg	202	199	190	189	187	178
Bull, kg	206	203	194	193	191	182
450 kg of SBW						
Heifer, kg	260	257	244	244	241	229
Steer, kg	263	259	247	247	244	232
Bull, kg	268	265	252	252	249	236
550 kg of SBW						
Heifer, kg	322	317	301	302	298	283
Steer, kg	325	320	304	305	301	286
Bull, kg	332	327	311	312	307	292

[1]$eCW = 0.41764 \times SBW^{\beta 1}$, where eCW = experimental carcass weight (kg); SBW = shrunk body weight (kg); β1 = genotype and gender effect, if Zebu bull = 1.0583, if crossbred beef bull = 1.0561, if crossbred dairy bull = 1.0479, if Zebu steer = 1.0549, if crossbred beef steer = 1.0527, if crossbred dairy steer = 1.0445, if Zebu heifer = 1.0533, if crossbred beef heifer = 1.0511, and if crossbred dairy heifer = 1.0429;
[2]$cCW = 0.9391 \times eCW$, where cCW = commercial carcass weight (kg).

Table 6.15 - Backfat thickness estimations[1] of beef cattle with different carcass weights (cCW) and average daily gains (ADG), from eq.6.5

Item	Zebu			Crossbred beef cattle			Crossbred dairy cattle		
cCW, kg	200	260	320	200	260	320	200	260	320
0.5 kg of ADG									
Heifer, mm	5.07	7.20	9.33	5.73	8.05	10.37	3.85	5.62	7.38
Steer, mm	4.07	5.90	7.72	4.72	6.74	8.76	2.85	4.31	5.77
Bull, mm	2.74	4.17	5.60	3.39	5.02	6.64	1.52	2.59	3.65
1.0 kg of ADG									
Heifer, mm	5.43	7.56	9.68	6.08	8.40	10.73	4.21	5.97	7.73
Steer, mm	4.43	6.25	8.08	5.08	7.10	9.12	3.21	4.66	6.12
Bull, mm	3.10	4.53	5.96	3.75	5.37	7.00	1.88	2.94	4.00
1.5 kg of ADG									
Heifer, mm	5.78	7.91	10.04	6.44	8.76	11.08	4.56	6.32	8.09
Steer, mm	4.78	6.61	8.43	5.43	7.45	9.47	3.56	5.02	6.48
Bull, mm	3.45	4.88	6.31	4.10	5.73	7.35	2.23	3.30	4.36

[1]BFT = -2.37 + 0.709 × ADG + cCW × G; where BFT = backfat thickness (mm), ADG = average daily gain (kg/d), cCW = commercial carcass weight, and G = interaction between genotype and gender effect (if Zebu bull = 0.0238, if Zebu steer = 0.03043, If Zebu heifer = 0.03545, if crossbred beef bull = 0.02705, if crossbred beef steer = 0.03368, if crossbred beef heifer = 0.03871, if crossbred dairy bull = 0.01770, if crossbred dairy steer = 0.02433, and if crossbred dairy heifer = 0.02935.

REFERENCES

Abraham, H. C., Z. L. Carpenter, G. T. King, and O. D. Butler. 1968. Relationships of carcass weight, conformation and carcass measurements and their use in predicting beef carcass cutability. *J Anim Sci*. 27:604–610. doi:0.2527/jas1968.273604x.

Agricultural Research Council. *The Nutrient Requirements of Ruminant Livestock*. 1980. Commonwealth Agricultural Bureau. The Gresham Press, London.

Alves, D. D., M. F. Paulino, A. A. Backes, S. de C. Valadares Filho, and L. N. Rennó. 2004. Características de carcaça de bovinos zebu e cruzados holandês-zebu (F1) nas fases de recria e terminação. *Revista Brasileira de Zootecnia*. 33:1274–1284. doi:10.1590/S1516-35982004000500020.

Amaral, P. M., L. D. S. Mariz, D. Zanetti, L. F. Prados, M. I. Marcondes, S. A. Santos, E. Detmann, A. P. Faciola, and S. C. Valadares Filho. 2018. Effect of dietary protein content on performance, feed efficiency and carcass traits of feedlot Nellore and Angus × Nellore cross cattle at different growth stages. *Journal of Agricultural Science.* 156:110–117. doi:10.1017/S0021859617000958.

Andrade, D. R. de. 2021. *Desempenho e exigências nutricionais de bovinos alimentados com dietas contendo diferentes blends vitamínicos*. Available from: https://locus.ufv.br//handle/123456789/28052.

Arboitte, M. Z., J. Restle, D. C. Alves Filho, L. L. Pascoal, P. S. Pacheco, and D. C. Soccal. 2004. Características da carcaça de novilhos 5/8 Nelore-3/8 Charolês abatidos em diferentes estádios de desenvolvimento. *Revista Brasileira de Zootecnia.* 33:969–977. doi:10.1590/S1516-35982004000400017.

Assis, G. J. de F. 2021. *Análise de imagens na caracterização biométrica e avaliação da carcaça de bovinos.* Tese (Doutorado) Programa de Pós Graduação em Zootecnia, Universidade Federal de Viçosa, Viçosa - MG.

Benedeti, P. D. B., S. C. Valadares Filho, M. L. Chizzotti, M. I. Marcondes, and F. A. de S. Silva. 2021. Development of equations to predict carcass weight, empty body gain, and retained energy of Zebu beef cattle. *Animal.* 15. doi:10.1016/j.animal.2020.100028.

Berg, R. T., and R. M. Butterfield. 1976. *New concepts of cattle growth*. Macarthur Press, Sydney.

Bertrand, J. K., R. L. Willham, and P. J. Berger. 1983. Beef, Dairy and Beef × Dairy Carcass Characteristics. *Journal Animal Science*. 57:1440–1448. doi:10.2527/jas1983.5761440x.

Bethancourt-Garcia, J. A., R. Z. Vaz, F. N. Vaz, W. B. Silva, L. L. Pascoal, F. S. Mendonça, C. C. da Vara, A. J. C. Nuñez, and J. Restle. 2019. Pre-slaughter factors affecting the incidence of severe bruising in cattle carcasses. *Livestock Science*. 222:41–48. doi:10.1016/j.livsci.2019.02.009.

Bhatt, N., N. Singh, A. Mishra, D. Kandpal, R. Rajneesh, and S. Jamwal. 2021. A detailed review of transportation stress in livestock and its mitigation techniques. *International Journal of Livestock Research.* 1. doi:10.5455/ijlr.20201109102902.

Bravo, V., C. Gallo, and G. Acosta-Jamett. 2018. Effects of short transport and prolonged fasting in beef calves. *Animals*. 8. doi:10.3390/ani8100170.

Bruns, K. W., R. H. Pritchard, and D. L. Boggs. 2004. The relationships among body weight, body composition, and intramuscular fat content in steers1. *Journal Animal Science*. 82:1315–1322. doi:10.2527/2004.8251315x.

Brasileiro, L.A.A., 2023. *Avaliação de equações na predição de peso de carcaça e espessura de gordura subcutânea em bovinos.* Dissertação (Mestrado). Programa de Mestrado Profissional em Zootecnia, Universidade Federal de Viçosa, Viçosa - MG.

Camfield, P. K., A. H. Brown, P. K. Lewis, L. Y. Rakes, and Z. B. Johnson. 1996. *Effects of Frame Size and Time-on-Feed on Carcass Characteristics, Sensory Attributes, and Fatty Acid Profiles of Steers*.

Clímaco, S. M., E. L. de A. Ribeiro, I. Y. Mizubuti, L. das D. F. da Silva, M. A. A. de F. Barbosa, and A. M. Bridi. 2011. Desempenho e características de carcaça de bovinos de corte de quatro grupos genéticos terminados em confinamento. *Revista Brasileira de Zootecnia*. 40:1562–1567.

Coffey, K. P., W. K. Coblentz, J. B. Humphry, and F. K. Brazle. 2001. REVIEW: Basic Principles and Economics of Transportation Shrink in Beef Cattle. *Prof Animal Science*. 17:247–255. doi:10.15232/S1080-7446(15)31636-3.

Costa, D., J. B. R. de Abreu, R. de C. Mourão, J. C. G. da Silva, V. C. Rodrigues, J. C. Sousa, and R. A. F. de S. Marques. 2007. Características de carcaça de novilhos inteiros Nelore e F1 Nelore × Holandês. *Ciência Animal Brasileira*. 8:685–694.

Costa, E. C. da, J. Restle, F. N. Vaz, D. C. Alves Filho, R. A. L. C. Bernardes, and F. Kuss. 2002. Características da Carcaça de Novilhos Red Angus Superprecoces Abatidos com Diferentes Pesos. *Revista Brasileira de Zootecnia*. 31:119–128. doi:10.1590/S1516-35982002000100014.

Crouse, J. D., L. v. Cundiff, R. M. Koch, M. Koohmaraie, and S. C. Seideman. 1989. Comparisons of and Inheritance for Carcass Beef Characteristics and Meat Palatability. *Journal Animal Science*. 67:2661. doi:10.2527/jas1989.67102661x.

Cruz, G. M. da, R. R. Tullio, S. N. Esteves, M. M. de Alencar, and C. A. Cordeiro. 2004. Peso de abate de machos não-castrados para produção do bovino jovem. 2. Peso, idade e características da carcaça. *Revista Brasileira de Zootecnia.* 33:646–657. doi:10.1590/S1516-35982004000300013.

Domínguez-Viveros, J., F. A. Rodríguez-Almeida, G. N. Aguilar-Palma, F. Castillo-Rangel, J. F. Saiz-Pineda, and C. Villegas-Gutiérrez. 2020. Fitting of non-linear models to characterize the growth of five zebu cattle breeds. *Livestock Science*. 242. doi:10.1016/j.livsci.2020.104303.

Euclides Filho, K., V. P. B. Euclides, G. R. Figueiredo, and et al. 1997. Avaliação de animais Nelore e de seus mestiços com Charolês, Fleckvieh, e Chianina, em três dietas. 2. Características de carcaça. *Revista Brasileira de Zootecnia.* 26:73–79.

Fernandes, H. J., M. F. Paulino, R. G. R. Martins, S. de C. Valadares Filho, R. de A. Torres, L. M. Paiva, and A. T. S. da Silva. 2004. Composição corporal de garrotes inteiros de três grupos genéticos nas fases de recria e terminação. *Revista Brasileira de Zootecnia*. 33:1581–1590. doi:10.1590/S1516-35982004000600026.

Fitzhugh, H. A., C. R. Long, and T. C. Cartwright. 1975. Systems Analysis of Sources of Genetic and Environmental Variation in Efficiency of Beef Production: Heterosis and Complementarity. *Journal Animal Science*. 40:421–432. doi:10.2527/jas1975.403421x.

Fortin, A., S. Simpfendorfer, J. T. Reid, H. J. Ayala, R. Anrique, and A. F. Kertz. 1980. Effect of level of energy intake and influence of breed and sex on the chemical composition of cattle. *Journal Animal Science*. 51:604–614. doi:10.2527/jas1980.513604x.

Gesualdi Júnior, A., M. F. Paulino, S. de C. Valadares Filho, J. F. Coelho da Silva, C. M. Veloso, and P. R. Cecon. 2000. Níveis de concentrado na dieta de novilhos F1 Limousin x Nelore: características de carcaça. *Revista Brasileira de Zootecnia*. 29:1467–1473. doi:10.1590/S1516-35982000000500027.

Gomide, L. A. de M., E. M. Ramos, and P. R. Fontes. 2014. *Tecnologia de Abate e tipificação de carcaças*. Segunda. Editora UFV, Viçosa.

González, L. A., K. S. Schwartzkopf-Genswein, M. Bryan, R. Silasi, and F. Brown. 2012. Factors affecting body weight loss during commercial long haul transport of cattle in North America1. *Journal Animal Science*. 90:3630–3639. doi:10.2527/jas.2011-4786.

Gray, E. F., F. A. Thrift, and C. W. Absher. 1978. Heterosis Expression for Preweaning Traits under Commercial Beef Cattle Conditions. *Journal Animal Science.* 47:370–374. doi:10.2527/jas1978.472370x.

Hassen, A., D. E. Wilson, and G. H. Rouse. 1998. *Evaluation of Carcass, Live, and Real-Time Ultrasound Measures in Feedlot Cattle*: I. Assessment of Sex and Breed Effects.

Hicks, R. B., F. N. Owens, D. R. Gill, and et al. 1987. *The effect of slaughter date on carcass gain and carcass characteristics of feedlot steers.*

Huertas, S. M., F. van Eerdenburg, A. Gil, and J. Piaggio. 2015. Prevalence of carcass bruises as an indicator of welfare in beef cattle and the relation to the economic impact. *Vet Med Sci*. 1:9–15. doi:10.1002/vms3.2.

Huertas, S. M., J. Piaggio, S. Huertas, A. Gil, and F. van Eerdenburg. 2010. Transportation of beef cattle to slaughterhouses and how this relates to animal welfare and carcase bruising in an extensive production system. *Animal* Welfare. 19:281–285.

Jones, S. D. M., A. L. Schaefer, A. K. W. Tong, and B. C. Vincent. 1988. The effects of fasting and transportation on beef cattle. 2. Body component changes, carcass composition and meat quality. *Livestock Prodoction Science*. 20:25–35. doi:10.1016/0301-6226(88)90051-6.

Jorge, A. M., C. A. de A. Fontes, M. F. Paulino, P. Gomes Júnior, and J. N. Ferreira. 1999. Desempenho produtivo de animais de quatro raças zebuínas, abatidos em três estádios de maturidade: 2. características da carcaça. *Revista Brasileira de Zootecnia*. 28:381–387. doi:10.1590/S1516-35981999000200023.

Knowles, T. G., S. N. Brown, J. E. Edwards, A. J. Phillips, and P. D. Warriss. 1999. Effect on young calves of a one-hour feeding stop during a 19-hour road journey. *Veterinary Record*. 144:687–692. doi:10.1136/vr.144.25.687.

Lage, J. F., P. V. R. Paulino, S. C. V. Filho, E. J. O. Souza, M. S. Duarte, P. D. B. Benedeti, N. K. P. Souza, and R. B. Cox. 2012. Influence of genetic type and level of concentrate in the finishing diet on carcass and meat quality traits in beef heifers. *Meat Science*. 90:770–774. doi:10.1016/j.meatsci.2011.11.012.

Leme, P. R., S. da L. e Silva, A. S. C. Pereira, S. M. Putrino, D. P. D. Lanna, and J. C. M. Nogueira Filho. 2003. Utilização do bagaço de cana-de-açúcar em dietas com elevada proporção de concentrados para novilhos Nelore em confinamento. *Revista Brasileira de Zootecnia*. 32:1786–1791. doi:10.1590/S1516-35982003000700029.

Lôbo, R. N. B., Jo. A. M. Martins, C. H. M. Malhado, R. M. Filho, and A. A. A. Moura. 2002. Correlaçõess entre características de crescimento, abate e medidas corporais em tourinhos da raça Nelore. *Revista Ciência Agronômica*. 33:5–12.

Luchiari Filho, A. 2000. *Pecuária da carne bovina*. R Vieira Gráfica e Editora, São Paulo.

Marcondes, M. I., S. de C. Valadares Filho, I. M. de Oliveira, P. V. R. Paulino, R. F. D. Valadares, and E. Detmann. 2011. Eficiência alimentar de bovinos puros e mestiços recebendo alto ou baixo nível de concentrado. *Revista Brasileira de Zootecnia*. 40:1313–1324. doi:10.1590/S1516-35982011000600021.

Marques, R. S., R. F. Cooke, C. L. Francisco, and D. W. Bohnert. 2012. Effects of twenty-four hour transport or twenty-four hour feed and water deprivation on physiologic and performance responses of feeder cattle 1. *Journal Animal Science*. 90:5040–5046. doi:10.2527/jas2012-5425.

May, S. G., H. G. Dolezal, D. R. Gill, F. K. Ray, and D. S. Buchanan. 1992. Effect of days fed, carcass grade traits, and subcutaneous fat removal on postmortem muscle characteristics and beef palatability. *Journal Animal Science*. 70:444–453. doi:10.2527/1992.702444x.

Mendonça, F. S., R. Z. Vaz, W. S. Leal, J. Restle, L. L. Pascoal, M. B. Vaz, and G. D. Farias. 2016. Genetic group and horns presence in bruises and economic losses in cattle carcasses. *Semina: Ciencias Agrarias*. 37:4265–4274. doi:10.5433/1679-0359.2016v37n6p4265.

Mendonça, F. S., R. Z. Vaz, F. N. Vaz, W. S. Leal, I. D. B. Silveira, J. Restle, A. A. Boligon, and F. F. Cardoso. 2019. Causes of bruising in carcasses of beef cattle during farm, transport, and slaughterhouse handling in Brazil. *Animal Science Journal*. 90:288–296. doi:10.1111/asj.13151.

Moreira, A. D., G. R. Siqueira, J. F. Lage, J. M. B. Benatti, M. H. Moretti, G. Z. Miguel, I. M. de Oliveira, and F. D. de Resende. 2018. Castration methods in crossbred cattle raised on tropical pasture. *Animal Production Science*. 58:1307. doi:10.1071/AN16580.

NASEM. 2016. *Nutrient Requirements of Beef Cattle*. Eighth Rev. The National Academies Press, Washington, DC.

Neto, O. C., V. C. Rodrigues, D. Pereira Borges Da Costa, F. Dias Medeiros, D. H. Vieira, A. M. Camargo, and F. Teixeira De Pádua. 2010. Avaliação de algumas características da carcaça de bovinos e bubalinos. *Revista Brasileira de Medicina Veterinária*. 32:151–160.

Nour, A. Y. M., M. L. Thonney, and J. R. Stouffer. 1981. Muscle , fat and bone in serially slaughtered large dairy or small beef cattle fed corn or corn silage diets in one of two locations. 52:512–521. doi:10.2527/jas1981.523512x.

Nour, A. Y. M., M. L. Thonney, J. R. Stouffer, and W. R. C. White Jr. 1983. Changes in carcass weight and characteristics with increasing weight of large and small cattle. *Journal Animal Science*. 57:1154–1165. doi:10.2527/jas1983.5751154x.

Oliveira, E. A. de, A. A. M. Sampaio, A. R. M. Fernandes, W. Henrique, R. V. Oliveira, and G. M. Ribeiro. 2009. Desempenho e características de carcaça de tourinhos Nelore e Canchim terminados em confinamento recebendo dietas com cana-de-açúcar e dois níveis de concentrado. *Revista Brasileira de Zootecnia*. 38:2465–2472. doi:10.1590/S1516-35982009001200024.

Oliveira, I. M. de, P. V. R. Paulino, S. de C. Valadares Filho, E. Detmann, M. F. Paulino, L. A. de M. Gomide, M. de S. Duarte, and V. R. M. Couto. 2011. Carcass traits of Nellore, F1 Simmental × Nellore and F1 Angus × Nellore steers fed at maintenance or ad libitum with two concentrate levels in the diet. *Revista Brasileira de Zootecnia*. 40:2938–2946. doi:10.1590/S1516-35982011001200042.

Owens, F. N., P. Dubeski, and C. F. Hanson. 1993. Factors that alter the growth and development of ruminants. *Journal Animal Science*. 71:3138–3150. doi:10.2527/1993.71113138x.

Paranhos da Costa, M. J. R., S. M. Huertas, C. Gallo, and O. A. Dalla Costa. 2012. Strategies to promote farm animal welfare in Latin America and their effects on carcass and meat quality traits. *Meat Science*. 92:221–226. doi:10.1016/j.meatsci.2012.03.005.

Pascoal, L. L., F. N. Vaz, R. Z. Vaz, J. Restle, P. S. Pacheco, and J. P. A. dos Santos. 2011. Relações comerciais entre produtor, indústria e varejo e as implicações na diferenciação e precificação de carne e produtos bovinos não-carcaça. *Revista Brasileira de Zootecnia*. 40:82–92.

Paulino, P. V. R., S. de C. Valadares Filho, E. Detmann, R. F. D. Valadares, M. A. Fonseca, and M. I. Marcondes. 2009. Deposição de tecidos e componentes químicos corporais em bovinos Nelore de diferentes classes sexuais. *Revista Brasileira de Zootecnia*. 38:2516–2524. doi:10.1590/S1516-35982009001200030.

Paulino, P. V. R., S. de C. Valadares Filho, E. Detmann, R. F. D. Valadares, M. A. Fonseca, R. M. L. Véras, and D. M. Oliveira. 2008. Desempenho produtivo de bovinos Nelore de diferentes classes sexuais alimentados com dietas contendo dois níveis de oferta de concentrado. *Revista Brasileira de Zootecnia*. 37:1079–1087. doi:10.1590/S1516-35982008000600019.

Plasse, D., H. Fossi, R. Hoogesteijn, O. Verde, R. Rodríguez, C. M. Rodríguez, and P. Bastidas. 1995. Growth of F1Bos taurus × Bos indicus versus Bos indicus beef cattle in Venezuela. I. Weights at birth, weaning and 18 months. *Journal of Animal Breeding and Genetics*. 112:117–132. doi:10.1111/j.1439-0388.1995.tb00548.x.

Restle, J., L. F. G. de Menezes, M. Z. Arboitte, L. L. Pascoal, P. S. Pacheco, and J. T. Pádua. 2005. Características das partes não-integrantes da carcaça de novilhos 5/8Nelore 3/8Charolês abatidos em três estádios de desenvolvimento. *Revista Brasileira de Zootecnia*. 34:1339–1348. doi:10.1590/S1516-35982005000400031.

Ribeiro, T. R., J. C. Pereira, M. V. M. de Oliveira, A. C. de Queiroz, P. R. Cecon, M. I. Leão, and R. C. de A. e Melo. 2001. Características da Carcaça de Bezerros Holandeses para Produção de Vitelos Recebendo Dietas com Diferentes Níveis de Concentrado. *Revista Brasileira de Zootecnia*. 30:2154–2162. doi:10.1590/S1516-35982001000800026.

Rocha Junior, V. R., F. V. e Silva, R. C. de Barros, S. T. dos Reis, M. D. da Costa, A. S. Souza, L. A. Caldeira, T. S. de Oliveira, and L. L. dos S. Oliveira. 2010. Desempenho e características de carcaça de bovinos Nelore e mestiços terminados em confinamento. *Revista Brasileira de Saúde e Produção Animal*. 11:865–875.

Schwartzkopf-Genswein, K., J. Ahola, L. Edwards-Callaway, D. Hale, and J. Paterson. 2016. SYMPOSIUM PAPER: Transportation issues affecting cattle well-being and considerations for the future. *Professional Animal Scientist*. 32:707–716. doi:10.15232/pas.2016-01517.

Schwartzkopf-Genswein, K., and T. Grandin. 2019. Cattle transport in North America. In: *Livestock handling and transport*. CABI, UK. p. 153–183.

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

Silva, S. da L. e, P. R. Leme, A. S. C. Pereira, and S. M. Putrino. 2003. Correlações entre características de carcaça avaliadas por ultra-som e pós-abate em novilhos Nelore, alimentados com altas proporções de concentrado. *Revista Brasileira de Zootecnia*. 32:1236–1242. doi:10.1590/S1516-35982003000500026.

Silva, S. da L. e, P. R. Leme, S. M. Putrino, and D. P. D. Lanna. 2006. Alterações nas características de carcaça de tourinhos Nelore, avaliadas por ultra-som. *Revista Brasileira de Zootecnia*. 35:607–612. doi:10.1590/S1516-35982006000200038.

Strappini, A. C., K. Frankena, J. H. M. Metz, B. Gallo, and B. Kemp. 2010. Prevalence and risk factors for bruises in Chilean bovine carcasses. *Meat Science*. 86:859–864. doi:10.1016/j.meatsci.2010.07.010.

Strappini, A. C., K. Frankena, J. H. M. Metz, C. Gallo, and B. Kemp. 2012. Characteristics of bruises in carcasses of cows sourced from farms or from livestock markets. In: *Animal*. Vol. 6. p. 502–509.

Tarouco, J. U., J. F. P. Lobato, A. K. Tarouco, and G. dos S. Massia. 2005. Relação entre medidas ultra-sônicas e espessura de gordura subcutânea ou área de olho de lombo na carcaça em bovinos de corte. *Revista Brasileira de Zootecnia*. 34:2074–2084. doi:10.1590/S1516-35982005000600033.

Tedeschi, L. O. 2006. Assessment of the adequacy of mathematical models. *Agric Syst*. 89:225–247. doi:10.1016/j.agsy.2005.11.004.

Valadares Filho, S. de C., L. F. Costa e Silva, M. P. Gionbelli, P. P. Rotta, M. I. Marcondes, M. L. Chizzotti, and L. F. Prados. 2016. *Nutrient Requirements of Zebu and Crossbred Cattle* - BR-CORTE. 3 rd. Suprema Gráfica Ltda.

Van Engen, N. K., and J. F. Coetzee. 2018. Effects of transportation on cattle health and production: A review. *Anim Health Res Rev*. 19:142–154. doi:10.1017/S1466252318000075.

Vaz, F. N., and J. Restle. 2000. Aspectos qualitativos da carcaça e da carne de machos Hereford, inteiros ou castrados, abatidos aos quatorze meses. *Revista Brasileira de Zootecnia*. 29:1894–1901. doi:10.1590/S1516-35982000000600040.

Vaz, F. N., J. Restle, M. Z. Arboitte, L. L. Pascoal, C. Faturi, and G. Joner. 2010. Fatores relacionados ao rendimento de carcaça de novilhos ou novilhas superjovens, terminados em pastagem cultivada. *Ciência Animal Brasileira*. 11. doi:10.5216/cab.v11i1.6747.

Véras, A. S. C., S. de C. Valadares Filho, J. F. Coelho da Silva, M. F. Paulino, P. R. Cecon, R. F. D. Valadares, M. de A. Ferreira, and C. M. S. Fontes. 2001. Efeito do nível de concentrado sobre o peso dos órgãos internos e do conteúdo gastrintestinal de bovinos Nelore não-castrados. *Revista Brasileira de Zootecnia*. 30:1120–1126. doi:10.1590/S1516-35982001000400029.

Vittori, A., A. C. de Queiroz, F. D. de Resende, A. Gesualdi Júnior, G. F. Alleoni, A. G. Razook, L. A. de Figueiredo, and A. C. L. de S. Gesualdi. 2006. Características de carcaça de bovinos de diferentes grupos genéticos, castrados e não-castrados, em fase de terminação. *Revista Brasileira de Zootecnia*. 35:2085–2092. doi:10.1590/S1516-35982006000700028.

Waldo, D. R., G. A. Varga, G. B. Huntington, B. P. Glenn, and H. F. Tyrrell. 1990. Energy components of growth in Holstein steers fed formaldehyde- and formic acid-treated alfalfa or orchard grass silages at equalized intakes of dry matter. *Journal Animal Science*. 68:3792. doi:10.2527/1990.68113792x.

Warriss, P., S. Brown, T. Knowles, S. Kestin, J. Edwards, S. Dolan, and A. Phillips. 1995. Effects on cattle of transport by road for up to 15 hours. *Veterinary Record*. 136:319–323. doi:10.1136/vr.136.13.319.

Werner, M., C. Hepp, C. Soto, P. Gallardo, H. Bustamante, and C. Gallo. 2013. Effects of a long distance transport and subsequent recovery in recently weaned crossbred beef calves in Southern Chile. *Livestock Science*. 152:42–46. doi:10.1016/j.livsci.2012.12.007.

Williams, J. L., I. Aguilar, R. Rekaya, and J. K. Bertrand. 2010. Estimation of breed and heterosis effects for growth and carcass traits in cattle using published crossbreeding studies. *Journal Animal Science*. 88:460–466. doi:10.2527/jas.2008-1628.

Yar, M. K., M. H. Jaspal, S. Ali, M. Ijaz, I. H. Badar, and J. Hussain. 2022. Carcass characteristics and prediction of individual cuts and boneless yield of Bos indicus and Bos indicus × Bos taurus bulls differing in age. *Livestock Science*. 264. doi:10.1016/j.livsci.2022.105041.

Zanardi, E., S. de Luca, G. L. Alborali, A. Ianieri, M. O. Varrà, C. Romeo, and S. Ghidini. 2022. Relationship between Bruises on Carcasses of Beef Cattle and Transport-Related Factors. *Animals*. 12. doi:10.3390/ani12151997

.