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Sample size and prediction of weight and yield of individual cuts from Braford steers pistol hindquarters

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ABSTRACT: Two hundred seventeen grass-finished Braford steers were assessed by ultrasonic scanning and subsequently harvested with their pistol hindquarters fabricated into boneless wholesale cuts. The *Longissimus thoracis* muscle area and subcutaneous fat depths were measured. The objectives of this study were: 1) to develop prediction equations for weights of the pistol hindquarter and high-value commercial cuts, and 2) to estimate sample size needed for experiments comparing pistol hindquarter retail product weight using either physically or ultrasonically measured carcass traits. Carcass measurements explained 44 % to 94 % of the variation in weights of individual cuts, whereas, measurements that were made using ultrasound explained 42 % to 90 % of the variation in the weights. Models used to predict the weight of pistol hindquarter retail product with carcass measures and ultrasound measures showed high coefficient of determination (R^2 = 0.92 and 0.97, respectively). Whether based on carcass or ultrasound measures, models used to estimate weight percentage of fat trimmed from the pistol hindquarter had lack of fit. In general, models for individual cuts weights that used traits measured with ultrasound as independent variables approached the accuracy of models using carcass traits. Thus, only slightly greater samples sizes were required to have equivalent power to detect differences in retail product weights using ultrasound measures. For experiments of equivalent power, differences in the number of animals required may be offset by avoiding costs for slaughter and fabrication.

Keywords: cattle, carcass, models, ultrasound

Introduction

Prediction of weights of individual cuts may provide a viable alternative for estimating value (Jardim et al., 1991; Teira et al., 2003) and aide in marketing to niches. Selection of independent variables for estimating either weight or yield of the product should include assessment of the difficulty and cost of taking the measurements, and their precision and reliability (Hedrick, 1983).

Further, with cattle fed on grass, subcutaneous fat depth is usually less at harvest than that normally observed in feedlot finished cattle (Kerth et al., 2007). Beef for export from Brazil to the European Economic Community must originate from animals raised exclusively on pasture, gives clear guidance on this issue (EC, No 810/2008). Relatively few studies have assessed regression models to estimate weight and yield of beef cuts from cattle finished on grass (Hopkins and Roberts, 1995). Consequently, a better understanding of fat and muscle deposition by grass-finished cattle may improve the quality of information used in the valuation of carcasses from Brazil. Use of indicator traits to reduce the cost of data collection is a well-accepted practice in genetic evaluation of livestock (Mark et al., 2007; MacNeil and Northcutt, 2008). For ethical and economic reasons, sound experimental design requires use of the minimum number of animals necessary to achieve a desired objective given the required precision (Festing and Altman, 2002).

In the assessment of beef carcasses, differences in a number of animals required for experiments using ultrasound for measuring phenotypes versus those using carcass traits commonly collected after harvest differ in their costs and the former obviate the need for slaughter.

Thus, knowledge of required sample sizes to achieve a pre-determined power-of-the-test for hypotheses regarding weight and yield of beef cuts with each of these paradigms can lead to perceived ethical benefits and reduced cost of experimentation and access of carcass composition. Therefore, the objectives of this study were to develop prediction equations using carcass and ultrasound measures for weight and yield of the pistol hindquarter and individual retail cuts contained therein from animals raised exclusively on pasture, and to estimate the number of experimental units required to achieve equal power-of-the-test when the experimental paradigm is based on these alternatives.

Materials and Methods

The 217 commercial Braford steers used in this study were managed following conventional industry standards as prescribed in the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010). The animals were sampled from two datasets that included those in the study (n = 111) of Tarouco et al. (2007) and an industrial dataset (n = 106) the animals represent the range of potential fabrication

weights and yields expected within the Brazilian beef population. They continuously grazed natural pasture enhanced with spring/winter species (*Lolium multiflorum*, *Trifolium repens*, and *Lotus corniculatus*). During finishing, the last 125 days on pasture, the steers gained an average of 1.116 ± 0.16 kg d⁻¹. Prior to slaughter, at 22.79 ± 3.68 months of age, the steers were held without feed for 12-h. Their average shrunk body weight (SBW) was 400.27 ± 82.60 kg.

Steers were weighed and ultrasonically evaluated 48 h before slaughter. An ALOKA SSD-500 unit, with a 17.2-cm, 3.5MHz linear probe model UST-5044 was used to collect the images. The images were recorded, stored, and saved using the Lince® software for ultrasound image capture and analysis system, *Longissimus thoracis* muscle area (ULMA) and subcutaneous fat thickness (UFAT) were measured between the 12th and the 13th ribs. The UFAT measurement was at ¾ of the lateral distance across the *Longissimus thoracis*. Vegetable oil was used as an acoustic coupling for recording the ULMA and UFAT images and an acoustic rule (standoff) was used to facilitate contact between the transducer and the back of the animal. The images were recorded by an Ultrasound Guidelines Council (UGC) certified technician. Images were interpreted by an UGC-certified laboratory technician using the Lince® software for ultrasound image capture and analysis system.

The steers were slaughtered at the commercial slaughterhouse in Bagé, Rio Grande do Sul, Brazil, 166 and 65 km distant from the farms where they were raised. Hot carcass weight (HCW) was recorded immediately after slaughter. Carcasses were cooled for 24 h after harvest at 2.0 °C and cold carcass weight (CCW), cold weight of the left half of the carcass (CLW), forequarter weight (FQW), rib weight (RW), and pistol hindquarter weight (PHW) were recorded. The carcasses were deboned 48 h after slaughter and carcass *Longissimus thoracis muscle* area (CLMA) at the 12th-13th rib interface was measured by tracing the outline of the muscle on acetate paper and then using a planimeter to determine the inscribed area. Carcass subcutaneous fat thickness (CFAT) at the 12th-13th rib interface was measured directly using a digital caliper.

The pistol hindquarter (1020, UNECE, 2004) was prepared from the entire hindquarter by removing the Thin flank, lateral portion of the ribs, and a portion of the Navel End Brisket (Handbook of Australian Meat, 2005) and trimming fat to approximately 3 mm. Weights of the pistol hindquarter fat trim (PFATTR) and Eye of rump (2093), Inside (2010), Outside flat (2050), Eye of round (2040), Strip loin (2140), Tender loin (2150), Tri-tip (2131), Heel muscle (2364), Shin shank (1680), Knuckle (2070), and Rump cap (2091) were recorded (numeric codes for trade in brackets were produced according to United Nations Economic Commission for Europe Standard (UNECE, 2004). Weights of the individual cuts were summed (HQRTP), percentages of product (HQRTP %), and fat of pistol hindquarter (PFATTR %) were calculated relative to PHW.

Statistical analysis

Descriptive statistics were calculated using PROC MEANS of SAS (Statistical Analysis System, version 9.2). Regression analyses were conducted using the PROC GLMSELECT (SAS, version 9.2) with maximum partial R² as the selection criterion. Significance levels of $p \leq 0.15$ and $p \leq 0.10$ were required for a variable to enter and remain in the model, respectively. Two alternative sets of independent variables were evaluated: 1) "live measures" - SBW, ULMA, and UFAT; and 2) "carcass measures" - HCW, CLMA and CFAT. Root mean square error (RMSE) and Mallows C_p (Mallows, 1973) statistics were used as additional indicators for the goodness of fit. When C_p values are graphed against the number of predictor variables (p), the models with a little bias will tend to cluster near the line where $C_p = p$ (Daniel and Wood, 1980). All models were validated using a k-fold cross validation (n = 5) with Mallows C_p was used as a criterion in the model selection, and the CVPRESS statistics which the fitted model is used to compute the predicted residual sum of squares on the omitted part, this process is repeated for each k fold and the sum of the k predicted residual sum of squares obtained is the estimate of prediction error, the cross validation is stopped when the CVPRESS statistics found the low value between the k folds.

Determination of the required number of experimental units was calculated following MacNeil (1983),

$$N = (3t)^2 / [\Delta / \sqrt{(2 - R_i^2)\sigma_y^2}]^2 ,$$

where t is the number of compared treatments, Δ is the difference in Y among any pair of SD differences (0.25 to 1 SD), R_i^2 is the coefficient of determination of model i (Ultrasound model R² = 0.92, Carcass R² = 0.97, and actual empirical perfect model R² = 1.0), and σ_y^2 is the variance of HQRTP trait.

Carcass and ultrasound equations with greatest R², lower C_p, and lower RMSE for HQRTP and HQRTP % were used to calculate the required sample sizes. A conceptual model with perfect fit was used as comparison control to the proposed models, the perfect fit was adjusted using an empirical model with the model R² = 1.0, like a perfect prediction equation to predict the HQRTP and HQRTP %.

Results and Discussion

Live and carcass measures averages and ranges (Table 1) are consistent with those of animals that are typically slaughtered in Brazil (Millen et al., 2009; Silva et al., 2012).

As expected, due to the part-whole relationship between them, prediction equations for FQW, RW, and PHW consistently had SBW or HCW as the most important independent variable (Table 2). *Longissimus thoracis* muscle area, whether measured using ultrasound was the second most important independent variable in

Table 1 – Means, standard deviations, maximum and minimum values for ultrasound and carcass measurements based on data from 217 Braford steers.

Trait[1]	Mean	SD	Minimum	Maximum
Live measures				
SBW, kg	400.27	82.60	245.00	565.00
UFAT, mm	3.86	1.40	1.00	8.30
ULMA, cm²	60.94	8.66	41.29	87.70
URPFAT, mm	6.55	2.23	2.30	13.46
UGM, mm	85.11	9.19	70.20	114.10
Carcass Measures				
HCW, kg	208.64	42.07	130.20	294.50
CFAT, mm	3.98	1.55	1.40	10.10
CLMA, cm²	60.57	8.93	40.63	89.00
FQW, kg	38.96	7.54	23.80	58.06
RW, kg	14.58	3.95	6.20	23.10
PHW, kg	49.00	9.63	31.50	67.50
INW, kg	6.65	1.48	3.92	10.33
OUTW, kg	3.78	1.04	2.08	7.39
ERUW, kg	2.86	0.74	1.47	4.59
RCW, kg	1.34	0.29	0.74	2.15
KNW, kg	4.00	0.94	2.12	6.01
TTW, kg	1.00	0.25	0.52	1.60
EROW, kg	1.80	0.44	1.06	4.46
SSW, kg	2.16	0.45	1.29	3.77
STLW, kg	7.20	1.30	4.21	10.72
HLW, kg	1.84	0.21	1.08	2.55
TLW, kg	1.49	0.40	0.81	2.90
HQRTP, kg	33.81	7.12	20.85	49.25
PFATR, kg	4.29	0.82	2.44	6.50
HQRTP%	69.20	2.07	64.04	74.78
PFATR%	9.10	2.21	4.34	14.56

[1]SBW = shrunk body weight 12-h fast; UFAT = ultrasound subcutaneous fat thickness between the 12th-13th ribs; ULMA = ultrasound *Longissimus thoracis* muscle area between the 12th-13th ribs; URPFAT = ultrasound rump fat thickness; UGM = ultrasound *Gluteus medius* depth; HCW = hot carcass weight; CFAT = carcass subcutaneous fat thickness between the 12th and the 13th ribs; CLMA = carcass *Longissimus thoracis* muscle area between the 12th and the 13th ribs; FQW = forequarter weight; RW = rib weight, PHW = pistola hindquarter weight (1020); INW = Inside weight (2010), OUTW = outside flat weight (2050); ERUW = Eye rump weight (2093), RCW = Rump cap weight (2091), KNW = Knucle weight (2070), TTW = Tri-tip weight (2131); EROW = Eye round weight (2040), SSW = Shin shank weight (1680); STLW = Strip loin weight (2140); HLW = Heel muscle weight (2364), TLW = Tender loin weight (2150); HQRTP = pistol hindquarter weight of retail product, and PFATR = pistol hindquarter fat trim; HQRTP% = pistol hindquarter percentage of retail product, PFATR% = pistol hindquarter fat percentage. Numeric codes for trade (in brackets) are according United Nations Economic Commission for Europe Standard (UNECE, 2004).

the prediction of FQW and PHW. However, for RW, the subcutaneous fat thickness was consistently the second most important independent variable. The addition of ULMA and UFAT variables to the regressions of PHW and RW on live measures did not result in large increases in R² but did lead to reduced lack of fit ($C_p \approx p$) and reduced residual variance.

Equations of FQW and PHW with carcass measures as independent variables fit better based on R², C_p, and RMSE than equations with live measures as in-

dependent variables (Table 2). However, even the latter equations explained greater than 90 % of the variation in these traits. Most previous attempts to predict weight or percentage of retail product from the pistol hindquarter have found carcass measures to be the more accurate predictors (Tarouco et al., 2007; Silva et al., 2012).

Both here and in Hassen et al. (1999), SBW of the live animal was found to be the most valuable predictor of HCW (Table 3). This was undoubtedly due to the very substantial part-whole relationship of HCW and SBW. In the present study, SBW explained 95 % of the variation in HCW. However, as in Hassen et al. (1999), the univariate regression model had considerable a lack of fit. Adding other indicators of muscularity and fatness to the prediction equation reduced the lack of fit to a more acceptable level while resulting in only minor improvements in RMSE and R².

The equation for predicting HQRTP using live measures was substantially similar to that for prediction of HCW (Table 3). This is again expected, as HQRTP is a substantial portion of HCW. Previous studies have found fat depth measured with ultrasound to be an important predictor of HQRTP (Greiner et al., 2003; Tarouco et al., 2007; Silva et al., 2012; Sakamoto et al., 2014). In the present study, a positive relationship was observed between HQRTP and UFAT, demonstrating that the first variable increases as consequence of the increase of the second. Studies in which the amount of subcutaneous fat are high, the sign of coefficients are negative in relation to the amount of HQRTP (Silva et al., 2012; Sakamoto et al., 2014), as well as the amount of wholesale retail product (Greiner et al., 2003; Sakamoto et al., 2014). However, when the subcutaneous fat are low, the sign of coefficient change for a positive influence for HQRTP (0.150) as demonstrated by Tarouco et al. (2007). It can be explained because adipose is commonly the most variable tissue and its deposition is affected by breed and nutrition (Berg and Butterfield, 1976).

The present study and those cited above vary in both of these regards, perhaps indicating a need for different equations to account for these circumstances or, at a minimum, validation of any more broadly purposed equation. The equation for predicting HQRTP from carcass measures was qualitatively similar to its counterpart using live measures, but only 5 % more accurate.

In the 5-fold cross-validation exercise, the equations developed here were shown to be robust, as they, on average, explained 92 % of the variation in HQRTP trait by ultrasound equation and 97 % by carcass equation in the 1/5th of the data that was held apart for the estimation process (Table 3).

While finding significant partial regression coefficients for prediction of UFAT from live measures, the best equation developed here explained less than 15 % of the variation in it (Table 3). This may be due to UFAT being a relatively small component of HCW. Moreover, prediction of FAT from carcass measures was similar to live measures (Table 3). However, previous studies have

Table 2 – Prediction equations for weights of forequarter, rib, and pistol hindquarter from live and carcass measures based on data from 217 Braford steers.

Dependent variables[1]	Independent variable[2]	Entry order	Intercept	Regression coefficient[3]	RMSE[4]	Cumulative R^2	C_p
FQW, kg	SBW, kg	1	1.664	0.081	2.241	0.91	10.55
	ULMA, cm^2	2		0.078	2.196	0.91	2.63
RW, kg	SBW, kg	1	-5.002	0.044	1.339	0.88	65.17
	UFAT, mm	2		0.461	1.175	0.91	2.26
PHW, kg	SBW, kg	1	-1.364	0.101	2.642	0.92	27.71
	ULMA, cm^2	2		0.137	2.616	0.93	13.63
	UFAT, mm	3		0.435	2.493	0.93	4.00
FQW, kg	HCW, kg	1	3.947	0.182	1.472	0.96	13.68
	CFAT, mm	2		-0.268	1.439	0.96	5.40
	CLMA, kg	3		-0.032	1.430	0.96	4.00
RW, kg	HCW, kg	1	-4.716	0.086	1.275	0.90	27.19
	CFAT, mm	2		0.291	1.201	0.91	3.00
PHW, kg	HCW, kg	1	2.143	0.225	1.319	0.98	3.44

[1]FQW = forequarter weight; RW = rib weight; PHW = pistol hindquarter weight. [2]SBW = shrunk body weight; ULMA = ultrasound *Longissimus thoracis* muscle area between the 12th and the 13th ribs, UFAT = ultrasound subcutaneous fat thickness between the 12th and 13th rib, HCW= hot carcass weight, CLMA= carcass *Longissimus thoracis* muscle area between the 12th and the 13th ribs, CFAT = carcass subcutaneous fat thickness between the 12th and the 13th ribs.[3]Regression coefficient, RMSE, R^2, and C_p are updated in respect to a new independent variable to the prediction equation, the new independent variable is additionally in respect to the $C_p \approx p$ independent variables, and [4]Root-mean-square error.

Table 3 – Prediction equations for hot carcass, retail product, and trimmed fat weights based on data from 217 Braford steers.

Dependent variables[1]	Independent variable[2]	Entry order[3]	Intercept	Regression coefficient	RMSE[4]	Cumulative R^2	C_p
Live measures							
HCW, kg	SBW, kg	1	–11.556	0.459	9.103	0.95	34.229
	ULMA, cm^2	2		0.477	8.919	0.95	21.68
	UFAT, mm	3		1.894	8.489	0.96	4.00
HQRTP, kg	SBW, kg	1	–4.236	0.067	2.190	0.90	46.35
	ULMA, cm^2	2		0.165	2.190	0.92	9.26
	UFAT, mm	3		0.282	1.981	0.92	4.00
FAT,kg	UFAT, mm	1	3.064	0.169	0.819	0.09	6.54
	SBW, kg	2		0.001	0.787	0.11	4.02
HQRTP %	ULMA, cm^2	1	61.865	0.122	1.797	0.25	1.08
PFATR %	SBW, kg	1	15.432	-0.018	1.588	0.48	2.00
	UFAT, mm	2		0.253	1.553	0.51	7.12
Carcass measures							
FAT, kg	CFAT, mm	1	3.990	0.105	0.799	0.09	11.42
	HCW, kg	2		0.006	0.770	0.11	9.41
	CLMA, cm^2	3		-0.025	0.758	0.14	4.00
HQRTP, kg	HCW, kg	1	–2.703	0.148	1.304	0.96	47.86
	CLMA, cm^2	2		0.092	1.174	0.97	3.72
HQRTP %	CLMA, cm^2	1	61.71	0.125	1.756	0.28	4.86
PFATR %	HCW, kg	1	18.187	-0.025	1.614	0.47	2.00
	CLMA, cm^2	2		-0.063	1.569	0.50	3.00

[1]HCW = hot carcass weight; HQRTP = pistol hindquarther retail product weight; FAT = weights of the fat trim.[2]HQRTP % = pistol hindquarter percentage of retail product; PFATR % = pistol hindquarter fat percentage. SBW = shrunk body weight; ULMA = ultrasound *Longissimus thoracis* muscle area between the 12th and the 13th ribs; and UFAT = subcutaneous fat thickness between 12th and 13th ribs. [3]Regression coefficient, RMSE, R2, and C_p, are updated in respect to a new independent variable to the prediction equation, the new independent variable is additionally in respect to the $C_p \approx p$ independent variables, and [4]Root-mean-square error.

found fat depth to be an important predictor of FAT (Perkins et al., 1992; Robinson et al., 1992; Bergen et al., 2005; Sakamoto et al., 2014). The discrepancy between the present study and those conducted previously may be due to the relative leanness of the cattle in this study. In studies where cattle were finished on high feed concentrate rations prior to harvest and fat deposition was greater, prediction equations that used traits measure with ultrasound as independent variables were more accurate than was found in the present research (Herring et al., 1994; Realini et al., 2001; Silva et al., 2012). Therefore, the FAT thickness should be considered when using predictions equations that were developed from cattle that were reared in different production systems.

In the prediction of weights of individual commercial cuts, models based on carcass measures explained a greater proportion of variability than models that used live measures as independent variables (Tables 4 and 5). Either SBW or HCW was almost invariably the first independent variable to enter the regression model. Likewise, Tarouco et al. (2007) and Silva et al. (2012) among others all support the primary importance of body weight in the prediction of weights of HQRTP. Similarly, Huerta-Leidenz et al. (2018) found that HCW was the first variable in importance in regression models to explain HQRTP. Other traits that entered the models accounted for relatively little additional variation but improved goodness-of-fit. These equations consistent failed to attain the accuracy of prediction for HQRTP. Fabrication of individual cuts can introduce error due to variation in deboning and fat trimming (Tarouco, et al., 2007). Fat trim also varies among cuts with the level of trim changing nonlinearly with increasing fatness (Strydom and Smith, 2005).

There is also interest in yield (composition) of the carcass and retail product. Despite longstanding recognition of the inadequacy of percentages as measures of composition (Weil, 1962; Miller and Weil, 1963; Dinkel et al., 1965; Sakamoto et al., 2014; Huerta-Leidenz et al., 2018), such practice has been commonplace in studies similar to this one. Here, use of regression on SBW or HCW with variation in the deviations from the regression is advocated as being indicative of differences among animals in composition.

Sample size in carcass studies does not have information available. The sample size is the main problem when carcass studies are performed, not only for research but also for the industry. Studies that have provided predictions of an amount and a yield of carcass cuts from live and ultrasound measurements perform both carcass and ultrasound data (Tait et al., 2005; Tarouco et al., 2007; Silva et al., 2012; Sakamoto et al., 2014; Huerta-Leidenz et al., 2018), however, the number of animals necessary to do the researches are high (102 to 466) and the sample size to determine the maximum model fit was not determinate.

Generally, carcass and ultrasound data show a similarly coefficient of determination with weight of edible cuts, however, when data were presented as a percentage basis the relationship become weaker (Dinkel et al., 1965; Tarouco et al., 2007; Silva et al., 2012; Sakamoto et al., 2014; Huerta-Leidenz et al., 2018). The authors consider unnecessary the estimate the sample size of HQRTP % because the low model fit to this trait (data not showed).

The sample size required to detect a difference in HQRTP between two treatments means, by considering $\alpha = 0.05$, differences from 0.25 standard deviations (1.780 kg) to 1.00 standard deviations (7.120 kg) and power of the test equal to 0.80, are shown in Figure 1. To detect a difference of 1.780 kg in carcass HQRTP, the numbers of animals required would be: 622 scanned by ultrasound, 593 carcasses measured for HCW and CLMA, and 576 fabricated into product. Thus, in this

Table 4 – Multiple regression equations for prediction of commercial cut weights from the pistol hindquarter using ultrasound measures based on data from 217 Braford steers.

[1]Dependent variable	[2]Independent variable	[3]Entry order	Intercept	Regression coefficient	RMSE[4]	Cumulative R^2	C_p
INW, kg	SBW, kg	1	–0.494	0.014	0.622	0.82	13.29
	ULMA, cm^2	2		0.024	0.607	0.83	3.85
OUTW, kg	SBW, kg	1	–0.114	0.009	0.496	0.77	10.20
	ULMA, cm^2	2		0.018	0.485	0.78	2.65
ERUW, kg	SBW, kg	1	–0.814	0.007	0.241	0.89	17.84
	ULMA, cm^2	2		0.011	0.232	0.90	2.79
RCW, kg	SBW, kg	1	0.280	0.002	0.219	0.42	23.73
	UFAT, mm	2		0.051	0.208	0.48	2.27
TTW, kg	SBW, kg	1	–0.254	0.002	0.123	0.76	14.05
	ULMA, cm^2	2		0.017	0.123	0.77	9.34
	UFAT, mm	3		0.004	0.120	0.78	4.00
KNW, kg	SBW, kg	1	–0.580	0.009	0.381	0.83	12.34
	ULMA, cm^2	2		0.015	0.372	0.84	2.68
EROW, kg	SBW, kg	1	–0.180	0.003	0.262	0.65	8.99
	ULMA, cm^2	2		0.009	0.257	0.66	2.30
STLW, kg	ULMA, cm^2	1	–1.591	0.076	0.978	0.36	25.44
	SBW, kg	2		0.009	0.851	0.46	3.35
TLW, kg	SBW, kg	1	–0.431	0.003	0.211	0.72	13.63
	ULMA, cm^2	2		0.009	0.205	0.74	2.19

[1]INW = Inside weight; OUTW = Outside flat weight; ERUW = Eye rump weight; RCW = Rump cap weight; TTW = Tri-tip weight; KNW = Knucle weight; EROW = Eye round weight; STLW = Strip loin weight; TLW = Tender loin weight. [2]SBW = shrunk body weight; ULMA = ultrasound *Longissimus thoracis* muscle area between the 12th and the 13th ribs; and UFAT = subcutaneous fat thickness between the 12th and 13th ribs. [3]Regression coefficient, RMSE, R^2, and C_p are updated in respect to a new independent variable to the prediction equation, the new independent variable is additionally in respect to the $C_p \approx p$ independent variables, and [4]Root-mean-square error.

Table 5 – Multiple regression equations for prediction of commercial cut weights from the pistol hindquarter using carcass measures based on data from 217 Braford steers.

Dependent variable[1]	Independent variable[2]	Entry order[3]	Intercept	Regression coefficient	RMSE[4]	Cumulative R[2,5]	C_p
INW, kg	HCW, kg	1	–0.427	0.030	0.503	0.88	3.60
	CLMA, cm²	2		0.010	0.499	0.89	2.02
OUTW, kg	HCW, kg	1	–1.162	0.019	0.448	0.81	6.72
	CLMA, cm²	2		0.013	0.441	0.82	2.07
ERUW, kg	HCW, kg	1	–0.728	0.016	0.192	0.93	14.09
	CLMA, cm²	2		0.005	0.187	0.93	10.72
	CFAT, mm	3		-0.017	0.186	0.94	3.24
RCW, kg	HCW, kg	1	0.289	0.004	0.214	0.46	26.48
	CFAT, mm	2		0.049	0.201	0.53	2.00
TTW, kg	HCW, kg	1	–0.197	0.005	0.106	0.82	5.66
	CLMA, cm²	2		0.002	0.105	0.83	2.87
KNW, kg	HCW, kg	1	–0.573	0.019	0.301	0.90	5.48
	CLMA, cm²	2		0.008	0.297	0.90	2.00
EROW, kg	HCW, kg	1	0.035	0.009	0.229	0.73	8.80
	CFAT, mm	2		-0.029	0.226	0.74	3.41
STLW, kg	CLMA, cm²	1	–0.234	0.055	1.010	0.36	33.56
	HCW, kg	2		0.021	0.875	0.44	15.01
	CFAT, mm	3		-0.190	0.834	0.50	4.00
TLW, kg	HCW, kg	1	–0.421	0.007	0.189	0.78	9.48
	CLMA, cm²	2		0.006	0.185	0.79	2.13

[1]INW = Inside weight; OUTW = Outside flat weight; ERUW = Eye rump weight; RCW = Rump cap weight; TTW = Tri-tip weight; KNW = Knucle weight; EROW = Eye round weight; STLW = Strip loin weight; TLW = Tender loin weight.[2]HCW = hot carcass weight; CLMA = carcass *Longissimus thoracis* muscle area between the 12th and the 13th ribs; and CFAT = subcutaneous fat thickness between the 12th and 13th ribs.[3]Regression coefficient RMSE, R², C_p, and *p*-value are updated in respect to a new independent variable to the prediction equation, the new independent variable is additionally in respect to the $C_p \approx p$ independent variables, and [4]Root-mean-square error, and [5]Cumulative R².
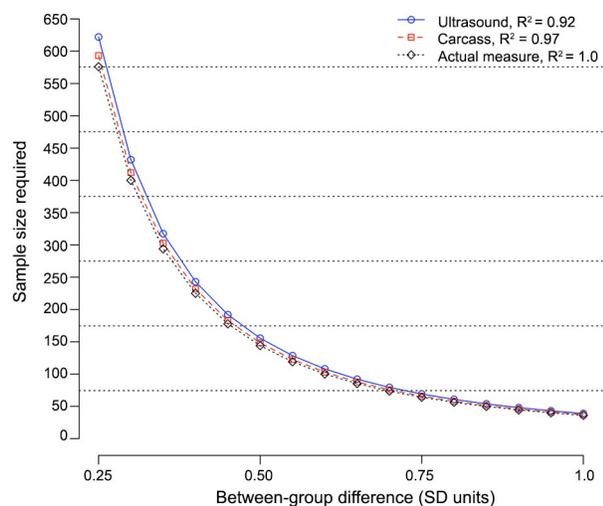
Figure 1 – Sample sizes required for detect (α = 0.05) a difference in weight of retail product from the pistol hindquarter HQRTP between two treatments over a range of critical effect sizes from 0.25 to 1.00 standard deviations (SD = 7.120 kg) with power-of-the test equal to 0.80 for carcasses of 130 to 294 kg.

case, ultrasonic measurement of live animals increases the required sample sizes for experiments of equal inferential power by 5 and 7 % compared to those using carcass indicators and direct HQRTP measures (by model with R² = 1.0).

As the critical difference between treatments increases, the number of animals required decreases substantially. For example, the sample size to detect a difference between treatments of 1.00 SD in HQRTP was 39 when using live measures, 37 when using carcass measures, and 36 when the product was fabricated. If the desired inference were to yield of product rather than to its mass, the standard deviation that is appropriate to experimental planning is reduced to the degree that variation in HQRTP. As these experiments are equivalent in inferential power, efficient use of resources obligates the least cost paradigm. Numerous equations were identified for a large number of different end points under widely varying sets of experiments (Hedrick, 1983, Tait et al., 2005; Silva et al., 2012; Sakamoto et al., 2014; Huerta-Leidenz et al., 2018).

As the direct measurements of composition requires the animal death, the dissection or the debone methods are not suitable for selection or replacement animals or for time series data and the prediction of body composition can be obtained in a less costly and nondestructive manner. In the cost benefit analysis to decide whether or not to utilize a prediction equation, the value of this additional information should be viewed as a benefit of the direct measurement of dependent variable (MacNeil, 1983). Additionally, the reduction of the number of experimental units justify the use of techniques that are in agreement with the

reduction principle and the use of methods that minimize the number of experimental units, reduce negligible damage, and distress, to the great benefit of their accuracy (Russell and Burch, 1959).

Conclusions

Results of this study demonstrates that ultrasound may be used to estimate the weight of pistol hindquarter cuts with only a slight degradation of accuracy relative to the use of carcass measures. Thus, in many circumstances it is possible to replace post-slaughter carcass measurement for pre-slaughter ultrasound measurements. Models for individual cuts weights that used traits measured with ultrasound as independent variables approached the accuracy of models using carcass traits. Slightly greater samples sizes were required to have equivalent power to detect differences in retail product weights using ultrasound measures as compared to carcass traits.

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Authors' Contributions

Conceptualization: Cardoso, L.C.; Tarouco, J.U.; MacNeil, M.D. Data acquisition: Cardoso, L.C.; Tarouco, J.U.; Lobato, J.F.P.; Dambrós, M.C.; Freitas, A.K.; Devincenzi, T.; Feijó, F.D. Design of Methodology: Cardoso, L.C.; Tarouco, J.U.; MacNeil, M.D.; Cardoso, F.F. Writing and editing: Cardoso, L.C.; Tarouco, J.U.; MacNeil, M.D.; Cardoso, F.F.

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