Technical note: Estimating body weight and body composition of beef cattle trough digital image analysis[1]

R. A. Gomes,* G. R. Monteiro,* G. J. F. Assis,† K. C. Busato,* M. M. Ladeira,* and M. L. Chizzotti†[2]

*Department of Animal Science, Universidade Federal de Lavras, Lavras, Minas Gerais, Brazil 37.200-000; and †Department of Animal Science, Universidade Federal de Viçosa, Viçosa, Minas Gerais, Brazil 36.570-000

ABSTRACT: The use of digital images could be a faster and cheaper alternative technique to assess BW, HCW, and body composition of beef cattle. The objective of this study was to develop equations to predict body and carcass weight and body fat content of young bulls using digital images obtained through a Microsoft Kinect device. Thirty-five bulls with an initial BW of 383 (±5.38) kg (20 Black Angus, 390 [±7.48] kg initial BW, and 15 Nellore, 377 [±8.66] kg initial BW) were used. The Kinect sensor, installed on the top of a cattle chute, was used to take infrared light–based depth videos, recorded before the slaughter. For each animal, a quality control was made, running and pausing the video at the moment that the animal was standing with its body and head in line. One frame from recorded videos was selected and used to analyze the following body measurements: chest width, thorax width, abdomen width, body length, dorsal height, and dorsal area. From these body measurements, 23 indexes were generated and tested as potential predictors. The BW and HCW were assessed with a digital scale, whereas empty body fat (EBF) was estimated through ground samples of all tissues. To better understand the relationship among the measurements, the correlations between final BW (488 [±10.4] kg), HCW (287 [±12.5] kg), EBF (14 [±0.610] % empty BW) content, body measurements (taken through digital images), and developed indexes were evaluated. The REG procedure was used to develop the regressions, and the important independent variables were identified using the options STEPWISE and Mallow's Cp in the SELECTION statement. Chest width was the trait most related to weights and the correlations between this measurement and BW and HCW were above 0.85. The analysis of linear regressions between observed and predicted values showed that all models pass through the origin and have a slope of unity (null hypothesis [H_0]: $a = 0$ and $b = 1$; $P \geq 0.993$). The models to estimate BW and HCW of Angus and Nellore presented R^2 between 0.69 and 0.84 ($P < 0.001$), whereas R^2 from equations to estimate the EBF were lower ($R^2 = 0.43$–0.45; $P \leq 0.006$). Index I5 [(chest width)^2 × body length], related to the animal volume, was significant in all models created to estimate BW and HCW, and it explained more than 70% of the variation. This study indicates that digital images taken through a Microsoft Kinect system have the potential to be used as a tool to estimate body and carcass weight of beef cattle.

Key words: Angus, body fat, hot carcass weight, imaging, Kinect, Nellore

J. Anim. Sci. 2016.94:5414–5422
doi:10.2527/jas2016-0797

INTRODUCTION

Body weight is one of the most important animal traits for livestock management. The traditional method to record cattle weight is using a ground scale; however, this practice is laborious and stressful to both animal and operator (Schofield et al., 1999). The use of machine vision systems could be a noncontact and faster alternative technique to estimate animal BW. Because there is a significant correlation between body size and BW, the animal's mass could be estimated through analysis of biometric indexes from digital images (Schofield et al., 1999; Wang et al., 2008; Li et al., 2014; Ozkaya et al., 2015).

[1]This work was supported by grants from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).
[2]Corresponding author: mariochizzotti@ufv.br
Received July 6, 2016.
Accepted September 19, 2016.

Table 1. Description of the index used in the equations

Index	Description[1]
I1	Difference between dorsal height and the height at the point wherein chest width was measured
I2	(dorsal area)$^{1/2}$
I3	(dorsal area)$^{0.75}$/(dorsal height)^2
I4	chest width/(dorsal area)$^{1/2}$
I5	(chest width)^2 × body length
I6	dorsal area/(dorsal area × 1000)^2
I7	(dorsal height)^2
I8	chest width + thorax width + abdomen width
I9	chest width + abdomen width
I10	chest width/I8
I11	thorax width/I8
I12	abdomen width/I8
I13	I8/I2
I14	abdomen width/I2
I15	thorax width/abdomen width
I16	abdomen width × (dorsal area)$^{0.75}$/(dorsal height × 1,000)^2
I17	(dorsal area)$^{0.75}$/(dorsal height × 1,000)
I18	(I1)^2 × dorsal height
I19	Difference between dorsal height and the height at the point wherein abdomen width was measured
I20	(I19)^2 × dorsal height
I21	(I1)^2 × body length
I22	(I19)^2 × body length
I23	(abdomen width)^2 × body length

[1]Body length, chest width, thorax width, abdomen width, and dorsal area are expressed in pixels; dorsal height is expressed in meters.

Table 2. Statistical description of animal characteristics in the data set used for predicting BW, HCW, and fat content on empty body weight

Item	Mean	SD	Minimum	Maximum
Overall, n = 35				
BW, kg	488	61.3	363	598
HCW, kg	287	36.4	225	355
Empty body fat, % EBW[1]	14.0	1.78	8.9	17.2
Chest width, pixels	162	7.3	144	174
Thorax width, pixels	140	11.0	118	162
Abdomen width, pixels	179	10.0	160	196
Dorsal area, pixels	129,530	21,110	108,239	197,190
Body length, pixels	480	27.3	402	538
Dorsal height, m	1.33	0.082	1.22	1.51
Angus, n = 20				
BW, kg	521	45.0	441	598
HCW, kg	304	29.5	251	355
Empty body fat, % EBW	13.8	1.71	8.9	16.2
Chest width, pixels	162	7.3	144	174
Thorax width, pixels	144	8.7	129	162
Abdomen width, pixels	181	8.1	164	193
Dorsal area, pixels	131,476	22,673	108,239	197,190
Body length, pixels	474	26.5	402	511
Dorsal height, m	1.26	0.027	1.22	1.31
Nellore, n = 15				
BW, kg	444	52.5	363	543
HCW, kg	265	32.8	225	329
Empty body fat, % EBW	14.2	1.88	11.6	17.2
Chest width, pixels	146	11.5	128	166
Thorax width, pixels	135	12.0	118	159
Abdomen width, pixels	176	11.8	160	196
Dorsal area, pixels	126,936	19,288	108,313	185,686
Body length, pixels	489	27.0	449	538
Dorsal height, m	1.42	0.036	1.38	1.51

[1]EBW = empty BW.

Vision systems based on visible light are affected by ambient light and the animal's hide color, but these interferences are minimized by the use of infrared light–based depth sensors, such as a Microsoft Kinect device (Kongsro, 2014; Microsoft Corporation, Redmond, WA). In swine, a Microsoft Kinect prototype weighing system was able to estimate animal weight using depth map images (Kongsro, 2014). We hypothesized that dorsal images from beef cattle could be used to estimate their body and carcass weight and body composition. Therefore, the objective of this study was to develop equations to predict body and carcass weight of Angus and Nellore young bulls using body measurements obtained through infrared light–based depth images taken by a Microsoft Kinect device.

MATERIAL AND METHODS

All animal procedures were approved by Bioethic Committee in Utilization of Animals of Universidade Federal de Lavras, protocol number 048/2012, and followed established standards for humane care and use.

Thirty-five bulls with an initial BW of 383 (±5.38) kg (20 Black Angus, 390 [±7.48] kg initial BW, and 15 Nellore, 377 [±8.66] kg initial BW) were used and individually fed 1 of the 3 experimental diets. Eight Angus and 7 Nellore were fed a total mixed ground corn with silage diet (300 g/kg silage, 580 g/kg cracked corn grain, 100 g/kg soybean meal, and 20 g/kg commercial premix, on a DM basis; 589 g/kg DM, 117 g/kg CP, 23 g/kg ether extract, 267 g/kg NDF, and 541 g/kg nonfibrous carbohydrate; 2.59 Mcal/kg ME, on DM basis) on an ad libitum basis. Eight Angus and 5 Nellore were fed a whole shelled corn diet (850 g/kg whole shelled corn and 150 g/kg of a soybean meal and mineral–based pellet supplement, DM basis; 878 g/kg DM, 136 g/kg CP, 28 g/kg ether extract, 151 g/kg NDF, and 639 g/kg nonfibrous carbohydrate; 2.97 Mcal/kg ME, on DM basis) also on an ad libitum basis. Four Angus and 3 Nellore were limit-fed the total mixed ground corn with silage diet at 55% (calculated as a percentage of metabolic weight) of the intake of bulls fed ad libitum. The different diets were included in this study to increase the BW range and thus improve the data set.

Table 3. Person correlation coefficients between BW, HCW, and empty body fat and body traits taken through digital images

	BW		HCW		EBF, % EBW[2]	
Item[1]	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value
Overall						
Chest width, pixels	0.85	<0.001	0.87	<0.001	0.12	0.488
Thorax width, pixels	0.71	<0.001	0.74	<0.001	0.16	0.371
Abdomen width, pixels	0.61	<0.001	0.66	<0.001	0.16	0.369
Dorsal area, pixels	0.50	0.003	0.54	<0.001	0.09	0.601
Body length, pixels	0.27	0.114	0.27	0.114	0.16	0.381
Dorsal height, m	−0.55	<0.001	−0.47	0.005	0.10	0.569
I1	−0.17	0.311	−0.25	0.15	−0.27	0.118
I2	0.51	0.002	0.55	<0.001	0.11	0.518
I3	0.73	<0.001	0.70	<0.001	−0.01	0.95
I4	0.38	0.026	0.36	0.034	−0.01	0.95
I5	0.88	<0.001	0.89	<0.001	0.17	0.336
I6	0.71	<0.001	0.69	<0.001	0.004	0.981
Angus						
Chest width, pixels	0.71	0.005	0.79	<0.001	0.33	0.151
Thorax width, pixels	0.49	0.029	0.53	0.017	0.31	0.185
Abdomen width, pixels	0.54	0.014	0.57	0.008	0.27	0.252
Dorsal area, pixels	0.71	<0.001	0.73	<0.001	0.11	0.635
Body length, pixels	0.62	0.002	0.54	0.015	0.26	0.270
Dorsal height, m	0.39	0.091	0.41	0.075	0.22	0.355
I1	−0.45	0.046	−0.60	0.005	−0.32	0.166
I2	0.73	<0.001	0.74	<0.001	0.14	0.567
I3	0.62	0.003	0.63	0.003	0.06	0.804
I4	−0.35	0.130	−0.30	0.192	0.05	0.837
I5	0.84	<0.001	0.85	<0.001	0.36	0.123
I6	0.65	0.002	0.66	0.002	0.07	0.768
Nellore						
Chest width, pixels	0.78	<0.001	0.83	<0.001	0.24	0.382
Thorax width, pixels	0.76	0.001	0.81	<0.001	0.17	0.552
Abdomen width, pixels	0.67	0.006	0.72	0.003	0.14	0.629
Dorsal area, pixels	0.35	0.190	0.38	0.18	0.10	0.72
Body length, pixels	0.52	0.047	0.50	0.060	−0.04	0.887
Dorsal height, m	−0.11	0.680	−0.14	0.610	−0.30	0.273
I1	0.06	0.83	0.009	0.97	−0.29	0.289
I2	0.37	0.169	0.39	0.148	0.12	0.666
I3	0.36	0.185	0.39	0.148	0.20	0.469
I4	0.43	0.106	0.48	0.069	0.10	0.734
I5	0.83	<0.001	0.87	<0.001	0.20	0.465
I6	0.35	0.196	0.38	0.158	0.17	0.552

[1]I1, I2, I3, I4, I5, and I6 are the indexes used in the equations (see Table 3).

[2]EBF = empty body fat; EBW = empty BW.

The Kinect sensor was installed on the top of a cattle chute, 2.95 m from the floor, and was used to record infrared light–based depth videos, recorded the evening before slaughter. The Kinect sensor is a device composed of an infrared laser projector, an infrared camera, and a red–green–blue depth camera. The depth information is obtained by a triangulation process, in which a constant pattern of speckles created by the laser source is projected onto the object and recorded by the infrared camera. The color spectrum is defined by the distance from the object to the device's camera lens (Kawasue et al., 2013). In the day prior to slaughter, the bulls were individually kept in the cattle chute, and then, while they were standing, a 20-s video was recorded and stored on a computer hard disk for further analysis. To avoid possible lighting and shadow effects, the video were recorded at night with no artificial light. The videos were initially analyzed using the software Microsoft Kinect Studio version 1.7.0.0 (Microsoft Corporation) and a quality control was manually made, pausing the video in the

Table 4. Multiple and single regressions of BW, HCW, and body fat linear effects of body measurements through digital image analysis in Angus and Nellore bulls

Item	Model	Equations[1,2,3]	R^2	Parameter probability[4] (P-value)	RMSE[5]	P-value	Analysis of residues: Normal distribution (P-value)[6]	Analysis of residues: Homoscedasticity test (P-value)[7]	Analysis of residues: Independence (D-value)[8]
BW, kg									
Overall	1	81.4 (±40.23**) + 58.3 (±34.12**) × I1 + 0.0000222 (±0.00000296****) × I5 + 0.0310 (±0.00897***) × I3	0.84	0.999	19.4	<0.001	0.325	0.458	1.46
Angus	2	389.8 (±106.15***) − 399.9 (±198.56**) × I4 + 0.0000249 (±0.00000371****) × I5	0.76	0.999	23.3	<0.001	0.282	0.461	1.94
Nellore	3	210.2 (±44.54****) + 0.0000223 (±0.00000417****) × I5	0.69	0.999	304.8	<0.001	0.917	0.807	1.32
HCW, kg									
Overall	4	74.8 (±17.57****) + 0.0000141 (±0.00000175****) × I5 + 0.0124 (±0.00509***) × I3	0.83	0.993	15.4	<0.001	0.683	0.553	1.42
Angus	5	24.1 (±42.27^{NS}) + 0.329 (±0.1544***) × I2 + 0.0000129 (±0.00000307****) × I5	0.78	0.994	14.7	<0.001	0.611	0.608	1.87
Nellore	6	112.1 (±24.75****) + 0.0000146 (±0.00000232****) × I5	0.75	0.994	16.9	<0.001	0.646	0.867	1.13
Empty body fat, % EBW									
Overall	7	22.4 (±3.94****) + 0.0319 (±0.00752****) × BW − 6.46 (±1.977***) × I1 − 28.2 (±9.30***) × I4 − 118.2 (±30.04****) × I6	0.43	0.993	1.4	0.002	0.068	0.600	1.97
Angus	8	0.619 (±3.731^{NS}) + 0.0359 (±0.00973***) × BW − 0.0000422 (±0.0000193***) × Dorsal area	0.45	0.999	1.3	0.006	0.724	0.581	1.64

[1]For BW and HCW, all variables left in the models are significant at the 0.10. For empty body fat, the significant level adopted was 0.15.

[2]The descriptions of the index are in Table 1.

[3]EBW = empty BW (kg); dorsal area is expressed in pixels. NS = not significant.

[4]Null hypothesis (H_0): $a = 0$ and $b = 1$ (Mayer et al., 1994).

[5]RMSE = root mean squared error.

[6]Shapiro–Wilk's W statistic.

[7]White test.

[8]Durbin–Watson D.

**$P < 0.10$; ***$P < 0.05$; ****$P < 0.001$.

moment wherein the image covered the entire bull and the animal was standing with its body and head in line (Fig. 1A). The body measurements were made using images of the top view of the animals, taken from the digital videos, and included chest width (the widest diameter along the superior border of the scapula), thorax width (diameter measured caudal to the scapulas, in pixels), abdomen width (the widest diameter of the abdomen, in pixels), body length (a line in the sagittal plane, from the shoulder to the tail base), and dorsal height (measured at the point where the lines used to measure the abdomen width and body length intersect, as the difference between the distance from the sensor to the ground and from the sensor to the back of the animal, in meters). Measurements were made using the Microsoft Kinect Studio, crossing a straight line for each measurement (Fig. 1A) and counting the number of pixels in the line. After the neck and tail have been digitally removed from the images (Fig. 1B), the dorsal area, in pixels, was calculated using the wand tool of the software ImageJ version 1.49 (National Institutes of Health, Bethesda, MD). From the relationship of these body measurements, 23 indexes were generated from relations of widths and height and were tested as potential predictors (Table 1).

After 84 d in feedlot, the bulls were feed fasted for 12, h and immediately before the slaughter, the BW was recorded using a ground scale (Coimma LTDA, model B-01; Dracena, Sao Paulo, Brazil). Cattle were desensitized with a nonpenetrating stunner and harvested by exsanguination using conventional humane procedures followed by evisceration and hide removal. Hide and blood were weighed and sampled. Head and feet were weighed, ground, and sampled. The gastrointestinal tract was emptied, washed, and weighed and then ground together with internal organs, reproductive tract, tongue, and tail. These ground viscera, together with the hide, head, feet, and blood, formed a pooled sample, with each component sampled in proportion to its contribution to empty BW. The carcass was split into 2 longitudinal halves and weighed. The left half of the carcass was separated into bone and soft tissues, which were weighed, sampled in proportion, and ground, forming a

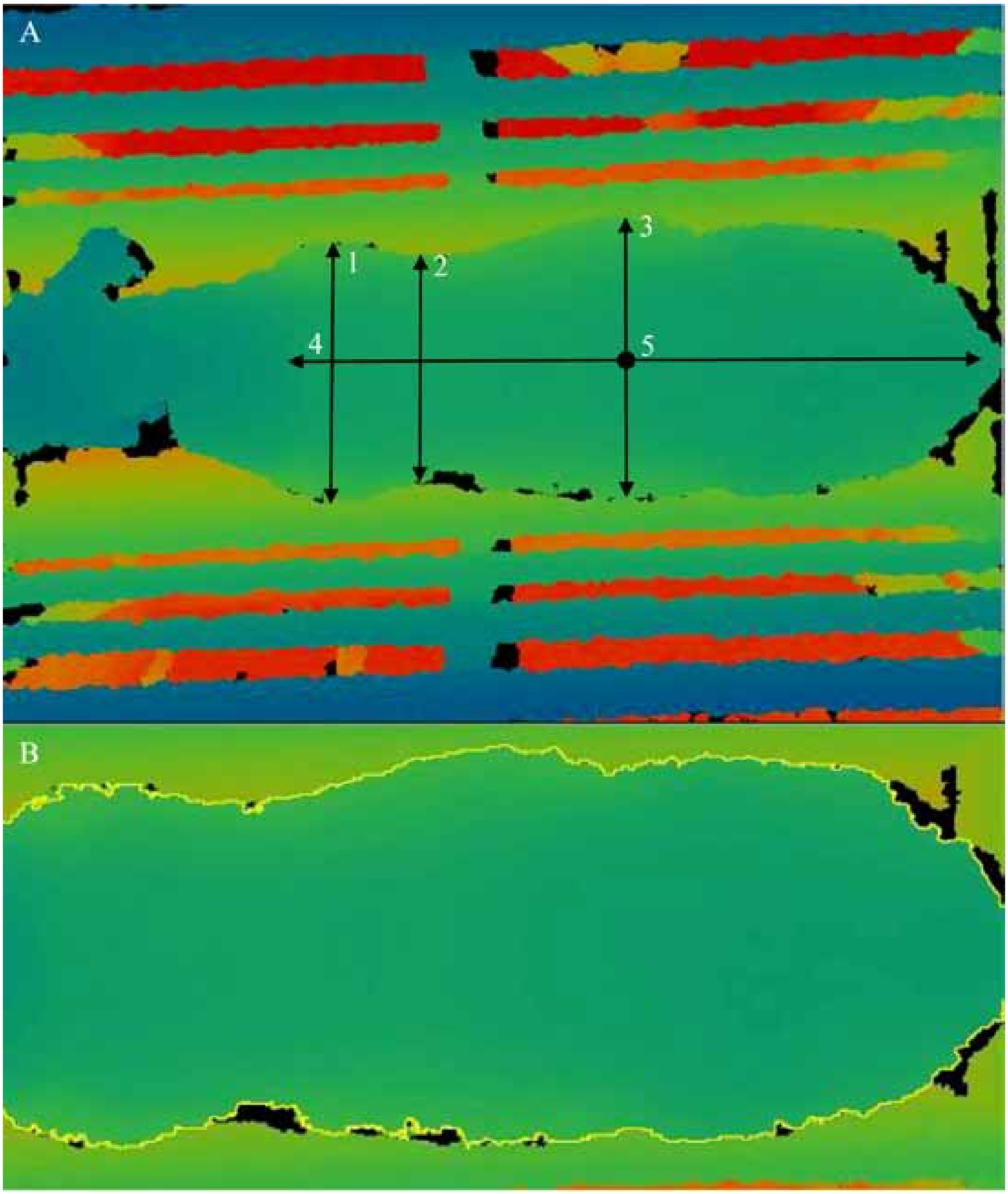

Figure 1. Illustration of the measurements obtained by image analysis (A) include 1) chest width, 2) thorax width, 3) abdomen width, 4) body length, and 5) dorsal height and (B) the dorsal area (surrounded by the yellow line).

left half carcass sample, assuming the right half carcass had the same chemical composition as the left side. The empty BW was determined by the sum of the weight of carcass, blood, internal organs, reproductive tract, empty gastrointestinal tract, tongue, head, feet, and tail. The collected samples (carcass and noncarcass compounds) were frozen, freeze-dried, and ground. An Association of Official Analytical Chemists (1990) method was used to determine ether extract (method 920.39).

The statistical analysis were performed using the software SAS (SAS Inst. Inc., Cary, NC). To better understand the relationship among the measurements, Pearson correlations were performed between BW, HCW, empty body fat (**EBF**) percentage, and body measurements obtained by digital images and developed indexes, using the CORR procedure.

The REG procedure was used to develop the regressions, using the overall, Angus, and Nellore data sets. We included in the model the body measurements and all 23 indexes described in Table 1. The important independent variables were identified using the options STEPWISE and Mallow's Cp in the SELECTION statement, and all interactions between the variables used and their effects were evaluated and removed from the statistical model when they were not significant at $P \leq 0.10$, except for EBF percentage, where the parameters were removed when they were not significant at $P \leq 0.15$. Only models with less than 4 variables were chosen. The predictive

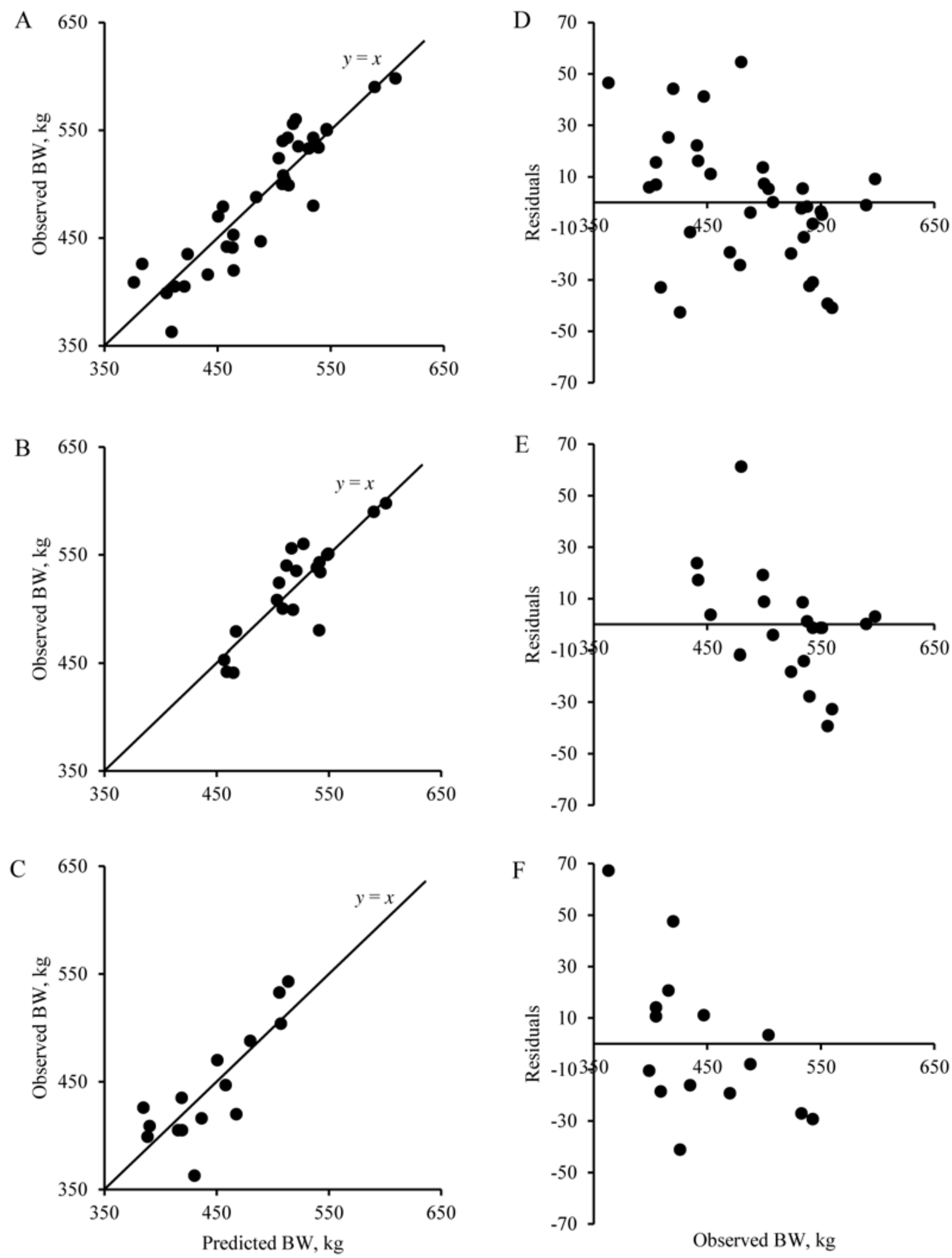

Figure 2. Relationship between observed and predicted values and residuals of BW: (A) and (D) for the overall model (BW, kg = 81.4 + 58.3 × I1 + 0.0000222 × I5 + 0.0310 × I3), (B) and (E) for the Angus model (BW, kg = 389.8 − 399.9 × I4 + 0.0000249 × I5), and (C) and (F) for the Nellore model (BW, kg = 210.2 + 0.0000223 × I5). Indexes I1, I3, I4, and I5 are described in Table 1.

ability was evaluated based on the coefficient of determination (R^2) and the root mean squared error between the observed and predicted values using the final model.

The regressions were evaluated using the software MES version 3.1.15 (Texas A&M University, College Station, TX) following the statistical hypothesis (Mayer et al., 1994) null hypothesis (H_0): $\alpha = 0$ and $\beta = 1$; alternative hypothesis (H_1) $\neq H_0$.

If the null hypothesis was not rejected ($P \leq 0.05$), it could be concluded that the equations accurately estimate the variables.

The variance, independence, and distribution of residues were tested. The independence of residues was verified by the Durbin–Watson statistic using the DW statement in the REG procedure. The homoscedasticity of residues was tested by the White test using the Spec statement, also in the REG procedure, following the statistical hypothesis H_0 = the variance of the residues is homoscedastic; $H_1 \neq H_0$.

The Shapiro–Wilk W test was used to check the normal distribution of the residues, using the software MES version 3.1.15.

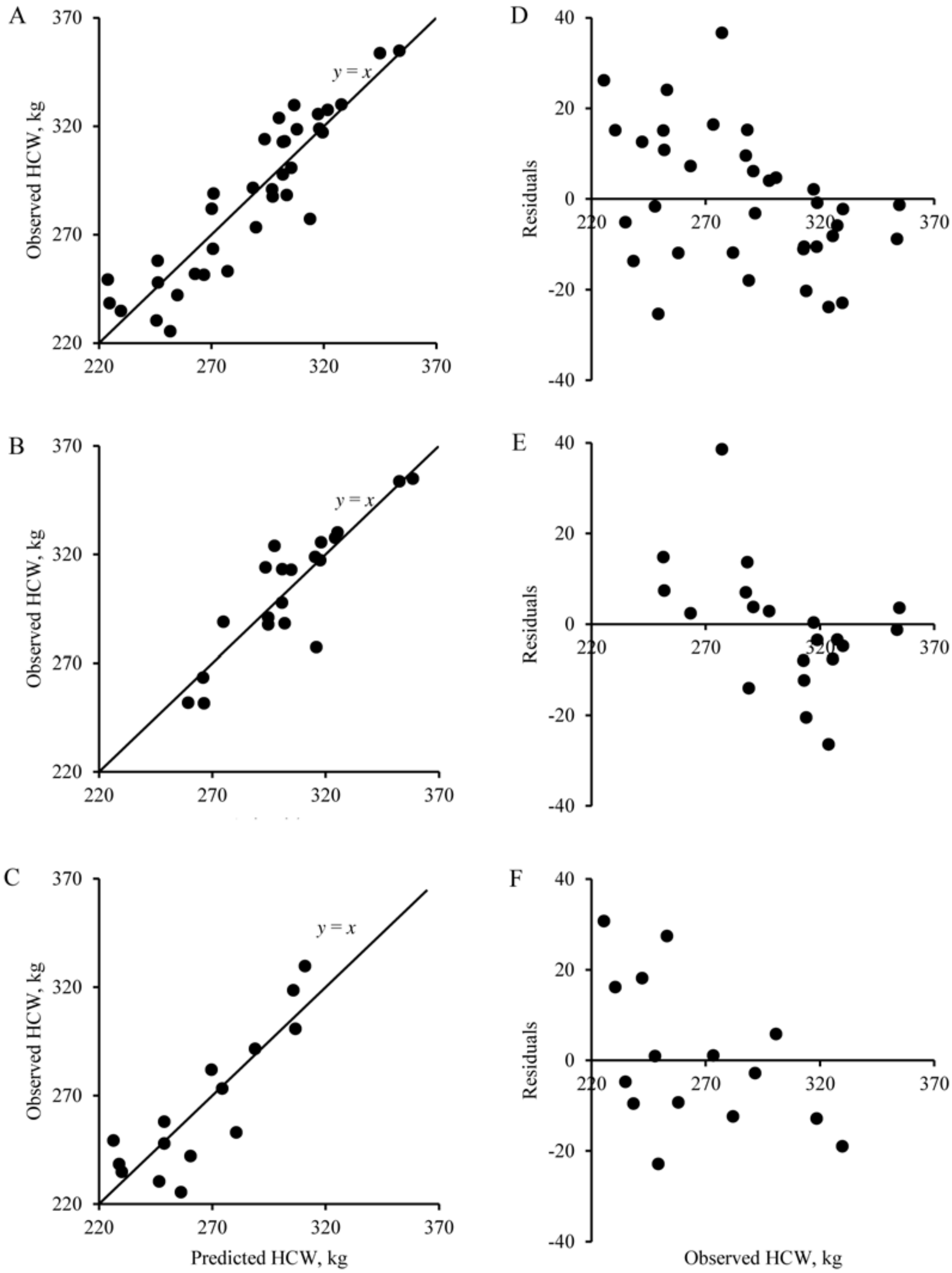

Figure 3. Relationship between observed and predicted values and residuals of HCW: (A) and (D) for the overall model (HCW, kg = 74.8 + 0.0000141 × I5 + 0.0124 × I3), (B) and (E) for the Angus model (HCW, kg = 24.1 + 0.329 × I2 + 0.0000129 × I5), and (C) and (F) for the Nellore model (HCW, kg = 112.1 + 0.0000146 × I5). Indexes I2, I3, and I5 are described in Table 1.

RESULTS AND DISCUSSION

The mean, range (minimum and maximum), and SD values of the body measurements are shown in Table 2. The data set varied considerably, with BW ranging from 363 to 598 kg and HCW ranging from 225 to 355 kg. For the overall data set, the variables chest, thorax, and abdomen widths and dorsal area, which are related to the animal size, showed moderate to high positive correlations with BW and HCW (Table 3; $P \leq 0.003$, $r = 0.50$–0.85). Other authors also found high correlation between body measurements taken directly from animals by linear measurements with BW (Fernandes et al., 2010). Of the body traits, chest width was the most related trait to BW and HCW and the correlations were above 0.85. When the data set from Angus and Nellore were separately analyzed, chest width was also correlated with weights for both breeds. However, other body measurements, such as thorax width and dorsal area, did not have the same behavior,

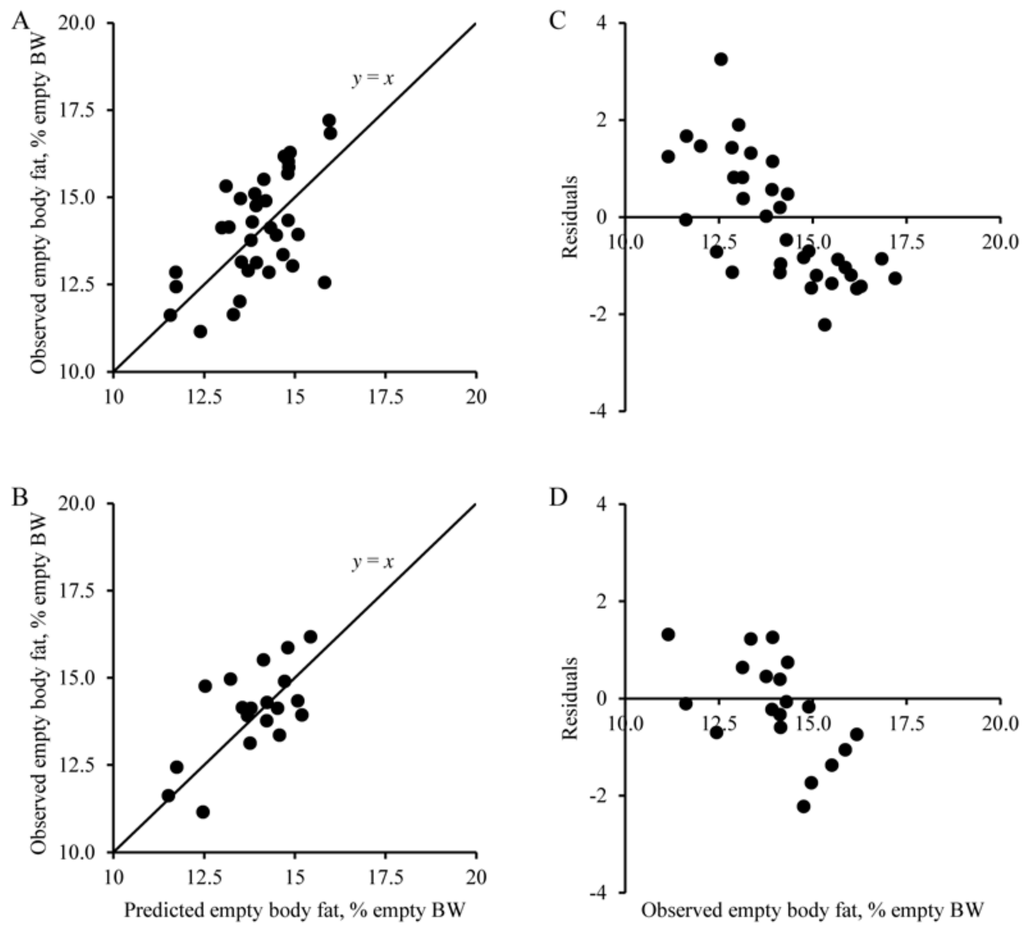

Figure 4. Relationship between observed and predicted values and residuals of empty body fat (EBF): (A) and (C) for the overall model (EBF, % EBW = 22.4 + 0.0319 × BW − 6.46 × I1 − 28.2 × I4 − 118.2 × I6) and (B) and (D) for the Angus model (EBF, % EBW = 0.619 + 0.0359 × BW − 0.0000422 × dorsal area). EBW = empty BW (kg). Indexes I1, I4, and I6 are described in Table 1.

presenting higher correlations for one breed than for the other. This might be related to differences in the body shape and frame size between the 2 breeds, in which Angus bodies are more compact compared with Nellore, which, in turn, are generally higher, slimmer, and longer than Angus. The EBF percentage was not correlated with any of the body measurements.

From the 23 indexes generated, only 6 were significant and used in the models. Table 4 displays the best fit equations to estimate BW and HCW. The analysis of linear regressions between observed and predicted values showed that the all models pass through the origin and have a slope of unity (H_0: $a = 0$ and $b = 1$; $P \geq 0.993$; Fig. 2, 3, and 4). The residues (Table 4; Fig. 2, 3, and 4) were identically distributed ($P \geq 0.068$), homoscedastic ($P \geq 0.458$), and independent (D-value closer to 2 than to 0 or 4).

Index I5 was significant in all models created to estimate BW and HCW, and it explained more than 70% of the variation (data not shown). Among the indexes used, I5 showed the higher correlation with BW and HCW ($r \geq 0.83$, $P \leq 0.001$) and estimated animal volume as a parallelepiped. Other author also found strong correlation between body volume and BW (Fernandes et al., 2010; Puputunga et al., 2015), whereas Core et al. (2008) and Kongsro (2014) also considered the animal volume estimate by digital images a good tool to estimate the body weight of animals. Index I5 was the only index that presented correlations with weights in Nellore bulls and it was the only variable included in the equations to estimate BW and HCW for this breed (models 3 and 6). The models to estimate BW and HCW of the overall and Angus data sets were more precise (R^2 between 0.74 and 0.84) than the ones of Nellore data sets, and this was probably due the small Nellore sample size used in this study.

The models to estimate the EBF percentage for overall and Angus data set presented R^2 around 0.45. Nonetheless, for Nellore animals, none of the predictors were significant for EBF. Similar to our findings, Doeschl et al. (2004) found a significant correlation between body measurements taken by the visual image analysis and the carcass fat content, with R^2 raging between 0.46 and 0.66. The equation to predict EBF of Angus cattle (model 8) included, besides the BW, the dorsal area. According to Doeschl et al. (2004), shape indexes related to the trunk region appear to be relevant descriptors for relative fat and lipid weight in the carcass of pigs.

Some black spots were detected in the videos, mainly in the records from dark coat Angus bulls (Fig. 1). Negretti et al. (2008), using a visual image system in buffalos, reported that the dark coat could hinder the visibility of some points of the image and the performance of telemeter laser because of the greater absorption of the signal. In this study, the measurements in the images were made manually, allowing the detection of these anomalies and the counting of pixels inside of these spots. However, as evidenced by Schofield et al. (1999), problems similar to this should be considered in further studies about the technique and in the development of software to process the images.

Without BW, the equations to estimate EBF were not significant, but the inclusion of the image-based indexes improved the precision of the models. It should be emphasize that this was a preliminary work to evaluate the use of infrared light images to estimate animal body weight and fat and that more studies are necessary to validate the equations proposed here. Nonetheless, infrared light images are a potential tool to measure morphometrical body traits that can be used to estimate body and carcass weight of beef cattle.

LITERATURE CITED

Association of Official Analytical Chemists. 1990. Official methods of analysis of AOAC International. Assoc. Off. Anal. Chem., Arlington, VA.

Core, S., S. Miller, and M. Kelly. 2008. Development of the laser remote caliper as a method to estimate surface area and body weight in beef cattle. https://journal.lib.uoguelph.ca/index.php/surg/article/view/402/672 (Accessed 25 May 2016.) 1(2):57–72.

Doeschl, A. B., D. M. Green, C. T. Whittemore, C. P. Schofield, A. V. Fisher, and P. W. Knap. 2004. The relationship between the body shape of living pigs and their carcass morphology and composition. Anim. Sci. 79:75–83.

Fernandes, H. J., L. O. Tedeschi, M. F. Paulino, and L. M. Paiva. 2010. Determination of carcass and body fat compositions of grazing crossbred bulls using body measurements. J. Anim. Sci. 88:1442–1453. doi:10.2527/jas.2009-1919

Kawasue, K., T. Ikeda, T. Tokunaga, and H. Harada. 2013. Three-dimensional shape measurement system for black cattle using Kinect sensor. Int. J. Circuits, Syst. Signal Process 7(4):222–230.

Kongsro, J. 2014. Estimation of pig weight using a Microsoft Kinect prototype imaging system. Comput. Electron. Agric. 109:32–35. doi:10.1016/j.compag.2014.08.008

Li, Z., C. Luo, G. Teng, and T. Liu. 2014. Estimation of pig weight by machine vision: A review. In: D. Li and Y. Chen, editor, Computer and computing technologies in agriculture VII : 7th IFIP WG 5.14 International Conference, CCTA 2013, Beijing, China, September 18–20, 2013, Revised Selected Papers, Part II. Springer Berlin Heidelberg, Berlin, Germany. p. 42–49. doi:10.1007/978-3-642-54341-8_5.

Mayer, D. G., M. A. Stuart, and A. J. Swain. 1994. Regression of real-world data on model output: An appropriate overall test of validity. Agric. Syst. 45:93–104. doi:10.1016/S0308-521X(94)90282-8

Negretti, P., G. Bianconi, S. Bartocci, S. Terramoccia, and M. Vern. 2008. Determination of live weight and body condition score in lactating Mediterranean buffalo by visual image analysis. Livest. Sci. 113(1):1–7. doi:10.1016/j.livsci.2007.05.018

Ozkaya, S., W. Neja, S. Krezel-Czopek, and A. Oler. 2015. Estimation of bodyweight from body measurements and determination of body measurements on Limousin cattle using digital image analysis. Anim. Prod. Sci. doi:10.1071/AN14943

Puputunga, U., L. Hakim, G. Ciptadi, and H. F. N. Lapian. 2015. Application of body volume formula for predicting live weight in Ongole crossbred cows. Int. J. Livest. Prod. 6(3):35–40. doi:10.5897/IJLP2014.0243

Schofield, C. P., J. A. Marchant, R. P. White, N. Brandl, and M. Wilson. 1999. Monitoring pig growth using a prototype imaging system. J. Agric. Eng. Res. 72:205–210. doi:10.1006/jaer.1998.0365

Wang, Y., W. Yang, P. Winter, and L. Walker. 2008. Walk-through weighing of pigs using machine vision and an artificial neural network. Biosystems Eng. 100(1):117–125. doi:10.1016/j.biosystemseng.2007.08.008