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Determination of Saleable Product in Finished Cattle and Beef Carcasses Utilizing Bioelectrical Impedance Technology[1]

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ABSTRACT: Two experiments were performed to develop prediction equations of saleable beef and to validate the prediction equations. In Exp. 1, 50 beef cattle were finished to typical slaughter weights, and multiple linear regression equations were developed to predict kilograms of trimmed boneless, retail product of live cattle, and hot and cold carcasses. A four-terminal bioelectrical impedance analyzer (BIA) was used to measure resistance (Rs) and reactance (Xc) on each animal and processed carcass. The IMPS cuts plus trim were weighed and recorded. Distance between detector terminals (Lg) and carcass temperature (Tp) at time of BIA readings were recorded. Other variables included live weight (BW), hot carcass weight (HCW), cold carcass weight (CCW), and volume (Lg2/Rs). Regression equations for predicting kilograms of saleable product were $[11.87 + (.409 \times \mathrm{BW}) - (.335 \times \mathrm{Lg}) + (.0518 \times \mathrm{volume})]$ for live ($R^2 = .80$); $[-58.83 + (.589 \times \mathrm{HCW}) - (.846 \times \mathrm{Rs}) + (1.152 \times \mathrm{Xc}) + (.142 \times \mathrm{Lg}) + (2.608 \times \mathrm{Tp})]$ for hot carcass ($R^2 = .95$); and $[32.15 + (.633 \times \mathrm{CCW}) + (.33 \times \mathrm{Xc}) - (.83 \times \mathrm{Lg}) + (.677 \times \mathrm{volume})]$ for cold carcass ($R^2 = .93$). In Exp. 2, 27 beef cattle were finished in a manner similar to Exp. 1, and the prediction equations from Exp. 1 were used to predict the saleable product of these animals. The Pearson correlations between actual saleable product and the predictions based on live and cold carcass data were .91 and .95, respectively. The Spearman and Kendall rank correlations were .95 and .83, respectively, for the cold carcass data. These results provide a practical application of bioelectrical impedance for market-based pricing. They complement previous studies that assessed fat-free mass.

Key Words: Beef Cattle Finishing, Impedance, Carcass Composition

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Introduction

Most beef cattle are sold on a live weight basis and are marketed on averages instead of true value. To determine a true value, one must devise a system that will objectively and accurately measure characteristics that differentiate animal value. Berg et al. (1996) has evaluated several systems and concluded that bioelectrical impedance (**BIA**) seems to be as accurate as some of the other technologies. In a recent review, Lukaski (1991) concluded that BIA had a wide variety of potential applications. Bioelectrical impedance has been used to assess the leanness and fat-free mass of pigs and pork carcasses (Swantek et al., 1992), Boston butts (Marchello and Slanger, 1992), beef cattle carcasses and cuts (Marchello and Slanger, 1994; Slanger and Marchello, 1994), and sheep and lamb carcasses (Berg and Marchello, 1994; Berg et al., 1996; Cosgrove et al., 1988; Jenkins et al., 1988). Slanger et al. (1994) used BIA to determine retail-ready cuts in live lambs and carcasses and showed that BIA has the potential for value-based marketing. Four-terminal bioelectrical analyzers can be integrated into present computer systems and can be used by producers, processors, and retailers. Therefore, the objectives of this research were 1) to develop prediction equations that would accurately predict the saleable product of finished beef cattle and carcasses and 2) to validate these equations.

Materials and Methods

Two experiments were performed in order to develop and validate prediction equations of saleable beef from finished cattle and beef carcasses. Protocol for this project was approved by the North Dakota State University committee for animal welfare. Cattle were weighed and impedance measurements taken the day before slaughter. The animals were held off feed and then transported

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to a commercial facility the next morning, where they were slaughtered and processed.

A four-terminal bioelectrical impedance analyzer (Model BIA-101, RJL Systems, Detroit, MI) was used to measure resistance (**Rs**, ohms) and reactance (**Xc**, ohms) of 50 fed cattle and processed carcasses. Twenty-gauge Vacutainer needles (Becton Dickinson, Rutherford, NJ) were used as electrodes and inserted (12.7 mm) into the live animal along the dorsal midline 10 and 20 cm caudal from the top of the shoulder (first thoracic vertebrae) and at the tail head (first coccygeal vertebrae) and 10 cm cranial to it. Kilograms of saleable (NAMP, 1992) cuts was estimated by regression procedures using BIA and live cattle measurements collected approximately 20 h before slaughter. Hot carcass measurements were collected approximately 45 min after slaughter. Measurements included carcass weight and BIA measurements on carcass halves. Carcasses were chilled for 48 h and then measured for BIA measurements, carcass weight, longissimus muscle area (**LMA**), backfat (**BF**) at the 12th rib, kidney, pelvic, and heart fat percentage (**KPH**), yield grade (**YG**), and quality grade (**QG**). One carcass side per animal (side from which all measurements were collected) was processed into IMPS cuts (NAMP, 1992) and weighed after a 48-h chill.

Measurements collected with the BIA on hot and cold carcasses were used to develop regression equations to

Table 1. Live animal and carcass measurements and characteristics (Exp. 1)

Variable	n	Mean	SD	Min.	Max.
Live weight, kg	50	493.9	46.2	420.5	588.3
Live resistance, Ω	50	26.0	3.5	20.0	35.0
Live reactance, Ω	50	3.5	.6	3.0	5.0
Live length, cm	50	96.7	7.3	83.0	112.0
Live volume 1[a]	50	365.7	65.1	267.6	545.2
Live volume 2[b]	50	362.2	63.9	264.7	535.6
Hot weight, kg	50	297.5	29.3	250.8	347.5
Hot weight, side-kg	50	148.9	14.7	126.1	176.0
Hot resistance, Ω	50	75.2	7.6	60.0	91.0
Hot reactance, Ω	50	17.5	2.3	12.0	21.0
Hot length, cm	50	111.5	5.6	99.0	127.0
Hot temperature, °C	50	37.6	0.5	36.7	38.9
Cold weight, kg	50	291.7	28.8	245.4	340.2
Cold weight, side-kg	50	146.0	14.5	123.4	172.4
Cold resistance, Ω	50	167.4	16.2	137.0	199.0
Cold reactance, Ω	50	49.9	5.9	39.0	66.0
Cold length, cm	50	112.8	4.5	104.0	122.0
Cold temperature, °C	50	2.3	.8	1.1	5.0
Cold volume 1	50	76.9	9.8	60.7	96.6
Cold volume 2	50	73.7	9.5	57.9	93.3
Dressing %	50	60.2	1.8	55.4	64.9
Fat cover, cm	50	.7	.3	.2	1.7
Loin eye area, cm	50	79.5	10.2	63.2	99.4
KPH, %[c]	50	2.3	1.1	.5	4.7
Kidney fat, kg	50	4.2	1.4	1.9	7.2
Marbling score[d]	50	431.8	101.2	270.0	750.0
Quality grade[e]	50	9.6	1.2	7.0	13.0
Yield grade	50	2.3	.7	1.2	4.3
Sum of IMPS cuts + trim, kg	50	99.4	12.1	79.4	120.4
Ribeye roll (112A)	50	4.7	.6	3.1	6.2
Chuck shoulder clod (114)	50	6.4	1.1	4.7	9.5
Chuck roll (116A)	50	9.5	1.3	7.0	12.3
Chuck tender (116B)	50	1.1	.2	.7	1.5
Brisket (120)	50	3.7	.8	2.0	6.0
Round knuckle (168)	50	4.5	.7	3.4	6.2
Top round (169)	50	8.0	1.1	5.8	10.4
Bottom round (170)	50	9.5	1.3	7.3	12.2
Loin strip (180)	50	4.2	.5	3.3	5.1
Loin top sirloin (184)	50	4.1	.7	2.9	7.2
Loin bottom sirl (185)	50	1.9	.5	1.2	4.7
Full tenderloin (189A)	50	2.3	.4	.8	3.1
Trim	50	39.4	5.4	27.9	49.9

[a] Volume 1 = (length × length)/resistance.
[b] Volume 2 = (length × length)/[(resistance × resistance) + (reactance × reactance)].
[c] Percentage kidney, pelvic, and heart fat.
[d] Marbling 200–299, traces; 700–799 slightly abundant.
[e] Quality grade of 7 = Standard, 13 = Prime.

predict kilograms of IMPS cuts. Twenty-gauge needles were inserted 25.4 mm from the external side of hot and cold (48-h chill) carcasses to measure Rs and Xc. Detector electrodes were placed at the midpoint of the carcass width along the sagittal plane at the ball of the femur and the head of the humerus. The respective transmitter electrodes were inserted 10 cm caudal (into the round) and 10 cm cranial (into the shoulder) to detector electrodes.

Development of prediction equations for IMPS cuts used the many statistical techniques of PROC REG from SAS (1988). The data were analyzed with R^2 and multiple linear regression procedures to determine statistical relationships between kilograms of IMPS and impedance measurements (SAS, 1991). Mallows's C_P (Mallows, 1973) statistic was used to determine the number of independent variables regressed for the prediction of kilograms of IMPS cuts.

Table 2. Live animal and carcass measurements and characteristics (Exp. 2)

Variable	n	Mean	SD	Min.	Max.
Live weight, kg	27	588.9	75.3	513.5	764.3
Live resistance, Ω	26	23.7	3.1	18.0	29.0
Live reactance, Ω	26	3.6	.9	2.0	5.0
Live length, cm	50	96.7	7.3	83.0	112.0
Live volume 1[a]	26	111.7	9.9	96.0	127.0
Live volume 2[b]	26	533.5	118.0	330.4	815.6
Live hot weight, kg	27	352.6	42.2	302.5	441.8
Live hot weight, side-kg	27	175.4	20.9	152.0	220.4
Hot resistance, Ω	16	74.5	5.3	63.0	86.0
Hot reactance, Ω	16	18.4	1.6	16.0	21.0
Hot length, cm	16	120.1	6.2	106.0	129.0
Hot temperature, °C	16	40.1	.9	38.9	42.8
Cold weight, kg	27	345.2	41.2	297.1	432.7
Cold weight, side-kg	27	171.7	20.4	149.2	215.9
Cold resistance, Ω	27	165.2	18.3	130.0	193.0
Cold reactance, Ω	27	50.6	8.1	36.0	64.0
Cold length, cm	27	123.2	8.1	108.0	138.0
Cold temperature, °C	27	2.3	3.8	–15.6	4.9
pH	27	5.5	.07	5.4	5.7
Cold volume 1	27	93.3	16.1	67.2	132.1
Cold volume 2	27	89.2	15.4	65.3	126.3
Dressing, %	27	60.0	1.9	57.2	63.6
Fat cover, cm	27	.6	.3	.13	1.4
Loin eye area, cm	27	85.3	10.2	67.7	107.1
KPH, %[c]	26	2.0	.5	1.0	3.0
Kidney fat, kg	27	4.2	1.8	2.0	9.6
Marbling score[d]	27	398.5	87.6	260.0	710.0
Quality grade[e]	26	9.3	1.2	7.0	13.0
Yield grade	27	2.2	.7	.6	3.6
Sum of IMPS cuts + trim, kg	27	117.0	12.3	101.2	144.7
Ribeye roll (112A)	27	5.2	.9	4.3	8.1
Chuck shoulder clod (114)	27	7.9	.8	6.7	9.9
Chuck roll (116A)	27	9.8	1.2	7.9	12.5
Chuck tender (116B)	27	1.5	.2	1.3	2.0
Brisket (120)	27	4.2	.8	1.4	5.3
Round knuckle (168)	27	5.2	.7	4.3	6.6
Top round (169)	27	9.5	1.4	7.4	12.3
Bottom round (170)	27	11.4	1.7	9.3	14.7
Loin strip (180)	27	4.9	.5	3.8	6.1
Loin top sirloin (184)	27	5.5	.6	4.6	6.7
Loin bottom sirl (185)	26	2.1	.6	1.2	3.4
Full tenderloin (189A)	27	2.7	.5	1.6	3.9
Trim	27	47.3	4.7	39.3	59.1
Retail product (kg) predicted from equations of Exp. 1					
Live	26	122.7	15.0	106.6	159.5
Cold	27	118.4	16.9	100.4	159.5

[a] Volume 1 = (length × length)/resistance.

[b] Volume 2 = (length × length)/[(resistance × resistance) + (reactance × reactance)].

[c] Percentage kidney, pelvic, and heart fat.

[d] Marbling 200–299, traces; 200–299, slightly abundant.

[e] Quality grade of 7 = Standard, 13 = Prime.

Table 3. Equations from live animal, hot carcass, and cold carcass measurements for predicting kilograms of IMPS cuts plus trim

Live prediction[a]

$$\text{IMPS, kg} = 11.87 + (.409 \times \text{BW, kg}) - (.355 \times \text{Lg, cm}) + (.0518 \times \text{vol}^{d})$$

$$R^2 = .799,\ C_P = 5.5,\ \text{RMSE} = 5.6$$

Hot carcass prediction[b]

$$\text{IMPS, kg} = -58.84 + (.59 \times \text{HCW, kg}) - (.85 \times \text{Rs}, \Omega)\ (1.15 \times \text{Xc}, \Omega) + (.14 \times \text{Lg, cm}) + (2.6 \times \text{Tp, C}^{\circ})$$

$$R^2 = .948,\ C_P = 6.7,\ \text{RMSE} = 2.9$$

Cold carcass prediction

$$\text{IMPS, kg} = 32.15 + (.63 \times \text{CCW, kg}) + (.33 \times \text{Xc}, \Omega)\ (83 \times \text{Lg, cm}) + (.68 \times \text{vol})$$

$$R^2 = .931,\ C_P = 7.6,\ \text{RMSE} = 3.3$$

[a] Prediction based on live measurements collected prior to slaughter.

[b] Prediction based on measurements collected 45 min after bled.

[c] Prediction based on measurements collected after a 48-h chill.

[d] $\text{Vol} = \text{Length}^2/\text{Rs}$.

Berg and Marchello (1994) provide detailed descriptions of needle function and placement. Hot and cold carcass temperatures (**Tp**, °C) were obtained with a standard probe meat thermometer inserted into the thickest part of the inside round. Impedance readings are affected by temperature because of its direct relationship with conductance (Serway and Faughn, 1989). The Rs and Xc readings increase from live animal to hot carcass to cold carcass because of the loss of body fluids and changes in the distribution of electrolytes between intracellular and extracellular tissues in the carcasses (Swatland, 1984).

The same procedures in Exp. 2 were followed as described previously. Twenty-seven animals were evaluated and the developed equations were used to predict the amount of saleable product from live animals and the cold carcasses. Pearson, Spearman, and Kendal correlations were calculated between actual values and values predicted from live and cold carcass measurements. The R^2 values and regression coefficients of the Exp. 2 data fit to the prediction equations of Exp. 1 were calculated. The coefficients were compared with *t*-tests. The data from both experiments were combined and a third set of prediction equation coefficients was calculated.

Results and Discussion

Live and carcass measurements and characteristics for Exp. 1 are shown in Table 1. There was considerable variation in the various characteristics. Live weight ranged from 420 to 588 kg, and this variation carried through in the carcass. Dressing percentage averaged 60%. Fat cover varied from .2 cm to 1.9 cm, and percentage of KPH ranged from .5 to 4.7%. This produced yield grades that ranged from 1.2 to 4.3.

Similar results were observed and collected in Exp. 2, as shown in Table 2 with the exception of live and carcass weight. Animals in Exp. 2 were 95 kg heavier at the time of slaughter and consistently produced carcasses that weighed 55 kg more. The difference in saleable product was 18 kg, but the percentages were similar (68%) based on saleable product from cold carcass weight and(or) hot carcass weight (67%). As shown in Table 2, dressing percentage averaged 60%, and fat cover ranged from .1 to 1.4 cm. Percentage KPH had a slightly narrower range of 1 to 3%, and yield grades showed a slightly lower range of .6 to 3.6, but the overall average was the same (2.3).

Table 3 shows the best model equation for live animal, hot carcass, and cold carcass measurements for pre-

Table 4. Comparison of the coefficients, standard error, and *P*-value of live animals in Experiments 1 and 2

	Exp. 1 (n = 50)			Exp. 2 (n = 26)			
Variable	Coeff	SE	*P*-value	Coeff	SE	*P*-value	*t*-Test *P*-values[a]
Intercept	11.87	14.76	.43	−1.50	18.53	.94	.2891
Weight	.20	.020	.0001	.17	.014	.0001	.0619
Length	−.33	.15	.0305	.015	.162	.93	.0638
Volume	.05	.019	.0079	.036	.013	.0108	.2451
R^2	.7997	—	—	.8631	—	—	—
Adjusted R^2	.7866	—	—	.8445	—	—	—
Root MSE	5.60	—	—	4.85	—	—	—
Mallows's C_P	5.6	—	—	11.8	—	—	—

[a] *t*-Test is testing that the true coefficients are the same for Exp. 1 as for Exp. 2.

Table 5. Comparison of the coefficient standard error plus *P*-value for cold carcass in Experiments 1 and 2

	Exp. 1 (n = 50)			Exp. 2 (n = 20)			
Variable	Coeff	SE	*P*-value	Coeff	SE	*P*-value	*t*-Test *P*-values[a]
Intercept	2.15	13.8	.0246	56.02	13.6	.0004	.1156
Weight	.63	.06	.0001	.49	.10	.0001	.1050
Length	−.83	.19	.0001	−.63	.26	.0258	.2737
Volume	.68	.13	.0001	.45	.11	.0005	.0987
Reactance	.33	.17	.0652	.27	.18	.1423	.4135
R^2	—	—	—	.9122	—	—	—
Adjusted R^2	—	—	—	.8963	—	—	—
Root MSE	—	—	—	3.98	—	—	—
Mallows's C_P	—	—	—	6.4	—	—	—

[a] *t*-Test is testing that the true coefficients are the same for Exp. 1 as Exp. 2.

dicting kilograms of saleable product. The R-square, Mallows's C_P, and the square root of the mean square error (**RMSE**) were used to determine the best equation. Mallows's C_P gives the best estimated variance and determined the point at which inclusions of independent variables did not increase R^2 significantly. Models were also selected based on significance level ($P < .05$) of independent variables because they contribute to the explanation of total variance. Weight accounted for 77, 87, and 87% of the variation in saleable product of live animal and hot and cold carcasses, respectively. Resistance accounted for only 28% of the variation in the live animal but increased to 63% in the hot and cold carcasses. When volume was incorporated into the equation, it explained 72% of the variation of saleable product.

The Pearson correlations between the 27 actual measures of retail product and the 27 predictions of retail product based on live and cold carcass data were .91 and .95, respectively. Spearman and Kendall rank correlations were .95 and .83, respectively, for the cold carcass data. The analogous rank correlations were .74 and .56 for the live data.

The Exp. 2 data fit prediction equations from Exp. 1 with R^2 values of .74 and .74 for live data and cold carcass data, respectively. These high correlation coefficients bode well for bioelectrical impedance as an approach that is repeatable from one set of finished cattle to another.

Table 6. Combined equation from Experiments 1 and 2 to predict saleable product from live animals and cold carcass measurements

Live prediction[a]

$$\text{IMPS, kg} = 28.44 + (.16 \times \text{BW, kg}) - (.28 \times \text{Lg, cm}) + (.05 \times \text{vol}^{c})$$
$$R^2 = .85,\ C_P = 9.0,\ \text{RMSE} = 5.70$$

Cold carcass prediction[b]

$$\text{IMPS, kg} = 40.9 + (.61 \times \text{CCW, kg}) + (.25 \times \text{Xc}, \Omega) - (.70 \times \text{Lg, CW}) + (.49 \times \text{vol})$$
$$R^2 = .92,\ C_P = 3.2,\ \text{RMSE} = 4.0$$

[a] Prediction based on live measurements collected prior to slaughter.

[b] Prediction based on measurements collected after a 48-h chill.

[c] Vol = $\text{Length}^2/\text{Rs}$.

Tables 4 and 5 show the coefficients and standard errors for the live animal and cold carcasses of the saleable product. The equations, R^2, and RMSE are similar. The big difference is that length was not a significant predictor variable for Exp. 2, but length is an integral part of impedance. As one increases the length, the resistant values also increase.

Because the *t*-tests are nonsignificant, these studies suggest that the data bases should be combined. The new equations are shown in Table 6 with adjusted R^2 of .85 and .92 for live animals and cold carcasses, respectively.

Previous work in our laboratory and others (Cosgrove et al., 1988; Jenkins et al., 1988; Berg et al., 1996) has concentrated on fat-free mass. This study concentrated on the amount of saleable product, which is the ultimate goal of packers and processors. Slanger et al. (1994) provided excellent correlations ($R^2 = .97$) for saleable products from lambs. However, Berg et al. (1996) found that BIA was only a marginal estimator for boneless, trimmed primal cuts from lambs. These differences may be due to the fact that Berg et al. (1996) did not take into account all of the saleable product, as did Slanger. Furthermore, BIA may be more precise when there are larger volumes to measure. The BIA measurements are lowest in cattle, higher in pigs, and highest in sheep. Thomason et al. (1997), using multifrequency BIA, showed good results when animals had a wide range of body condition and weight but not in cattle that had a narrow weight range. Our study substantiated that finished cattle can be evaluated with BIA. Furthermore, Thomason et al. (1997) concluded that in normal cattle any single frequency gives an equally good prediction.

Previous work by Marchello and Slanger (1994) provided equations based on cow data. Those equations are probably not applicable to finished cattle because cows are less uniform than fed animals. Fed animals are commonly fed, are of similar age and weight when marketed, and are in an active growing state, which has an effect on overall metabolism and electrolyte balance.

Implications

Bioelectrical impedence analysis has the potential to become a rapid, noninvasive procedure to predict saleable product from live animals and processed carcasses. All segments of the beef industry can use this technology, and its use could lead to the development of carcass merit payment programs.

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