Prediction of Carcass Composition Using Carcass Grading Traits in Hanwoo Steers

Jooyoung Lee, Seunggun Won, Jeongkoo Lee, and Jongbok Kim*

College of Animal Life Science, Kangwon National University, Chuncheon 24341, Korea

ABSTRACT: The prediction of carcass composition in Hanwoo steers is very important for value-based marketing, and the improvement of prediction accuracy and precision can be achieved through the analyses of independent variables using a prediction equation with a sufficient dataset. The present study was conducted to develop a prediction equation for Hanwoo carcass composition for which data was collected from 7,907 Hanwoo steers raised at a private farm in Gangwon Province, South Korea, and slaughtered in the period between January 2009 and September 2014. Carcass traits such as carcass weight (CWT), back fat thickness (BFT), eye-muscle area (EMA), and marbling score (MAR) were used as independent variables for the development of a prediction equation for carcass composition, such as retail cut weight and percentage (RC, and %RC, respectively), trimmed fat weight and percentage (FAT, and %FAT, respectively), and separated bone weight and percentage (BONE, and %BONE), and its feasibility for practical use was evaluated using the estimated retail yield percentage (ELP) currently used in Korea. The equations were functions of all the variables, and the significance was estimated via stepwise regression analyses. Further, the model equations were verified by means of the residual standard deviation and the coefficient of determination (R^2) between the predicted and observed values. As the results of stepwise analyses, CWT was the most important single variable in the equation for RC and FAT, and BFT was the most important variable for the equation of %RC and %FAT. The precision and accuracy of three variable equation consisting CWT, BFT, and EMA were very similar to those of four variable equation that included all for independent variables (CWT, BFT, EMA, and MAR) in RC and FAT, while the three variable equations provided a more accurate prediction for %RC. Consequently, the three-variable equation might be more appropriate for practical use than the four-variable equation based on its easy and cost-effective measurement. However, a relatively high average difference for the ELP in absolute value implies a revision of the official equation may be required, although the current official equation for predicting RC with three variables is still valid. (**Key Words:** Carcass Composition, Carcass Grading Traits, Coefficient of Determination, Hanwoo Steer, Prediction Equation, Residual Standard Deviation)

INTRODUCTION

Carcass composition is important for value-based marketing of a carcass and for the establishment of an optimal feeding scheme (Drennan et al., 2008; Minchin, et al., 2009). However, the actual values of composition obtained from carcass dissection may not facilitate the determination of carcass pricing because the pricing of carcasses is typically completed prior to the carcass dissection. Thus, many studies have focused on the development of equations that predict carcass composition based on carcass traits, such as carcass weight (CWT), back-fat thickness (BFT), eye-muscle area (EMA), marbling score (MAR), and the percentage of kidney, pelvic and heart fat (%KPH) (Greiner et al., 2003b). Various efforts have been made to improve the prediction equation using a large dataset and focusing on the reduction of differences between the predicted and observed values with a low standard error for the estimate (Kauffman et al., 1975) and further ultrasonic measurement of fat has been widely used for the development of a prediction equation (Anderson et al., 1983; Herring et al., 1994). However, ultrasound technology may not be available at the farm level and the official equation includes three independent carcass variables (CWT, BFT, and EMA) and is widely used to estimate the percentage of retail cut for the Hanwoo carcasses (MAFRA, 2009a);

* Corresponding Author: Jongbok Kim. Tel: +82-33-250-8624, Fax: +82-33-244-2532, E-mail: jbkim@kangwon.ac.kr

several studies have been conducted to develop an equation with improved predictive ability for Hanwoo carcasses (Lee et al., 2005; 2008; Choy et al., 2010). However, the development and proof of prediction equations must be continuously reconfirmed due to the environmental changes in the beef production system and the endless efforts to genetically improve the cattle to ensure high productivity, which could lead to biological changes in Hanwoo cattle that could affect feed efficiency, growth performance, and body composition (Kim and Lee, 2000).

Thus, this study aimed to develop equations to predict carcass composition, such as retail cut, trimmed fat and separable bone weights and percentages, of Hanwoo steer using carcass traits (CWT, BFT, EMA, and MAR) on the steer field data collected from the private farm of Korea and to verify the predictive ability of the model equation developed.

MATERIALS AND METHODS

Animals and traits

Data were obtained from 7,907 Hanwoo steers raised at a private farm in Gangwon Province, South Korea, and slaughtered in the period between January 2009 and September 2014. The number of animals per slaughter year were 1,162, 1,227, 1,857, 1,450, 1,168, and 1,043 for year 2009, 2010, 2011, 2012, 2013, and 2014, respectively, and mean age in month was 31.97±3.22. The feeding and management of the steers has been explained by Koh et al. (2014).

Following the standard normal industrial procedures recommended by the Korean government (MAFRA, 2009a), the slaughtering of the steers was conducted at an abattoir that was located at a transport distance less than an hour from the steer farm by truck. After slaughtering, each carcass was immediately halved and held in a chilling room at 4°C for one night, and then both sides of the carcasses were taken from the chilling room and transferred to the evaluation venue for the weight measurement. The left sides were dissected at the position between the last rib and the first lumbar vertebra, and these were used for the measurements of BFT, EMA, and MAR. The BFT was measured at the three-fourths position of the longissimus muscle from the spinal column. The EMA was measured using a transparent grid. The MAR was evaluated from 1 (poor) to 9 (best) according to the Korea Beef Marbling Standard, and the estimated retail yield percentage (ELP) was calculated according to the Korea Beef Grading Standards as follows.

$$\text{ELP (\%)} = 71.414 - (0.625 \times BFT) + (0.130 \times EMA) - (0.024 \times CWT)$$

Carcass fabrication procedures were performed at the adjacent commercial packing plant based on the standards recommended by the Korean government (MAFRA, 2009b). The entire carcass was dissected into several sub-primal cuts, and all bones were removed with the exception of the ribs. Rib bones were left in the rib. After the de-boning, the excessive fat and intermuscular fat were closely trimmed.

All sub-primal cuts were summed as retail cut weight (RC), while the bones removed from the sub-primal cuts and tail were summed as bone weight (BONE). The trimmed fat weight (FAT) was calculated by subtracting the RC and BONE from the CWT, since the measurement of FAT was not possible due to the conditions of the packing plant. The percentages for the retail cuts (%RC), separated bones (%BONE), and trimmed fats (%FAT) were obtained based on the cold CWT.

After data collection, the unrealistic values that were regarded as recording errors were deleted, and the furthest values from the normal, as determined by 3 standard deviations from the mean values in the ratios of RC to FAT, RC to BONE, and FAT to BONE, were excluded (Hickey et al., 2007; McPhee et al., 2008). A total of 7,152 carcass records were used in the subsequent statistical analyses.

Statistical analyses

A randomly determined half of the 7,152 records (n = 3,576) was assigned to the development of prediction equations, while the other half of the dataset (n = 3,576) was assigned to verifying the equations developed. The simple statistics for the development and test datasets are presented in Table 1.

The prediction equations for the six carcass compositional traits—RC, %RC, FAT, %FAT, BONE, and %BONE—were developed using a stepwise regression procedure, using CWT, BFT, EMA, and MAR as independent variables that had to retain statistical significance ($p<0.05$) within the model equation. The predictive ability of the equations developed was determined by the coefficient of determination (R^2) and the residual standard deviation (RSD), and the equations with the highest R^2 and the lowest RSD values were considered to have the best predictive ability.

The difference and correlation coefficients between the predicted and observed values were calculated using the dataset and the equations developed in this study and compared to the predictive ability of the equations. In addition, since ELP represents the predicted percentage of retail yield calculated by the current official equation for Hanwoo carcasses, the difference and correlation coefficients between the ELP and %RC observed were compared to those values calculated from the %RC equations developed in this study, whereby the feasibility of the %RC equations were evaluated for practical use.

All the statistical analyses, including the elementary statistics, correlation coefficients, and stepwise regressions,

Table 1. Simple statistics for the independent and dependent variables in the development dataset (n = 3,576) and the test dataset (n = 3,576)

Traits	For equation development			For test of equation developed		
	Mean	SD	CV	Mean	SD	CV
CWT (kg)	454.0	45.5	10.03	453.3	44.9	9.9
BFT (mm)[1]	14.8	5.0	34.0	14.8	4.9	33.1
EMA (cm^2)[1]	96.2	10.6	11.0	95.8	10.6	11.1
MAR[1,2]	6.3	1.7	27.4	6.3	1.7	27.2
ELP (%)[3]	60.6	3.7	6.0	60.5	3.6	5.9
RC (kg)	279.2	28.8	10.3	278.8	28.2	10.1
%RC (%)[4]	61.5	2.6	4.2	61.6	2.5	4.1
FAT (kg)	121.1	20.3	16.7	120.7	20.1	16.7
%FAT (%)[4]	26.6	2.9	10.9	26.6	2.9	10.9
BONE (kg)	53.7	5.3	9.8	53.7	5.2	9.7
%BONE (%)[4]	11.9	1.0	7.9	11.9	0.9	7.9

SD, standard deviation; CV, coefficient of variation; CWT, cold carcass weight; BFT, back fat thickness; EMA, eye-muscle area (cm^2); MAR, marbling score; ELP, estimated lean yield percentage; RC, retail cut weight; %RC, retail cut percentage; FAT, trimmed fat weight; %FAT, trimmed fat percentage; BONE, trimmed bone weight; %BONE, trimmed bone percentage.

[1] Measured from the last rib to the first lumbar vertebra cross-sectioned.

[2] Evaluated based on the Korean Beef Marbling Standard with scores from 1 (poor) to 9 (best).

[3] Estimated retail cut percentage using the current official equation for Hanwoo carcasses (ELP = 71.414–0.024 CWT–0.625 BFT+0.130 EMA).

[4] Percentages for cold carcass weight.

were performed using SAS software (Version 9.2, SAS Inst., Inc., Cary, NC, USA).

RESULTS

Stepwise regressions for RC and %RC

Stepwise regression equations for predicting RC and %RC from the four carcass grading traits of CWT, BFT, EMA, and MAR are shown in Table 2. For presentation purposes, the equations for each step of the regression analyses were labeled as Eq. 1, Eq. 2, Eq. 3, and Eq. 4, respectively.

The CWT was the most important for the prediction of RC, since CWT alone governed RC values with a variation of 83.4%. For %RC, the BFT covered 10.7% of the variation of %RC (Eq. 1). The EMA was the second most influential variable on both RC and %RC, and it increased the power of predictability an additional 2.5% and 9.2% of variations in RC and %RC, respectively (Eq. 2). The MAR was the last variable in the equation for RC and %RC in the stepwise process, but its influence on the increase in the R^2 value was not significant.

The RSD and R^2 of Eq. 3 with three independent variables were estimated as 10.350 kg and 87.1%, respectively, and the values for Eq. 4 in which MAR was added were 10.342 kg and 87.1%, respectively. The RSD and R^2 between Eq. 3 and Eq. 4 showed little difference for the dependent variables of RC and %RC.

Stepwise regressions for FAT and %FAT

The results of the stepwise regression analyses for predicting FAT and %FAT are presented in Table 3. The CWT again governed the equation, accounting for 59.7% of the variations for FAT. The second variable, BFT, was added to the equation for FAT, which resulted in an increase of the R^2 value by 5.3%, while the further addition of EMA increased the R^2 value to 68.8%. The MAR was the last variable in the equation, but its contribution to the variation in FAT was insignificant and induced an increase of only 0.2% in the equation evaluation with three variables (Eq. 3).

In the stepwise analyses for %FAT, the most influential

Table 2. Regression equations for predicting weight in kilograms (RC) and percentage of retail cut (%RC) using carcass traits

Dependent variable and equation no.	RSD	R^2 (%)	Intercept	Partial regression coefficients*			
				CWT	BFT[1]	EMA[1]	MAR[1,2]
RC							
Eq. 1	11.714	83.4	17.351	0.576	-	-	-
Eq. 2	10.796	85.9	–6.043	0.527	-	0.479	-
Eq. 3	10.350	87.1	–6.529	0.556	–0.658	0.446	-
Eq. 4	10.342	87.1	–5.926	0.556	–0.659	0.459	–0.268
%RC[3]							
Eq. 1	2.425	10.7	63.997	-	–0.167	-	-
Eq. 2	2.297	19.9	57.094	-	–0.179	0.074	-
Eq. 3	2.248	23.3	60.041	–0.012	–0.142	0.096	-
Eq. 4	2.246	23.5	60.178	–0.013	–0.143	0.099	–0.061

RSD, residual standard deviations for the model; CWT, cold carcass weight (kg); BFT, back fat thickness (mm); EMA, eye-muscle area (cm^2); MAR, marbling score.

[1] Measured from the last rib to the first lumbar vertebra cross-sectioned.

[2] Evaluated based on the Korean Beef Marbling Standard with scores of 1 (poor) to 9 (best).

[3] Percentages for cold carcass weight.

* Variables in the models included only those that were significant at p<0.05.

Table 3. Regression equations for predicting weight in kilograms (FAT) and percentage of trimmed fat (%FAT) using carcass traits

Dependent variable and equation no.	RSD	R^2 (%)	Intercept	Partial regression coefficients*			
				CWT	BFT[1]	EMA[1]	MAR[1,2]
FAT							
Eq. 1	12.889	59.7	−35.069	0.344	-	-	-
Eq. 2	12.004	65.0	−31.936	0.305	1.000	-	-
Eq. 3	11.340	68.8	−11.826	0.351	0.917	−0.417	-
Eq. 4	11.298	69.0	−13.173	0.352	0.918	−0.446	0.600
%FAT[3]							
Eq. 1	2.633	17.7	23.017	-	0.243	-	-
Eq. 2	2.566	21.9	28.261	-	0.252	−0.056	-
Eq. 3	2.471	27.6	23.946	0.018	0.198	−0.089	-
Eq. 4	2.462	28.2	23.644	0.018	0.199	−0.095	0.134

RSD, residual standard deviations for the model; CWT, cold carcass weight (kg); BFT, back fat thickness (mm); EMA, eye-muscle area (cm^2); MAR, marbling score.

[1] Measured from the last rib to the first lumbar vertebra cross-sectioned.

[2] Evaluated based on the Korean Beef Marbling Standard with scores of 1 (poor) to 9 (best).

[3] Percentages for cold carcass weight.

* Variables in the models included only those that were significant at p<0.05.

factors in the equation were BFT, EMA, CWT, and MAR, in this order, and the addition of EMA and CWT in the equation with BFT resulted in an increase of the R^2 by 9.9% in the equation (from 17.7% in Eq. 1 to 27.6% in Eq. 3). However, the addition of MAR showed an increase in the R^2 of only 0.6% for the equation fit (from 27.6% in Eq. 3 to 28.2% in Eq. 4).

Stepwise regressions for BONE and %BONE

The results of the stepwise analyses for predicting BONE and %BONE are delineated in Table 4. The CWT and EMA were the first and last variables, respectively, entered into the equation for predicting BONE and %BONE. As the third variable, MAR with CWT and BFT improved BONE and %BONE by 1.3% and 2.0%, respectively.

The R^2 values in Eq. 3 and Eq. 4 for BONE were 53.3% and 53.4%, respectively, which corresponded with 27.5% and 27.6% for %BONE, respectively. The differences in R^2 and RSD between the final four-variable equation (Eq. 4) and the three-variable equation in the third step (Eq. 3) were not very significant in BONE and %BONE.

Evaluation of the equation

The three- and four-variable equations (Eq. 3 and 4, respectively) were selected as the best probable equations because of their high R^2 and small RSD, and they were applied to the test dataset for the evaluation of the equations. Each dependent variable predicted from Eq. 3 and Eq. 4 were compared with an extra retail cut percentage from the official equation (ELP).

Table 4. Regression equations for predicting weight in kilograms (BONE) and percentage of trimmed bone (%BONE) using carcass traits

Dependent variable and equation no.	RSD	R^2 (%)	Intercept	Partial regression coefficients*			
				CWT	BFT[1]	EMA[1]	MAR[1,2]
BONE							
Eq. 1	3.834	47.0	17.717	0.079	-	-	-
Eq. 2	3.647	52.0	16.927	0.089	−0.252	-	-
Eq. 3	3.597	53.3	18.530	0.091	−0.257	-	−0.351
Eq. 4	3.596	53.4	19.099	0.092	−0.259	−0.014	−0.331
%BONE[3]							
Eq. 1	0.851	18.0	15.836	−0.009	-	-	-
Eq. 2	0.811	25.5	15.665	−0.007	−0.055	-	-
Eq. 3	0.800	27.5	16.023	−0.006	−0.056	-	−0.078
Eq. 4	0.799	27.6	16.178	−0.006	−0.056	−0.004	−0.073

RSD, residual standard deviations for the model; CWT, cold carcass weight (kg); BFT, back fat thickness (mm); EMA, eye-muscle area (cm^2); MAR, marbling score.

[1] Measured from the last rib to the first lumbar vertebra cross-sectioned.

[2] Evaluated based on the Korean Beef Marbling Standard with scores of 1 (poor) to 9 (best).

[3] Percentages for cold carcass weight.

* Variables in the models included only those that were significant at p<0.05.

Table 5 indicated the means predicted from Eq. 3 and Eq. 4 and observed from the test dataset. Eq. 3 and Eq. 4 were evaluated using the average differences and the correlation coefficients. The differences between the predicted and observed values were calculated by subtracting the observed value from the predicted value.

The correlation coefficients between the predicted and observed values in Eq. 3 were almost the same as those in Eq. 4 for every dependent variable, and the correlation coefficients of RC, FAT, and BONE were higher than those of %RC, %FAT, and %BONE in both Eq. 3 and Eq. 4.

The differences between the predicted and observed values for %RC and %BONE were statistically determined using a T-test in Eq. 3 and for %RC, %FAT, and %BONE in Eq. 4. Eq. 3, with three variables, overestimated %RC and %BONE, while Eq. 4 underestimated %RC, BONE, and %BONE. Using the ELP (official equation) for prediction, the average differences of %RC, with an absolute value of 1.01, were higher than the differences of 0.15 and 0.28 from Eq. 3 and Eq. 4, respectively, and the average differences from Eq. 3 tended to be smaller than those from Eq. 4 for all dependent variables, except RC, for which the average difference in Eq. 3 was slightly higher.

DISCUSSION

The model equation in the final step was functions of all four carcass-grading traits (CWT, BFT, EMA, and MAR) in order to obtain each dependent variables. The MAR was the last variable in the equation for RC, %RC, FAT, and %FAT, while the EMA was the last for BONE and %BONE. However, compared to the RSD and R^2 values, there were no practical differences between Eq. 3 and Eq. 4, which indicates that the last variables in the equation rarely contributed to the predictive ability of the equation. The inclusion of MAR, as the last variable in Eq. 3, with CWT, BFT, and EMA, increased the R^2 value of the equation for %RC and %FAT by only 0.02% and 0.06%, respectively (Tables 2 and 3). The inclusion of EMA, as the last variable in the Eq. 3, with CWT, BFT, and MAR increased the R^2 value of the equation for both BONE and %BONE by only 0.01% (Table 4).

The low contribution of MAR to the predictive ability of the equation for %RC and %FAT differs from the results of Griffin et al. (1999) and Greiner et al. (2003a), where the addition of MAR to the equation for %RC, which consisted of four independent variables (CWT, BFT, the percentage of kidney, pelvic and heart fat [%KPH], and EMA), increased the model R^2 values by sizable amounts (2% to 4%). The low contribution of MAR in predicting %RC and %FAT in this study could be due to a low correlation between MAR and %RC and %FAT in Hanwoo steer carcasses. Koh et al. (2014) reported a small and positive phenotypic correlation between MAR and %RC and %FAT in Hanwoo steer data (r = +0.04 and +0.07, respectively), of which similar and positive correlation coefficients of +0.02 and +0.03 were estimated in the preliminary analyses of this study (data not shown).

On the contrary, many previous studies in the US have shown a negative and moderate correlation between MAR

Table 5. Predicted and observed mean and average difference and correlation coefficients between the predicted and observed values for the dependent variables using the prediction equation with the test dataset (n = 3,576)

Dependent	Equations[1]	Predicted mean	Observed mean	Average difference[2]	Correlation coefficients[3]
RC	Eq. 3	278.52		−0.31	0.93
	Eq. 4	278.67	278.83	−0.16	0.93
%RC	Eq. 3	61.70		0.15***	0.49
	Eq. 4	61.28		−0.28***	0.50
	ELP[4]	60.54	61.55	−1.01***	0.49
FAT	Eq. 3	120.86		0.13	0.84
	Eq. 4	120.97	120.73	0.24	0.84
%FAT	Eq. 3	26.50		−0.05	0.54
	Eq. 4	26.48	26.55	−0.07	0.55
BONE	Eq. 3	53.78		0.04	0.72
	Eq. 4	53.56	53.74	−0.18**	0.72
%BONE	Eq. 3	11.99		0.09***	0.52
	Eq. 4	11.79	11.90	−0.11***	0.52

RC, retail cut weight (kg); %RC, retail cut percentage; ELP, official equation currently used for predicting the lean yield percentage for Hanwoo carcasses; FAT, trimmed fat weight (kg); %FAT, trimmed fat percentage; BONE, trimmed bone weight (kg); %BONE, trimmed bone percentage.
[1] Equation for the final step of four variable (coded by Eq. 4) and third step equation of three variable (coded by Eq. 3).
[2] Difference between predicted and observed value.
[3] Correlation coefficients between the predicted and observed values.
[4] Official equation currently used for predicting the lean yield percentage in Hanwoo carcass grading.
* Null hypothesis (H_0), differences are equal to zero (** p<0.01, *** p<0.001).

and %RC and a moderate positive correlation between MAR and %FAT (Herring et al., 1994; Shackelford et al., 1995; Johnson and Rogers, 1997; Griffin et al., 1999; May et al., 2000; Greiner et al., 2003b).

When compared to the R^2 values of the equations for %RC, %FAT, and %BONE measured in percentages units, the R^2 values corresponding to the RC, FAT, and BONE in kg units, respectively, were higher, of which trends had generally been shown in previous studies (Herring et al., 1994; Shackelford et al., 1995; Williams et al., 1997; Dikeman et al., 1998; Realini et al., 2001; Greiner et al., 2003b; Lee et al., 2005; Maeno et al., 2014). These results imply that the equations for RC or FAT constructed using carcass traits might be more accurate than the equations for %RC and %FAT. Further, CWT among the independent variables showed the strongest correlation in the equation with the highest R^2 value as the best single predictor. The correlation coefficients for RC, FAT, and BONE with CWT, which were obtained using the square root of the R^2 values of Eq. 1 for each weight variable, were 0.91, 0.77, and 0.69, respectively, in this study.

The official Korean equation for predicting %RC includes the three independent variables of CWT, BFT, and EMA, which were the same independent variables used to construct Eq. 3 for RC and %RC in this study. Lee et al. (2005 and 2008) and Choy et al. (2010) also developed equations using the same three independent variables to predict the RC and %RC for Hanwoo steer carcasses. The R^2 values in Eq. 3 for RC and %RC were 87.1% and 23.5%, respectively, in the present study, and these seem to concur with the values reported by Lee et al. (2005). However, the R^2 value of 23.5% for %RC is lower than the 54% reported by Choy et al. (2010). On the other hand, the R^2 values reported for equations for %RC with exotic beef carcasses ranged from 32.2% (Williams et al., 1997) to 75% (Cannell et al., 1999), which are generally higher than the R^2 values from Eq. 3 and Eq. 4 in the present study. The different R^2 values from the various studies might be due to a number of factors, including different cattle types, feeding management, fat trimming level, carcass fatness, variables for equation development, and cutting procedures. Another plausible reason, which might be exclusive to the study on commercial data, was the inconsistent fat trimming level due to the purchaser's demand. In this study, the fat trimming of the retail cut was conducted within the 6 mm fat cover, but the fat trimming level could differ based on the purchaser's demand.

When the overall predictability of an equation is evaluated in terms of accuracy and precision, the RSD or the difference between the predicted and observed values were used to determine the level of accuracy, and the precision was determined through the comparison of R^2 values or the correlation coefficients of the predicted and observed values

(Johnson and Rogers, 1977; Tedeschi, 2006). In this study, almost identical correlation coefficients were found for Eq. 3 and Eq. 4 regarding the predicted and observed values for all the dependent variables, which indicates that equal precision was achieved by Eq. 3 and Eq. 4. The small average difference in the absolute value for Eq. 3 implies that Eq. 3 is more accurate than Eq. 4 in predicting %RC, BONE, and %BONE; furthermore, the three variables in the current official equation for predicting RC were found to still be valid. However, compared to Eq. 3 and Eq. 4 for predicting %RC, a relatively high absolute value in the average difference for the ELP suggests that further study may be necessary to revise the official equation.

CONCLUSION

In stepwise process, the CWT was the most important trait for predicting RC, FAT, BONE, and %BONE, and the BFT was the most important trait for predicting %RC, %FAT.

There are no differences in the model precision between the three- and four-variable equations for predicting all six dependent variables, and the model accuracy is similar for the prediction of RC, FAT, and %FAT; however, three-variable equation (Eq. 3) is more accurate than the four-variable equation for predicting %RC, BONE, and %BONE.

We concluded that Eq. 3, which has three variables, might be the optimal choice for practical use in predicting the six dependent variables, and this should facilitate the investigation of new variables with easy and cost-effective measurements in order to increase the precision of the equations for predicting percentage variables, such as %RC, %FAT, and %BONE. The three variable equations included CWT, BFT, and EMA may be used for predicting lean and fat composition of Hanwoo carcasses and might be target variables for improving lean yield productivity of Hanwoo.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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