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Prediction model of a joint analysis of beef growth and carcass quality traits

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ABSTRACT. A joint growth-carcass analysis was conducted to develop equations for predicting carcass quality traits associated with variation in growth path of crossbred cattle. During a four-year period (1994-1997) of the Australian "Southern Crossbreeding Project", mature Hereford cows (r = 581) were mated to 97 sires of Jersey, Wagyu, Angus, Hereford, South Devon, Limousin, and Belgian Blue breeds, resulting in 1141 calves. Data included body weight measurements of steers and heifers from birth until slaughter and four carcass quality traits: hot standard carcass weight, rump fat depth, rib eye muscle area, and intramuscular fat content. The model provides nine outputs: median and mean of carcass quality traits, predicted means, and lower and upper confidence intervals, as well as predicted intervals of carcass quality traits (95%) and economic values for domestic market and export markets. Input to the model consists of sex, sire breeds, age (in days)-weight (kg) pairs and slaughter age (500 days for heifer and 700 days for steers). The prediction model is able to accommodate different sexes across seven sire breeds and various management groups at any slaughter age. Its strength lies in its simplicity and flexibility, desirable to accommodate producers with different management schemes. In general, fat depth and intramuscular fat were found to be more affected by differences in growth rate than hot carcass weight and eye muscle area. Also, export market value was more sensitive to growth rate modifications than domestic market value. This model provides a tool by which the producer can estimate the impact of management decisions.

Key words: Crossbred cattle; Prediction model; Growth;
Carcass quality traits

INTRODUCTION

Today, in the beef industry, it is a challenge to design the "best" management strategies for individual breeders and backgrounder and finisher operations to get optimum end products under different circumstances. Thus, a solution is to develop flexible and feasible models to predict carcass quality resulting from specific growth paths under a variety of management regimes that consequently lead to those cattle to be marketed at the optimum time. There are two approaches to develop such predictive models; mechanistic and empirical.

Empirical models allow an animal's weight gain to be expressed as a relatively simple function, allowing experimental comparison of different genetics and/or feeding regimes and investigation of body composition (Parks, 1982). While, empirical models cannot give a true understanding of the system under study, they can be used to predict the behavior of the system where data do not exist. Many attempts have been made in developing beef cattle growth and body composition models (Keele et al., 1992; Williams and Jenkins, 1998; Hoch and Agabriel, 2004). However, so far, empirical models for prediction of carcass quality based on the longitudinal body weights at various stages of growth have not been published. Thus, the objective of this study was to develop an empirical model to predict carcass quality traits of crossbred steers and heifers given a growth path.

MATERIAL AND METHODS

The model

Successful prediction of the carcass quality following specific growth path requires estimation of variation in growth traits and carcass traits and their association over growth path. Growth and carcass traits were both modeled on a log-scale. The underlying normal distribution used in modeling the mean that if y_w is log-weight for an animal and y_c is the log-carcass quality

$$\begin{array}{c} \mathbf{y_w} \\ \mathbf{y_c} \end{array} \sim \mathbf{N} \begin{array}{c} \boldsymbol{\mu}_\mathbf{w} \\ \boldsymbol{\mu}_\mathbf{c} \end{array} , \begin{array}{cc} \boldsymbol{\Sigma}_\mathbf{ww} & \boldsymbol{\Sigma}_\mathbf{wc} \\ \boldsymbol{\Sigma}_\mathbf{cw} & \boldsymbol{\Sigma}_\mathbf{cc} \end{array}$$

where $\mu_w = E(y_w)$, $\mu_c = E(y_c)$ and Σ_{ww} is the variance-covariance matrix for log-weight, Σ_{cc} is the variance-covariance matrix for log-carcass traits, and Σ_{wc} $(=\Sigma_{cw}^{T})$ is the cross-covariance matrix between log-weight and log-carcass traits. Of interest is to "predict" y_c given y_w at the first level, that is, to consider the distribution of $y_w\ y_c$, namely

$$\mathbf{y_c|y_w \sim N(\boldsymbol{\mu}_c + \boldsymbol{\Sigma}_{cw}\boldsymbol{\Sigma}_{ww}{}^{1}(y_w\ \boldsymbol{\mu}_w), \boldsymbol{\Sigma}_{cc}\ \boldsymbol{\Sigma}_{cw}\boldsymbol{\Sigma}_{ww}{}^{1}\boldsymbol{\Sigma}_{wc})}$$

Thus, we can provide an estimate of the mean log-carcass quality by

$$\boldsymbol{\mu}_{cw} = \boldsymbol{\mu}_{c} + \boldsymbol{\Sigma}_{cw}\boldsymbol{\Sigma}_{ww}{}^{1}(\mathbf{y}_{w}\ \boldsymbol{\mu}_{w})$$

We have estimates of μ_c, Σ_{cw}, Σ_{ww}, and μ_w from the joint model. Thus, given a growth path specified by y_w, we can estimate the log-carcass traits by

$$\hat{\boldsymbol{\mu}}_{cw} = \hat{\boldsymbol{\mu}}_{c} + \hat{\boldsymbol{\Sigma}}_{cw}\hat{\boldsymbol{\Sigma}}_{ww}{}^{1}(\mathbf{y}_{w}\quad \hat{\boldsymbol{\mu}}_{w}).$$

This is also our prediction. A confidence interval for μ_{cw} can be found as follows. First,

$$\hat{\boldsymbol{\mu}}_{c} = \mathbf{X}_{c}\hat{\boldsymbol{\tau}}_{c} \text{ and } \hat{\boldsymbol{\mu}}_{w} = \mathbf{X}_{w}\hat{\boldsymbol{\tau}}_{w}$$

where $\hat{\boldsymbol{\tau}}_{c}$ and $\hat{\boldsymbol{\tau}}_{w}$ are the log-carcass quality and log-body weights fixed effect parameter estimates. Then, conditional on y_w

$$\begin{aligned} &\mathrm{var}(\hat{\boldsymbol{\mu}}_{cw}) = \mathrm{var}(\hat{\boldsymbol{\mu}}_{c}) + \boldsymbol{\Sigma}_{cw}\boldsymbol{\Sigma}_{ww}{}^{1}\mathrm{var}(\hat{\boldsymbol{\mu}}_{w})\boldsymbol{\Sigma}_{ww}{}^{1}\boldsymbol{\Sigma}_{wc} \\ &\boldsymbol{\Sigma}_{cw}\boldsymbol{\Sigma}_{ww}{}^{1}\mathrm{cov}(\hat{\boldsymbol{\mu}}_{w},\hat{\boldsymbol{\mu}}_{c}) \qquad \text{(Equation 1)} \\ &\mathrm{cov}(\hat{\boldsymbol{\mu}}_{c},\hat{\boldsymbol{\mu}}_{w})\boldsymbol{\Sigma}\boldsymbol{\Sigma}_{w}{}^{1}\boldsymbol{\Sigma}_{wc} \end{aligned}$$

The (co)variance matrices can be found by noticing

$$\mathrm{var}\begin{matrix}\hat{\boldsymbol{\tau}}_{c} \\ \hat{\boldsymbol{\tau}}_{w}\end{matrix} = \boldsymbol{\sigma}^{2}(\mathbf{X}^{T}\mathbf{H}\ {}^{1}\mathbf{X})\ {}^{1}$$

where X is the fixed effect design matrix for the joint analysis of log-body weights and log-carcass quality and $\sigma^2 H$ is the full variance-covariance matrix for that analysis. Notice

$$\mathrm{var}\begin{matrix}\hat{\boldsymbol{\mu}}_{c} \\ \hat{\boldsymbol{\mu}}_{w}\end{matrix} = \mathrm{var}\begin{matrix}\mathbf{X}_{c} & \mathbf{0} \\ \mathbf{0} & \mathbf{X}_{w}\end{matrix}\ \begin{matrix}\hat{\boldsymbol{\tau}}_{c} \\ \hat{\boldsymbol{\tau}}_{w}\end{matrix}$$

$$= \boldsymbol{\sigma}^{2}\begin{matrix}\mathbf{X}_{c} & \mathbf{0} \\ \mathbf{0} & \mathbf{X}_{w}\end{matrix}\left(\mathbf{X}^{T}\mathbf{H}\ {}^{1}\mathbf{X}\right)^{1}\begin{matrix}\mathbf{X}_{c}{}^{T} & \mathbf{0}^{T} \\ \mathbf{0}^{T} & \mathbf{X}_{w}{}^{T}\end{matrix}$$

The terms in Equation 1 can be determined. Confidence intervals on the log-scale can then be determined in the standard manner using the normal approximation. On the original scale, the confidence interval is simply the back-transformation of the confidence interval on the log-scale. If the estimate is back-transformed, this is not the mean on the original scale, rather it is the median. Calculation of the mean involves

$$e^{\boldsymbol{\mu}_{cw,i} + \frac{1}{2}\boldsymbol{\sigma}^{2}c_{w,i}}$$

A prediction interval for a new y_c given y_w can be found using the distribution.

$$\mathbf{y}_c \quad \hat{\boldsymbol{\mu}}_{cw} \big| \mathbf{y}_w \sim \mathbf{N}(0, \boldsymbol{\Sigma}_{cc} \quad \boldsymbol{\Sigma}_{cw} \boldsymbol{\Sigma}_{ww} \; {}^{1}\boldsymbol{\Sigma}_{wc} + \mathbf{var}(\hat{\boldsymbol{\mu}}_{cw}))$$

The interval for y_c based on this distribution can be back-transformed as above with the same interpretation. These intervals will be wider than confidence intervals because they provide an interval for an observation rather than a mean.

Implementation of the model

With respect to the accessibility and the potential users of the model at this stage, it was decided to implement the model in the R program (2004). The model has three phases: input of data, calculation of predictions, and presentation of the results.

Model input

Input to the model is in four stages:

1. Sex, steer (default) or heifer
2. Breed (default is purebred Hereford, alternative sire breeds are Jersey, Wagyu, Angus, South Devon, Limousin, Belgian Blue)
3. Slaughter age (default is 700 days for steers and 500 days for heifers)
4. Series of age (in days) and weight (in kg) in pairs with space separating values

Model results

The program outputs predicted mean, confidence intervals and prediction intervals for each carcass trait. The predicted means were then used to calculate economic values for domestic or export markets. The economic value of slaughtered animals was determined by retail meat yield. Retail meat yield (Equation 2) was calculated from hot carcass weight (HCWt), rump fat depth (P8), and rib eye muscle area (EMA) on a sub-set of the animals from which the models herein were developed (Ewers et al., 1999). It was assumed that the domestic wholesale value was 4.00 AUD/kg (approximately US$3) of lean meat, equivalent to approximately $1.35/kg live weight (Equation 3). Some export markets (especially Japan) pay a premium for marbled meat, thus a premium of $0.30/kg/% intramuscular fat content (IMF) on marbling over 3% IMF (Equation 4). Note: $ refers to US$ or AUD to A$.

$$\text{Retail meat yield (kg)} = -24.51 + 0.66 \times (\text{HCWt}) - 0.59 \times (\text{P8}) + 0.55 \times (\text{EMA}) \qquad \text{(Equation 2)}$$

$$\text{Domestic value} = \$4.00 \times (\text{Retail meat yield}) \qquad \text{(Equation 3)}$$

$$\text{Export value} = [4.00 + 0.30\ (\text{IMF} - 3)] \times (\text{Retail meat yield}) \qquad \text{(Equation 4)}$$

Test of the model

The purpose of the test was to determine the effects of different backgrounding growth rate schemes on subsequent HCWt, P8, EMA, IMF, and economic values for domestic and export markets. This test was designed based on the data collected from the “Southern Crossbreeding Project” in which calves were weaned in summer (mid-December to early January) at 250-300 days. Calves were grown until 12-18 m and then transported to a commercial feedlot for 70-90 days (heifers) and 150-180 days (steers). The dry season occurred after weaning until nearly 470 days (December to June) and wet season, between approximately 470 and 600 days (July to December) every year. Feed was of low quality and availability during late summer-autumn each year. In the feedlot, steers and heifers were fed a minimum of 60% grain (various but primarily barley) with approximately 12 MJ/kg DM energy and 13% protein. This test included various schemes based on varying backgrounding and feedlot growth rates and keeping body weights at the 300 days constant. The design of the test in heifers and steers are given in Table 1. It was assumed that all heifers and steers were slaughtered at the same age and backgrounded and finished for the same days. However, further runs of the model could have provided information at different slaughter ages.

Table 1. Growth rate (kg/day) during backgrounding and finishing periods for various experimental schemes tested.

Heifer	Backgrounding		Feedlot	
VLVL	No gain	0.00	No gain	0.00
VLH	No gain	0.00	High	1.45
LVL	Low	0.68	No gain	0.00
AVE	Low	0.54	Low	0.30
LL	Low	0.68	Low	0.68
HH	High	1.45	High	1.45
Steer	Backgrounding		Feedlot	
VLVL	No gain	0.00	No gain	0.00
VLVH	No gain	0.00	Very high	2.11
LL	Low	0.49	Low	0.49
AVE	Low	0.49	High	1.48
MM	Medium	0.84	Medium	0.84
HVL	High	1.28	No gain	0.00
HH	High	1.28	High	1.28

VL = very low; L = low; M = medium; H = high growth; AVE = average.

RESULTS

Steers and heifers were alike with respect to breed differences in carcass traits, a result that follows not having sire x growth path interactions in the random effects model. All carcasses of crosses were grouped into heavy and light groups (Table 2). Belgian Blue, Limousin, South Devon, Angus, and Hereford had heavier HCWt and larger EMA than those of Wagyu and Jersey. P8 fat was the highest for Angus and the lowest for Belgian Blue. Carcasses of heifers from Belgian Blue, Limousin and South Devon had less marbling (lower IMF than those of Angus, Jersey, and Wagyu). The same pattern was observed for the domestic and export market values (Table 2). Prediction intervals (0.95%) were wider than the corresponding confidence intervals.

Heifers

Deviations of carcass traits of heifers obtained from growth schemes different from the average growth path indicated that the carcass fat traits were the most sensitive to growth variation (Figure 1). At slaughter, heifers that were backgrounded with no gain were lighter than those backgrounded with low growth rate (average) (Table 2; Figure 1). Those backgrounded and finished with high growth rate (HH) showed increased P8 and IMF compared to the average growth path. There were no significant differences between effects of the two

Table 2. Results for "average scheme (Table 1)" of heifers (Experiment 1).

	Jersey	Wagyu	Angus	Hereford	South Devon	Limousin	Belgian Blue
Predicted means for carcass quality traits							
HCWt	187.73	195.52	226.4	214.94	227.28	224.01	231.58
P8	11.09	11.76	14.55	12.50	10.12	10.40	8.55
EMA	69	73.94	77.11	73.31	81.94	84.97	90.98
IMF	4.21	3.90	4.17	3.36	3.44	2.84	2.69
Lower prediction interval for carcass quality traits							
HCWt	147.54	153.7	177.92	168.87	178.64	176.09	182.03
P8	4.28	4.54	5.61	4.82	3.91	4.02	3.30
EMA	51.83	55.54	57.91	55.03	61.53	63.82	68.33
IMF	1.65	1.53	1.63	1.32	1.35	1.11	1.060
Upper prediction interval for carcass quality traits							
HCWt	235.62	245.35	284.18	269.84	285.23	281.11	290.61
P8	23.89	25.32	31.34	26.96	21.78	22.40	18.40
EMA	90.12	96.58	100.73	95.80	107.04	110.98	118.85
IMF	8.98	8.31	8.90	7.18	7.34	6.05	5.74
Lower confidence interval for carcass quality traits							
HCWt	180.01	187.74	216.94	205.69	218.06	215.05	222.29
P8	8.78	9.36	11.49	9.81	8.03	8.27	6.80
EMA	64.92	69.57	72.47	68.77	77	79.91	85.53
IMF	3.35	3.11	3.31	2.65	2.73	2.26	2.14
Upper confidence interval for carcass quality traits							
HCWt	193.12	200.86	233.06	221.54	233.67	230.18	237.98
P8	11.65	12.29	15.31	13.23	10.60	10.88	8.94
EMA	71.94	77.10	80.49	76.66	85.54	88.63	94.94
IMF	4.43	4.09	4.40	3.57	3.62	2.98	2.83
Median body weights based on input (kg)							
Birth	32.29	34.72	36.05	38.88	39.30	39.67	39.67
250 days	224.58	225.48	247.00	245.28	249.50	250.03	250.85
420 days	306.54	303.85	340.7	335.24	344.35	338.47	344.34
500 days	327.96	325.26	366.41	359.94	372.44	363.58	370.60
Market values							
Domestic market $/carcass	520	550	631	598	654	651	689
Export market $/carcass	557	577	675	604	665	635	664

For abbreviations, see legend to Figure 1.

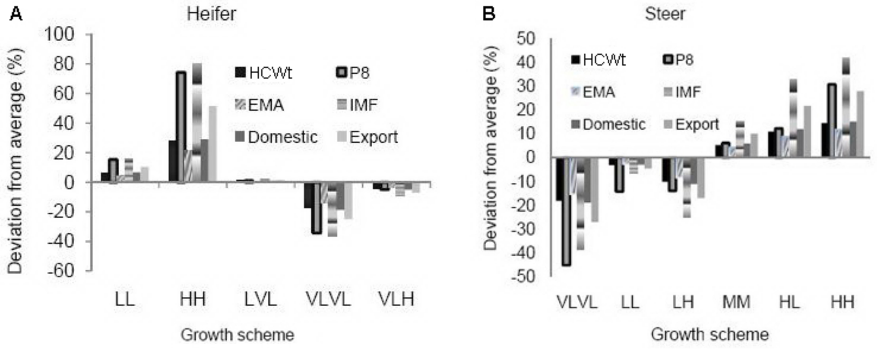

Figure 1. Percentage deviations of different schemes from average growth path for heifers (**A**) and steers (**B**). HCWt = hot carcass weight; P8 = rump fat depth; EMA = rib eye muscle area; IMF = intramuscular fat content. For other abbreviations, see legend to Table 1.

schemes: LVL and average growth path, in terms of carcass quality traits and the market values (Figure 2).

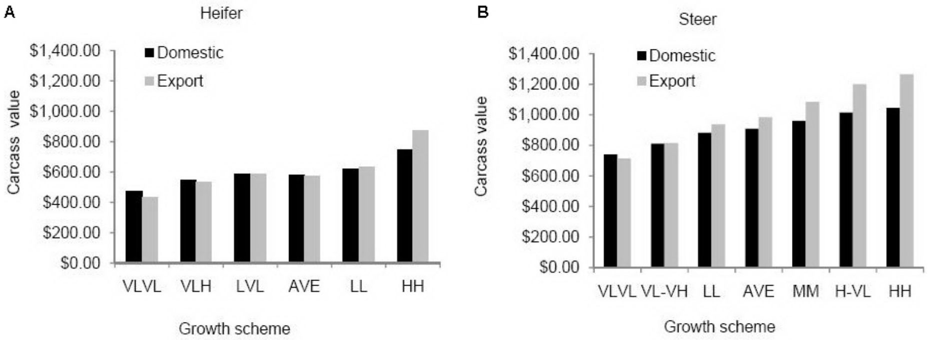

Figure 2. Carcass values of different schemes for heifers (**A**) and steers (**B**). For abbreviations, see legend to Table 1.

Steers

In general, like in heifers, carcass fat traits of steers were more affected by growth manipulations than quantity traits (Figure 1). Steers whose growth was limited during backgrounding and weighing were 30% less than with the average growth path and had leaner/ lower P8 fat and IMF at the end of feedlot (Figure 1). Carcass quality traits and economic values due to the HVL scheme were higher than with the HH scheme, though not significantly. The HVL scheme had XX% higher HCWt, 19% more P8, 3% larger EMA, and 9% more IMF than the HH scheme.

The export market was more sensitive to growth rate modifications than the domestic market, reflecting a greater economic value for fat (IMF). The VLVL scheme had the smallest and the HH scheme, by far the largest export value. No significant differences were detected between domestic and export market when there were low and no gains during backgrounding and feedlot periods, for both heifers and steer calves. As the growth rate increased, the differences between these two markets increased (Figure 2).

DISCUSSION

Application of the model

Robelin (1986) stated that as animals grow, their carcass composition changes and their body composition are controlled by weight. However, there are important exceptions to this weight dependency on composition at given weights. An example is the difference between sexes in composition at given weights as in breeds and animals fed on widely differing planes of nutrition. The ability of the current model to accommodate different sexes across seven sire breeds and various post-weaning management groups at any slaughter age provides the flexibility required by producers with varying situations. Moreover, patterns of growth can be altered in order to manipulate slaughter age or body weight at the point of slaughter. This manipulation is also possible because cattle were typically slaughtered at weights substantially less than mature weight (Owens et al., 1995). Estimates of carcass quality over growth path could help producers to predict the age required for each cattle to reach a specific target body weight and market specifications.

Potentially, the model can be useful in answering basic questions and examining "what if" scenarios that may apply to many different circumstances in beef production. If actual performance differs greatly from predicted performance, then it can be used to systematically evaluate why these differences are occurring. Furthermore, another potential use of this model would be to incorporate it into the economic beef production model that simulates the commercial and economic decision-making process involved in the practical management of beef production. It could also be used by animal nutritionists and lecturers in teaching students about meat science and encouraging them to investigate the response of the animal to a range of management and feeding planes.

Evaluation of the model

For evaluation of the current model, the hypothesis was that backgrounding and growing programs could have effects on target carcass quality characteristics. Therefore, patterns of growth during backgrounding and feedlot were altered in order to manipulate body weight at the point of slaughter. It has been shown that beef cattle backgrounding and growing programs can have profound effects on subsequent feedlot performance (Drouillard et al., 1991), body composition (Choat et al., 2002) and nutrient metabolism. It has also been reported that prior nutrition that restricts cattle growth and limits body fat deposition can positively affect cattle performance in the feedlot through increased growth.

In the test, it was assumed that calves exhibited four possible responses as a consequence of various growth rates during the backgrounding period. If steers had grown as in the average and heifers as in the VLH schemes (Figure 1), the steers and heifers were able to attain the same weight for age as unrestricted counterparts. This has most recently been observed in cattle (Yambayamba et al., 1996), but has been reported numerous times in sheep, pigs, and chickens (Zubair and Leeson, 1996; Kamalzadeh et al., 1997).

Often, feed restriction at a young age and, consequently, slow early growth may be followed by compensatory gain later in life, resulting in a similar body weight and body composition at slaughter as in unrestricted animals (Berge, 1991). This gain is valuable for enhanced efficiency when attempting to grow animals to particular slaughter weights.

In the VLVH scheme, apparently the growth pattern of calves backgrounded for lower growth rate was shifted toward later maturity in that they could not achieve the level of fatness as those backgrounded for faster growth rate (Figure 2A and B). Therefore, this scheme highlighted that allowing animals to slow down in the backgrounding phase may limit potential carcass quality.

If steers had grown as occurred in the LL scheme, then no compensation occurred during feedlot, which is a less common response to nutritional restriction followed by realimentation in practice (Figure 1). This is usually seen when nutrient restriction has occurred at a very young age (Morgan, 1972).

In some cases such as the VLVL scheme in heifers and steers, when nutrient restriction has been imposed during backgrounding and feedlot at a level much more severe than what might occur due to seasonal variation in a grazing system or other stresses, a reduction in mature size or permanent stunting has been observed (Taylor et al., 1981). However, the importance of such findings to this subject area is minimal since, while this could occur during periods of extended drought, this type of restriction would never purposely be applied at the field level due to its obvious negative results. The high growth rate during the feedlot period (e.g., HH scheme) had a significant influence on fat thickness and on intramuscular fat content in agreement with Robinson et al. (2001), who reported that finishing systems (feedlot or pasture) had a significant influence on fat thickness and on intramuscular fat content. This probably occurred because the high growth rate of feedlot-finished cattle predisposes them to increased fatness (Keele et al., 1992), and even at the same growth rate, feedlot-finished cattle deposit fat more than range-finished cattle (Sainz et al., 1995). This is also likely due to reducing maintenance needs in grain-fed cattle by lowering visceral mass and improving efficiency of nutrients used in grain-fed cattle by increasing the supply of glucose precursor molecules (Oddy et al., 2000). The variability in the body weights and gain responses that are seen within and among schemes in experiment 1, suggests the potential interaction of nutritional, physiological and genetic factors.

Prediction issues

Overall, the median and mean values for carcass quality traits were similar. This occurred because as given, the mean of body weight was

$$E(\text{Body Weight}) = \exp(\mu + \sigma^2 / 2)$$

and the median was $\exp(\mu)$. Because the standard error (σ) of estimation based on the log transformation is so small, the "$\sigma^2 / 2$" term then becomes negligible and can be ignored.

Wide prediction intervals were detected for carcass traits, perhaps because the permanent environmental variance for growth and environmental variance (permanent and temporary environmental) for carcass traits especially fat traits were significant (Table 2). In the case of fat traits, it may have occurred due to large permanent environmental variances and very small covariances between carcass fat traits and body weights. Large prediction intervals showed that the model did not perform well in the prediction of fat traits (Table 2).

The issue of error associated with the predictions obtained from the model has three main sources. One source is the stochastic character of the estimated model coefficients, which can be reduced only by gathering more growth data that contain more variation especially during the pre-weaning period. Therefore, besides using a larger number of body weights, it would be worthwhile using additional growth measures along with live weights, such as body measurements (height, length, girth, hip width, stifle width, etc.), scanned P8 and EMA.

Bias in the estimated parameters was also caused by measurement errors in the data used for model construction. It was contended that live weight may often be an unreliable indicator of empty body mass (Owens et al., 1995), due to large variations in gut fill (Stock et al., 1983), animal movement on the scales and the effects of diet switches on estimation of live weight (Tolley et al., 1988). Inaccurate or biased estimates of body weight can mask effects of treatments, leading to wrong conclusions with potentially significant economic ramifications (Owens et al., 1995).

Another source of errors is in some effects of the variables of the models not being estimated. For instance, carcass weight was the crucial trait in this study. The covariance between sire mean and linear could not be estimated. Also management covariances between mean and HCWt, P8, EMA, and IMF were not estimated. As discussed earlier, the size of the data set, ability of the program used, the nature of relationships between traits and number of parameters estimated could influence the possibility of estimations.

Using polynomials might have caused some problem here (Mirzaei et al., 2005). Since the current model involves a cubic regression model, further research may be necessary to develop other methods to overcome this issue.

IMPLICATION

The potential of the present model lies in its simplicity to give answers to "what if" questions in order to manipulate slaughter age or body weight at the point of slaughter. The model provides a tool by which the producer can assess the impact of possible changes in future management decisions. The empirical approach taken is potentially very useful if data structure issues are well addressed. However, some topics remain unsolved and need further research. Additional functions and traits measured in the live animal may greatly enhance the accuracy of prediction from the model.

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