MODELING EFFICIENCY AND CARCASS COMPOSITION

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SUMMARY

Models of efficiency and carcass composition have several uses in animal breeding, particularly because these traits are dynamic with time and weight. Models have been used to adjust data, determine selection objectives, suggest selection criteria, and extend results of experiments. Models are helpful when carcass value is not linearly related to individual traits. Use of a model to determine the suitability of different cattle genotypes for different markets and optimal slaughter weights under different management is illustrated. Future developments using dynamical systems approaches, simplified carcass trait models, and knowledge of genes and their physiological effects could make predictions more reliable.

Keywords: model, efficiency, carcass, growth

INTRODUCTION

Cost and value of the carcass are fundamental to the economics of livestock production for meat. Feed efficiency and carcass lean and fat composition are biological aspects of the growing animal that show genetic variability. These traits are closely linked to cost and value of the carcass. An understanding of efficiency and of carcass composition's relationship to value is needed before they can be manipulated to produce low-cost, desirable meat.

Unfortunately, understanding feed efficiency and the lean and fat composition of carcasses is difficult because they change dynamically with time. Furthermore, the relationship of the carcass to its value is nonlinear. Experiments can be designed to study the dynamic changes in efficiency and carcass composition when variables such as time on feed or live weight are held constant. However, maximum economic returns for two different genotypes or animals within a genotype is likely to occur when all variables are different. Good experimental designs are usually not synonymous with good economic management.

Modeling efficiency and carcass composition can play several roles in animal breeding and animal science. These roles include:

1. undoing the standardization and statistical adjustment of the design and analysis of a good experiment,
2. understanding the biological processes better, including the goal of identifying desirable components for genetic change,
3. identifying testing procedures and measurements to use for selection, and

4. extending results beyond the range of experimental data.

Attempts to fill these roles have resulted in models ranging from thought models to detailed mathematical models of metabolism. Models that are largely empirical can fulfill the role of undoing standardization and statistical adjustment. Models that employ some notion of cause and effect at some level are more appropriate for the other roles. Even though cause and effect are impossible to strictly validate (Oreskes *et al.* 1994), the alternative of using models that do not employ notions of cause and effect seems even less desirable.

MODELS FOR ADJUSTMENT

It is common and desirable to adjust efficiency and carcass composition data to constant endpoints such as time on feed, age, or fatness to interpret experiments. Simple, usually statistical, models are often used for adjustments. The least-squares means give equal weighting to all classes of a fixed effect such as ewes, wethers, and rams. A simple model might want to adjust the mean for the expected number in each class.

Even simple adjustment models can be inappropriately formulated and used. It is common to use a within group regression coefficient to adjust for weight differences, e.g., comparison of two genotypes at one slaughter date with different average weights. Changes in composition or efficiency resulting from differences in growth until slaughter are not the same as differences in composition resulting from additional days of growth. It is more appropriate to design the experiment with multiple slaughter dates allowing regression on time *(dx/d(time))* to be estimated. Ratios of theses regressions can then form the basis of an appropriate adjustment model to predict the differences in genotypes slaughtered at the same weight but different ages (Koch *et al.* 1979). Alternative valid designs include slaughter at fixed weights with variable ages and time on feed (Wolf *et al.* 1981). In this case, regressions on slaughter weight (*dx/d(slaughter weight)*) can be estimated and ratios of these regressions can be used to adjust data. In either case, valid models for adjusting genotypes to different endpoints can only be developed from regressions based on data where time is allowed to vary.

MODELS FOR UNDERSTANDING

Models developed to gain a better understanding of the biological processes of growth and efficiency usually purport to describe some level of cause and effect relationships. The level can range from a description of biochemical mechanisms to a description of the physiological purpose of the biological mechanism to a description of whole animal energetics. These models can be implemented several ways from thought models to systems of differential equations. Fowler *et al.* (1976) used a thought model based on utilization of metabolizable energy along with data to determine selection objectives and criteria. Parks (1982) developed a theory of relating time, feed consumption, and weight. Several models have been based on growth curves of an animal or its parts, e.g., Loewer *et al.* (1983) and Loewer *et al.* (1987). Other models have been based on the concept of DNA and protein accretion (Oltjen *et al.* 1986; Pomar *et al.* 1991). The model developed by Sainz and Wolff (1990) is representative of models developed at a more fundamental level.

MODELS FOR SELECTION CRITERIA

Fowler *et al.* (1976) used their model to identify selection criteria, both for the traits measured and the testing procedures. *Ad lib.* and restricted feeding regimes are examples of using a model to determine two different expected responses when the same trait is measured in the two regime. Parks (1982) model of growth leads to suggested selection criteria for different objectives. Purchas *et al.* (1991) developed an abstract geometric representation of muscle, fat, and bone in sheep carcasses to evaluate selection changes for muscularity. One still needs to be sure that selection for the estimated trait, e.g., estimated lean growth, leads to the same response as selection for the modeled trait, e.g., lean growth (Bennett 1992).

MODELS EXTENDING RESULTS

Extending the results of necessarily limited experimentation is a desirable application of models. Adjustment models can safely be used only within the range of the experiment. Models that correctly identify cause and effect should be able to extend beyond the range of experiments. Determining the range to which a model can be extended requires testing (Arnold and Bennett 1991) and identification of weaknesses and suitability for particular situations. For instance, Sainz and Wolff (1990) included body fat and protein turnover in their model of lamb metabolism and growth because they expected anabolic agents to act on these components.

One use of these models is to identify optimal endpoints to compare genotypes. Simple adjustment models can sometimes be used, but optimal endpoints can easily fall outside the range of an experiment, especially if management, feed energy levels, and time on feed are variable. Models that can extend beyond the data are necessary. Additionally, nonlinear definitions of carcass value (Garrick *et al.* 1986) may complicate finding optimal endpoints even more.

AN EXAMPLE

An example of the use of a model to study the dynamics of both efficiency and carcass value in beef cattle is the use of a model originating from Keele *et al.* (1992) and further extended by Williams and Jenkins (1997). The body composition model consists of a few differential equations embodying concepts about the proportion of fat in empty body gain depending on growth rate, proportion of mature fat-free reference weight, and previous growth rate and about the change in lean and fat composition when growing and mature cattle are held at weight stasis. Comparison of predictions with several experiments showed reasonable predictive ability (Williams *et al.* 1992). Other relationships in the model, e.g. breed parameters and conversion of empty body composition to carcass traits, are largely empirical.

One study using the model compared 17 steer genotypes in 18 production scenarios at 3 carcass weights (Williams *et al.* 1995b, 1995c). Using a modest 20 animals per combination would require 18,360 carcasses to duplicate this comparison experimentally. Data from the first 3 cycles of the Germ Plasm Evaluation project at the U.S. Meat Animal Research Center were used to parameterize the breeds (Williams *et al.* 1995a). The experimental comparison was done under a single production scenario. Use of the model extended the experimental results.

The model was used to predict carcass fat and the feed energy costs of empty body and fat-free weight. In addition the model was used to predict when each genotype and production scenario would produce carcasses averaging 28% fat and carcasses averaging a minimum level of marbling. Certain combinations of genotype and production scenario were deemed unfeasible. Unfeasible combinations were determined by days on feed and carcass weight. A minimum 56 days on feed was included for palatability, a maximum of 28 months of age was included for grading concerns, and a carcass weight range of 250 to 430 kg was included because some U.S. buyers discount carcasses outside this weight range. It is worth noting that all genotypes have the potential to produce carcasses with 28% fat but some cannot do it within the constraints of a specific production scenario or market requirements. Determining feasibility of genotypes and management systems for producing certain types of beef can be an important application of modeling.

All genotypes were able to produce carcasses averaging 28% fat or a minimum level of marbling in at least one production scenario. Some steer genotypes were able to produce carcasses with the desired fatness and marbling in all 18 production scenarios. These genotypes were better "centered" on growth rate, fatness and marbling traits than genotypes that produced the desired carcasses in only a few feasible systems. The best efficiency for different genotypes occurred in different systems showing that flexibility of genotypes and management is needed to maximize efficiency. Perhaps as important, these genotypes would be more valuable to feedlot managers who buy cattle from many different sources and feed them similarly.

A model of the distribution of carcass traits was connected to the model so that proportions of carcasses meeting certain targets (Bennett and Williams 1995) and economic value of carcasses assuming various pricing schemes as well as feed cost (Williams and Bennett 1995) could be predicted. The effects of specifying a minimum retail yield (Yield Grades of 3 or lower), a minimum marbling score (Quality Grade of Choice or greater), an acceptable weight range (250 to 430 kg), or combinations of these specifications on the percentage of carcasses meeting the targets was predicted. This percentage changes with the average carcass weight which is determined by time on feed, and it decreases as more specifications are added. Figure 1 shows the predicted percentages for different targets for steers typical of British crossbred genotypes fed a moderate-energy feed. Percentage of carcasses with a minimum retail product yield declined and the percentage of carcasses with a minimum quality grade based on marbling score increased with increasing carcass weight and time on feed. The combination of these specifications is maximized in the 280-290 kg range but near maximum percentages are attained over a much wider range. The addition of a 250-430 kg weight range reduces the percentage of carcasses when the average weights are near those limits but has little effect when average carcass weights range from 300-380 kg.

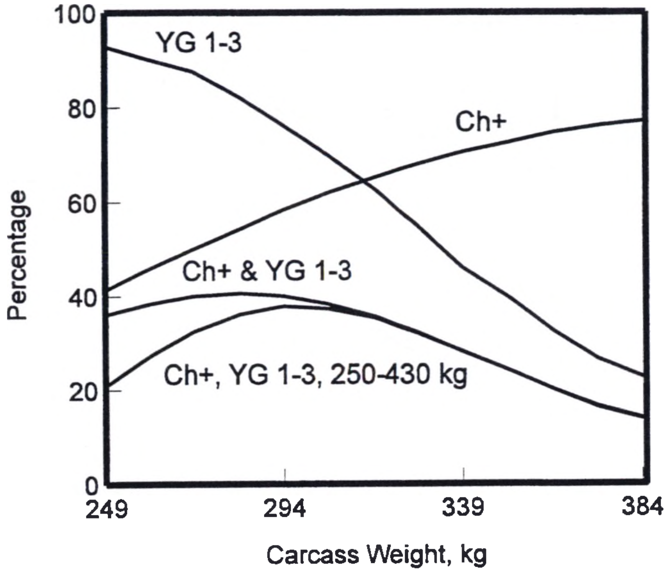

Figure 1. The effect of specifying a minimum retail yield (YG 1-3), a minimum U.S.D.A. quality grade (Ch+), a desired carcass weight range (250-430 kg) or combinations of these specifications on the percentage of carcasses as average carcass weight increases in British steers fed a moderate-energy diet.

Figure 2 shows the percentages of steers meeting the combination of yield, quality, and weight specifications when genotypes typical of British, Continental or British-Continental crosses fed high-energy feeds either beginning at weaning or after a period of limited growth from weaning until one year of age. The highest percentage of carcasses meeting all specifications occurred at lighter weights for British genotypes, at heavy weights for the continental genotype. and at intermediate weights for British-Continental cross genotype. Delaying high-energy feeding until one year of age significantly increased the percentage only for the British genotype. Delaying feeding increased the weight at which the maximum percentage occurred in both British and British Continental genotypes. The British-Continental genotype showed the highest percentage of carcasses meeting all specifications and also a wide weight range where the percentage was near the maximum.

Use of the model to illustrate the potential to evaluate the economics of beef production (Williams and Bennett 1995) found that the economic optimum for different genotypes did not occur at the same weight, age, or fatness confirming similar findings by Amer *et al.* (1994a, 1994b). Cost of feed, cost of other inputs, and value determined several ways could all be predicted by the model and used to determine profit. Comparisons of breed rankings for

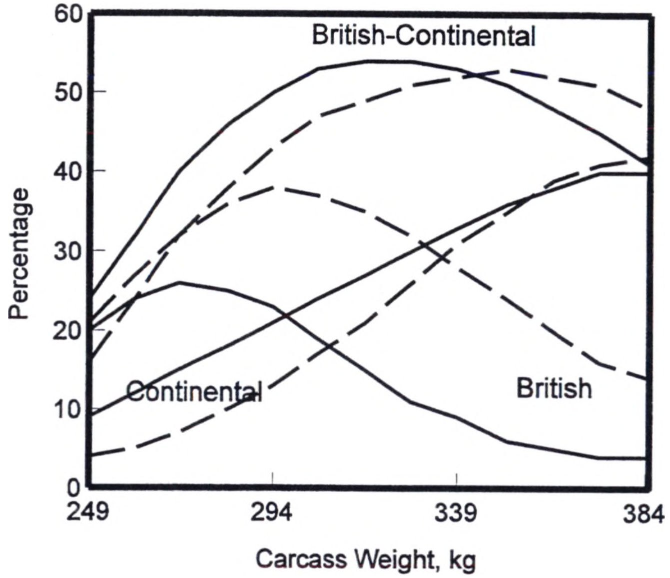

Figure 2. Predicted percentage of carcasses meeting a combination of yield, quality, and weight specifications when British, Continental, or British-Continental crossbred genotypes are fed a high-energy feed beginning at weaning (solid line) or at one year of age (dashed line).

maximum profits were not greatly affected by different schemes for assigning value to carcasses or by considering profit on either a per group purchased or per day basis. Finally, the ability of the model to determine predicted profit for different times on feed shows the potential for using this model as a decision aid for purchasing, managing and selling cattle by feedlot owners.

This model illustrates several important aspects of using models to predict efficiency and body composition of the growing animal. The model is based on conceptual ideas of the effects of growth on empty body composition and metabolizable energy utilization. If correct, this conceptual basis should allow the model to be used in many situations. It is supplemented with empirical relationships that allow the model to be connected with data for testing and estimating parameters for genotypes. These relationships also allow value to be put on carcasses based on the same traits that the meat industry uses to define value. Value of carcass composition is often nonlinear with respect to several traits and is not sufficiently predicted by trait averages. Because both feed efficiency and composition are dynamic and value is nonlinear, the use of the model is needed to define optimal slaughter points. Difference in efficiency, weight, and composition at one of several fixed experimental endpoints may not be realized in practice

(Bennett and Williams 1994). The potential for using this model as a decision aid means that an accumulated knowledge base can be made more accessible to producers who need to put knowledge into action.

THE FUTURE

Future avenues to understanding and modeling body composition and efficiency are beginning to open. The branch of mathematics known as dynamical systems may lead to a better understanding and prediction of feed intake, growth, and body composition (Oddy *et al.* 1997). These models have the potential to predict results that might seem random, odd, and unpredictable if they occurred in an experiment. In fact, many experimental results seem to fit this description! The most difficult responses to predict are those when intake and growth change. Of course changing intake and growth is an important aspect of many ruminant animal production systems. Better prediction under these conditions should lead to better utilization of different genotypes.

Prediction of carcass traits has largely relied on empirical or allometric relationships. Simplistic models of carcass traits such as the geometric model of muscularity (Purchas *et al.* 1991) may be an avenue to better prediction of carcass traits. Variability of carcass traits within groups of animals is important in determining market value for many schemes. Here again, dynamical systems may be a useful tool for predicting the development of variability within a group of animals. Developments in these areas could lead to improved prediction of carcass value.

Identification of genes responsible for feed intake, efficiency, growth, and carcass composition could improve the predictive ability of models if the mode of action is known. Alleles of genes that affect specific physiological functions such as protein synthesis, protein degradation, fat regulation, or visceral mass could improve predictions. A model combining specific physiological effects of genes with the background genotype could be useful both in identifying good genetic backgrounds to move genes into and in predicting performance of very specific genotypes.

REFERENCES

Amer, P.R., Kemp, R.A., Buchanan-Smith, J.G., Fox, G.C. and Smith, C. (1994a) *J. Anim. Sci.* **72**:38-50.
Amer, P.R., Kemp, R.A., Fox, G.C. and Smith, C. (1994b) *Can. J. Anim. Sci.* **74**:7-14.
Arnold R.N. and Bennett, G.L. (1992) *Agric. Syst.* **36**:17-41.
Bennett, G.L. (1992) *J. Anim. Sci.* **70**:51-56.
Bennett, G.L. and Williams, C.B. (1994) *J. Anim. Sci.* **72**:2756-2763.
Bennett, G.L. and Williams, C.B. (1995) Proc. 5th Genet. Prediction Workshop, pp. 133-142.
Fowler, V.R., Bichard, R.M. and Pease, A. (1976) *Anim. Prod.* **23**:365-387.
Garrick, D.J., Purchas, R.W. and Morris, S.T. (1986) *Proc. N.Z. Soc. Anim. Prod.* **46**:49-54.
Keele, J.W., Williams, C.B. and Bennett, G.L. (1992) *J. Anim. Sci.* **70**:841-857.

Koch, R.M., Dikeman, M.E., Lipsey, R.J., Allen, D.M. and Crouse, J.D. (1979) *J. Anim. Sci.* **49**:448-460.

Loewer, O.J., Smith, E.M., Taul, K.L., Turner, L.W. and Gay, N. (1983) *Agric. Syst.* **10**:254-256.

Loewer, O.J., Turner, L.W., Gay, N., Muntifering, R. and Brown, C.J. (1987) *Agric. Syst.* **10**:254-256.

Oddy, V.H., Ball, A.J. and Pleasants, A.B. (1997) In "Recent Advances in Animal Nutrition in Australia" pp. 209-222, editors J.L. Corbett, M. Choct, J.V. Nolan, J.B. Rowe, University of New England, Armidale, Australia

Oltjen, J.W., Bywater, A.C. and Baldwin, R.L. (1986) *J. Anim. Sci.* **62**:86-97.

Oreskes, N., Shrader-Frechette, K. and Belitz, K. (1994) *Sci.* **263**:641-646.

Parks, J.R. (1982) "A Theory of Feeding and Growth of Animals" Springer-Varlag, Berlin, Heidelberg, New York.

Pomar, C., Harris, D.L. and Minvielle, F. (1991) *J. Anim. Sci.* **69**:1468-1488.

Purchas, R.W., Davies, A.S. and Abdullah, A.Y. (1991) *Meat Sci.* **30**:81-94.

Sainz, R.D. and Wolff, J.E. (1990) *Anim. Prod.* **51**:535-549.

Williams, C.B. and Bennett, G.L. (1995) *J. Anim. Sci.* **73**:2903-2915.

Williams, C.B., Bennett, G.L. and Keele, J.W. (1995a) *J. Anim. Sci.* **73**:665-673.

Williams, C.B., Bennett, G.L. and Keele, J.W. (1995b) *J. Anim. Sci.* **73**:674-685.

Williams, C.B., Bennett, G.L. and Keele, J.W. (1995c) *J. Anim. Sci.* **73**:686-698.

Williams, C.B. and Jenkins, T.G. (1997) *Agric. Syst.* **53**:1-25.

Williams, C.B., Keele, J.W. and Bennett, G.L. (1992) *J. Anim. Sci.* **70**:858-866.

Wolf, B.T., Smith, C., King, J.W.B. and Nicholson, D. (1981) *Anim. Prod.* **32**:1-7.