Analysis of the Relationship Between Type Traits, Inbreeding, and Functional Survival in Jersey Cattle Using a Weibull Proportional Hazards Model

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ABSTRACT

A Weibull proportional hazards model was used to analyze the effects of 13 linear type traits, final score, and inbreeding on the functional survival of 268,008 US Jersey cows in 2416 herds with first calving from 1981 to 2000. Functional survival was defined as the number of days from first calving until involuntary culling or censoring. The statistical model included the time-dependent effects of herd-year-season of calving, parity by stage of lactation interaction, and within-herd-year quintile for mature equivalent milk yield, as well as the time-independent effects of inbreeding, age at first calving, and linear type traits or final score (analyzed one at a time). Each type trait was divided into 10 classes, and the relative risk of involuntary culling was calculated for animals in each class after accounting for the aforementioned management factors. Type traits with the greatest contribution to the likelihood function were udder depth, fore udder attachment, front teat placement, and udder support. Cows with low scores for these traits had a risk of culling that was 1.3 to 1.8 times that of cows with intermediate scores. Cows with high scores for udder depth and udder support had a risk of culling only 0.7 to 0.85 as great as that of cows with intermediate scores. Intermediate scores were desirable for rear leg set, dairy form, and strength, but stature, rump angle, and rump width had negligible effects on survival. Cows with low final scores had a risk of culling that was 1.35 times that of cows with intermediate scores, whereas cows with high final scores had a risk of culling that was 0.8 times that of cows with intermediate scores. Animals with inbreeding coefficients greater than 10% had a slightly higher risk of culling than animals with inbreeding coefficients less than 5%.

(Key words: survival, Jerseys, type traits, inbreeding)

INTRODUCTION

The relationship between type traits and longevity in dairy cattle has been examined on numerous occasions, and, through different approaches, authors have shown that these traits are significantly related to longevity (Short and Lawlor, 1992; Larroque and Ducrocq, 1999; Schneider et al., 1999; Cruickshank et al., 2002). When assessed during the first lactation, type traits can be used as early predictors of longevity. By combining information from these correlated traits with information regarding the actual time of death or culling, one can obtain precise estimates of breeding values for dairy sires without waiting until a large percentage of their daughters have been culled (Weigel et al., 1998). Besides being measured early in life, type traits are more highly heritable than longevity itself, which can be heavily influenced by management and environmental factors. Furthermore, the marginal cost of using type as an indirect predictor of longevity is minimal, because these data are already collected for aesthetic and marketing purposes.

At the time of genetic evaluation of a living cow, we know only the lower bound of an animal's productive life. Excluding the records of living cows or considering them as complete would lead to bias, so records of this type should instead be treated as censored (Vukasinovic, 1999). In addition, survival times typically have a skewed distribution, and analysis using traditional linear models may not be appropriate. Survival analysis methodology can accommodate both censored (incomplete) observations and nonnormality in the distribution of survival times. Another difficulty associated with genetic evaluation of longevity is that observed survival times may result from a product, rather than a sum, of factors that influence longevity (Beilharz and Luxford, 1993). When at least one of these factors is "defective", the longevity of an animal may be impaired. The relationship between longevity and some type traits seems to be linear, but other traits may have an intermediate optimum, with increased culling risk when type scores deviate from this optimum. For other traits, any score above a certain threshold may be satisfactory, such

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that only animals with scores below this threshold have impaired longevity (Larroque and Ducrocq, 1999). In addition, the environmental and management conditions to which an individual animal is exposed are likely to change throughout its lifetime. For example, previous analyses (Short and Lawlor, 1992; Cruickshank et al., 2002) assigned contemporary groups based on herd-year-season of first calving. However, management factors that affect an individual cow's risk of culling at a given time may differ dramatically from the conditions present at the time of first calving (e.g., the herd may have expanded, a disease outbreak may have occurred). These factors may increase or decrease the risk of culling for all cows that are present in the herd at a given time, regardless of their date of first calving. Likewise, analyses of functional longevity that adjust for milk production in only first (or last) lactation provide an incomplete picture of the true impact of an individual cow's milk yield on her risk of culling at various points during her lifetime. For these reasons, time-dependent explanatory variables should be used, and survival analysis methodology can efficiently handle the inclusion of time-dependent covariates that change at times prespecified by the user.

Because of the aforementioned advantages of survival analysis methodology, as well as a paucity in published information regarding the longevity of Jersey cattle, our objective was to investigate the phenotypic relationships between type traits, inbreeding, and survival in Jersey cattle using a Weibull proportional hazards model.

MATERIALS AND METHODS

Data

Data regarding survival, milk production, type, and inbreeding of 268,008 US Jersey cows with first calving from 1981 to 2000 in 2416 herds were provided by the USDA-Animal Improvement Programs Laboratory and the American Jersey Cattle Association. Cows were required to have type classification scores, valid sire identification, and age at first calving between 18 and 42 mo. Type scores were rounded to the nearest five points (e.g., 6 to 10, 11 to 15, 16 to 20, 21 to 25, 26 to 30, 31 to 35, 36 to 40, and 41 to 45 for linear traits or 56 to 60, 61 to 65, 66 to 70, 71 to 75, 76 to 80, 81 to 85, 86 to 90, and 91 to 95 for final score), and due to the large phenotypic correlations between some type traits, the impact of each type trait on functional longevity was assessed separately. In the analyses of linear type traits and final score, the inbreeding coefficient of the cow was included as a continuous covariate. However, in the analysis of inbreeding effects on longevity, inbreeding coefficients were rounded to the nearest 1% and subse-

quently treated as a categorical variable, such that possible nonlinear relationships between inbreeding and survival could be examined. Because our interest was in functional survival, which reflects culling due to illness, injury, infertility, or death, we attempted to remove the effects of voluntary culling for poor milk production (Ducrocq et al., 1998). Every lactation record for each cow was assigned a quintile score based on within herd-year ranking for 305-d mature equivalent milk production, and these scores were included as (categorical) explanatory variables in the analysis. Survival time was defined as the number of days that elapsed between first calving and death, culling, or censoring. Cows that were sold for dairy purposes and cows that resided in herds that discontinued milk recording were considered as censored, as were cows that were still alive after five complete (305 d) lactations and cows that were still alive at the time of the analysis. Many cows (particularly in the early years) had owner-reported culling codes that indicated normal completion of first, second, third, or fourth lactation, yet no subsequent lactation occurred. Therefore, cows that did not calve again within 6 mo after completion of their previous lactation were considered as uncensored failures.

Statistical model

The hazard function, which reflects the instantaneous probability of involuntary culling, for a given animal was modeled as:

$$h_{ijklmn}(t) = h_0(t) \exp[\beta_1 A_i + \beta_2 I_j + h_k(t) + P_l(t) + M_m(t) + T_n],$$

where:

- $h_{ijklm}(t)$ = hazard function of a given cow at time t ;
- $h_0(t)$ = Weibull baseline hazard function;
- A_i = time-independent effect of age at first calving, treated as a continuous variable;
- I_j = time-independent effect of inbreeding coefficient, treated as a continuous variable;
- $h_k(t)$ = time-dependent random effect of herd-year-season, assumed to be piecewise constant with change points at January 1, May 1, and September 1 of each year;
- $P_l(t)$ = time-dependent interaction of lactation number and stage of lactation, assumed to be piecewise constant with change points at calving, 45 d postpartum, and 270 d postpartum in lactations 1, 2, 3, 4, and 5;
- $M_m(t)$ = time-dependent effect of within herd-year quintile for mature equivalent 305-d milk

production, assumed to be piecewise constant with change points at the beginning of each lactation; and

T_n = time-independent effect of each linear type trait or final score (evaluated separately), rounded to the nearest five points.

Estimation

The Survival Kit Version 3.12, a set of FORTRAN programs written by Ducrocq and Sölkner (1998), was used for the analysis described herein. Details regarding the algorithms for estimation are given by Ducrocq (1994), and theoretical aspects are discussed by Ducrocq and Casella (1996). Briefly, an empirical Bayesian approach was used to estimate fixed effects and dispersion parameters. Estimates were obtained for ρ , the shape parameter, and γ , the parameter of the log-gamma distribution of herd-year-season effects.

RESULTS AND DISCUSSION

A summary of the data, with details regarding the amount of censoring, maximum, minimum, and average censoring and failure times, is shown in Table 1. Of the 268,008 longevity records, 120,499 (45%) were right-censored. The maximum observed failure time was 2516 d after first calving, and the corresponding mean failure time was 807 d. Likewise, the maximum censoring time was 2562 d after first calving, and the corresponding mean censoring time was 954 d.

Figure 1 shows the relative contribution of each linear type trait and final score to the likelihood, and this was determined by comparing the full model (with one particular type trait) with the reduced model (without any of the type traits). Because our dataset was so large, all type traits, except stature, had a statistically significant effect on longevity ($P < 0.01$). However, some traits had a rather small effect on cow survival. As shown in Figure 1, udder depth was by far the most important type trait, with respect to longevity, followed

Figure 1. Contribution of each linear type trait and final score to the likelihood of functional survival (as a percentage of the contribution of the most important trait).

by fore udder, front teat placement, and udder support. The contribution of final score to the likelihood function was slightly less than that of udder support, but greater than the remaining nine linear type traits.

Figure 2 shows the influence of udder traits on functional survival. The relative risk of involuntary culling for cows with udder depth scores of 6 to 10 was more than 1.6 times that of cows with udder depth scores of 21 to 25. Conversely, the risk of culling for cows with udder depth scores of 41 to 45 was only 0.7 times that of cows with scores of 21 to 25. As shown in Figure 2, udder depth was clearly the most important linear type trait, with respect to cow survival. Udder support was also an important predictor of longevity, particularly at the lower end of the scale, where cows with udder support scores of 6 to 10 had a culling risk of nearly 1.8 times that of cows with intermediate scores. However, no advantage in survival was noted for cows with

Figure 2. Relative risk of culling by classes of linear scores for udder traits (risk ratio for score 21 to 25 was constrained to 1).

Table 1. Summary of the data that were used in the present study.

Number of cows	268,008
Number of herds	2416
Right-censored records (%)	45
Time from first calving until censoring (days)	
Minimum	7
Average	954
Maximum	2562
Time from first calving until culling (days)	
Minimum	8
Average	807
Maximum	2516

Figure 3. Relative risk of culling by classes of linear scores for body traits (risk ratio for score 21 to 25 was constrained to 1).

Figure 4. Relative risk of culling by classes of linear scores for rump traits (risk ratio for score 21 to 25 was constrained to 1).

high udder support scores. Fore udder displayed a more nearly linear relationship with longevity; cows with scores of 6 to 10 had culling risk approximately 1.3 times that of cows with scores of 21 to 25, whereas cows with scores of 41 to 45 had a culling risk only 0.85 times that of cows with intermediate scores. The relationships between longevity and linear scores for rear udder height, rear udder width, and front teat placement also showed a pattern of diminishing returns, in that cows with scores of 6 to 10 or 11 to 15 had a significantly increased risk of culling, as compared with cows with intermediate scores, but scores higher than 25 appeared to confer no additional advantage in longevity.

Figure 3 shows the impact of body size traits on the relative risk of involuntary culling. As mentioned earlier, the relationship between stature and longevity was negligible, with culling risks for all categories of linear scores centered at or near unity. Strength and dairy form appeared to have an intermediate optimum, with respect to longevity, although high scores for either trait were much more detrimental than low scores. For example, cows with dairy form scores of 6 to 10 had a risk of culling 1.1 times that of cows with intermediate scores, but cows with scores of 41 to 45 had relative risk values that were nearly 1.4 times that of average cows. Bunger and Swalve (1999) also noted that, after correction for milk production, survival was greater for cows with intermediate or low scores for dairy form, and this may be a reflection of greater stress of production or poorer body condition among cows with high dairy form scores.

Figure 4 shows the relationship between risk of involuntary culling and linear scores for rump width and rump angle. Neither trait appears to have a strong relationship with survival, though cows with high pins had relative risk values that were approximately 1.15 times that of cows with level or sloping rumps.

Figure 5 shows the relative risk of involuntary culling by classes of linear scores for rear leg set and foot angle. The relationship between foot angle and longevity was minimal, with only slight deviations from unity in the culling risk for animals in the highest and lowest classes for foot angle score. On the other hand, rear leg set appeared to be a useful predictor of longevity, and intermediate scores seemed to be optimal. Cows with rear leg set scores of 6 to 10 (straight rear legs) had a risk of culling that was 1.15 times that of cows with intermediate scores, but cows with scores of 41 to 45 (curved rear legs) had a risk of culling that was more than 1.3 times that of cows with scores of 21 to 25.

Figure 6 shows the relationship between longevity and final score in US Jersey cows. Cows with extremely high final scores had a risk of culling slightly more than 0.8 times that of average cows, whereas cows with

Figure 5. Relative risk of culling by classes of linear scores for feet and leg traits (risk ratio for score 21 to 25 was constrained to 1).

Figure 6. Relative risk of culling by classes of final type score (risk ratio for score 71 to 75 was constrained to 1).

extremely low final scores had a risk of culling that was 1.35 times that of cows with intermediate scores. Thus, it appears that final type score can be an effective predictor of longevity. However, it is important to note that the impact of final score on involuntary culling was less than that of udder depth, fore udder, front teat placement, and udder support.

Figure 7 shows the relationship between inbreeding coefficients and the risk of involuntary culling. As shown in the graph, we observed a slight trend toward higher risk of culling among more inbred animals. The relative risk ratios for cows with inbreeding coefficients greater than 8% were from 1.05 to 1.1 times the risk ratio for cows with inbreeding coefficients of 7% or lower. These results agree with the study of Thompson et al. (2000), in which inbreeding led to a decrease in cow survival. However, it is important to note that the design of this study was not optimal, with respect to assessment of economic losses due to inbreeding in Jersey cattle. In this study, survival was measured as time

Figure 7. Relative risk of culling by inbreeding coefficient (risk ratio for inbreeding coefficient of 5% was constrained to 1).

from first calving until disposal, but one would hypothesize that animals with severe inbreeding depression would not survive until first calving. Inbreeding effects on conception rate, embryonic loss, abortion, stillbirth, calf mortality, and heifer fertility were ignored in this study, although one or more of these traits could be significantly impaired in highly inbred animals.

CONCLUSIONS

In summary, this application of survival analysis methodology provided concise estimates of the phenotypic contribution of each linear type trait to the hazard function, or instantaneous risk of involuntary culling, in US Jersey cows. Few previous studies have utilized data from Jersey cattle, and furthermore, the aforementioned advantages of survival analysis suggest that our results will be more credible than previous studies involving type and longevity in other US dairy breeds. Based on the results presented herein, it appears that genetic selection or management improvements that impact udder depth, udder support, rear leg set, fore udder, and front teat placement will have a positive influence on functional longevity. Avoidance of inbreeding through the application of computerized mating programs also seems justified, although the design of the present study precludes definitive statements about the economic impact of inbreeding in Jersey cattle. Future studies should focus on estimation of sire breeding values for functional longevity using survival analysis methodology, as well as investigation of differences in the importance of linear type traits between herd management systems.

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