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Evaluation of five lactation curve models fitted for fat:protein ratio of milk and daily energy balance

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ABSTRACT

Selection for milk yield increases the metabolic load of dairy cows. The fat:protein ratio of milk (FPR) could serve as a measure of the energy balance status and might be used as a selection criterion to improve metabolic stability. The fit of different fixed and random regression models describing FPR and daily energy balance was tested to establish appropriate models for further genetic analyses. In addition, the relationship between both traits was evaluated for the best fitting model. Data were collected on a dairy research farm running a bull dam performance test. Energy balance was calculated using information on milk yield, feed intake per day, and live weight. Weekly FPR measurements were available. Three data sets were created containing records of 577 primiparous cows with observations from lactation d 11 to 180 as well as records of 613 primiparous cows and 96 multiparous cows with observations from lactation d 11 to 305. Five well-established parametric functions of days in milk (Ali and Schaeffer, Guo and Swalve, Wilmink, Legendre polynomials of third and fourth degree) were chosen for modeling the lactation curves. Evaluation of goodness of fit was based on the corrected Akaike information criterion, the Bayesian information criterion, correlation between the real observation and the estimated value, and on inspection of the residuals plotted against days in milk. The best model was chosen for estimation of correlations between both traits at different lactation stages. Random regression models were superior compared with the fixed regression models. In general, the Ali and Schaeffer function appeared most suitable for modeling both the fixed and the random regression part of the mixed model. The FPR is greatest in the initial lactation period when energy deficit is most pronounced. Energy balance stabilizes at the same point as the decrease in FPR stops. The inverted patterns indicate a causal relationship between the 2 traits. A common pattern was also observed for repeatabilities of both traits, with repeatabilities being largest at the beginning of lactation. Additionally, correlations between cow effects were closest at the beginning of lactation ($r_c = -0.43$). The results support the hypothesis that FPR can serve as a suitable indicator for energy status, at least during the most metabolically stressful stage of lactation.

Key words: dairy cow, fat:protein ratio, energy balance, model evaluation

INTRODUCTION

A steady increase of milk yield has intensified the postpartum energy deficit in dairy cattle (Veerkamp and Koenen, 1999; Hüttmann et al., 2009). The extent of the energy deficit depends not only on the amount of milk produced, but also on feed intake. Milk yield and dry matter intake are positively correlated (Persaud et al., 1991; Veerkamp and Thompson, 1999), but the increase of feed intake has not kept pace with rising milk production, and energy intake does not cover the demand during early lactation (Butler and Smith, 1989; de Vries et al., 1999; Ingvartsen and Andersen, 2000). Cows in an extreme state of negative energy balance in early lactation are metabolically stressed and show greater incidence of diseases such as mastitis, lameness, and metabolic disorders including ketosis (Goff and Horst, 1997; Collard et al., 2000; Ingvartsen et al., 2003). Moreover, fertility is impaired (de Vries et al., 1999; Veerkamp et al., 2000; Wathes et al., 2007). Assuming the existence of a genetic component of coping with metabolic stress (de Vries et al., 1999; Drackley, 1999), the fat:protein ratio (**FPR**) of milk may be a potential and easily measurable trait to differentiate between cows that can or cannot adapt to the challenge of early lactation. The underlying context is well known: an energy deficit leads to increased lipolysis, and uptake of fatty acids mobilized from body fat is increased resulting in an increased fat synthesis in the udder. At the same time, inadequate intake of fermentable, energy-spending carbohydrates can cause an insufficient protein synthesis by ruminal bacteria. The

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flow of amino acids to the udder is compromised and milk protein content decreases (Gürtler and Schweigert, 2005). Both of these processes result in an increased FPR. An FPR >1.5 indicates abnormally high lipolysis and has proven to be a good predictor of ketosis, displaced abomasum, ovarian cysts, mastitis, and lameness (Geishauser et al., 1998; Heuer et al., 1999). Given that FPR reflects the energy balance status of a cow, it could be a useful variable for the identification of potential problems, especially because the measurement of energy balance itself is very cost intensive. Grieve et al. (1986) showed that FPR is negatively correlated to energy balance ($r_p = -0.36$ to -0.74). The FPR detects low energy balance more reliably than ketone body levels measured in body fluids or BCS (Heuer et al., 1999). Furthermore, Reist et al. (2002) estimated a phenotypic correlation of −0.50 between FPR and energy balance from wk 1 to 11 postpartum. Similar correlations were found by Seggewiß (2004) for the first 5 lactation months, with the closest relationship at the beginning of lactation. de Vries and Veerkamp (2000) found moderate phenotypic correlations between change in FPR from wk 2 of lactation to wk 6, 8, 11, or 15 with several energy balance traits, but stated that almost all information in the FPR was derived from the change in fat yield. However, Hüttmann (2007) calculated a significant positive genetic correlation between energy balance traits and protein content in milk, whereas the negative correlation between energy balance traits and fat content was not significant. Additionally, Grieve et al. (1986) showed that the ratio of milk fat and protein content was a better predictor of energy status than either component by itself.

Fat:protein ratio can be obtained from routine milk performance testing and is genetically determined. Vos and Groen (1998) and Meinert et al. (1989) estimated a large heritability for the protein-fat ratio ($h^2 = 0.69$ to 0.79). Protein-fat ratio has a strong negative correlation with fat percentage ($r_g = -0.77$) and a weak positive correlation with protein percentage ($r_g = 0.18$) (Vos and Groen, 1998).

The objective of this study was to investigate whether FPR can serve as a measure of energy balance (**EB**) status. Heritability and the correlation between FPR and important performance traits should be estimated for high-yielding dairy cows with state-of-the-art methods. The expected beneficial effect of using FPR as a new selection criterion for EB status should be established. To calculate heritability and genetic correlations, adequate models for evaluation are needed. Therefore, the fit of several fixed and random regression models describing the FPR was tested. As the relationship between FPR and EB is a matter of particular interest and most studies concerning EB traits concentrate on aggregated traits, analogous model evaluation was also done for daily EB.

MATERIALS AND METHODS

Data

Fat:protein ratio data were obtained from weekly measurements recorded between September 2005 and September 2008 at the dairy research herd Karkendamm of the Institute of Animal Breeding and Husbandry, Christian-Albrechts-University Kiel (Germany). The cows were milked twice daily at 0500 and 1600 h. Milk yield was automatically recorded at every milking. Milk composition was analyzed weekly based on samples collected from 2 consecutive milkings. Milk composition per day was obtained by weighting the analysis values per day with the respective milk yields. Energy-corrected milk was calculated using the formula of Kirchgeßner (1997):

$$\text{ECM (kg)} = (0.39 \times \text{fat \%} + 0.24 \times \text{protein \%} + 0.17 \times \text{lactose \%}) \times \text{milk yield (kg)}/3.17.$$

Cows were weighed after leaving the milking parlor beginning in March 2006; morning and evening BW were averaged. Body condition scores were recorded monthly by a single person. The animals were fed a TMR ad libitum. Independent of merit, fixed amounts of concentrates were delivered to primiparous cows until DIM 180; then concentrates were given according to yield. Primiparous cows in the first 180 DIM consumed an average of 2.7 kg concentrates (SD = 0.3 kg). Dry matter content of the TMR was analyzed twice weekly. The obtained values were corrected for losses of volatile components according to Weissbach and Kuhla (1995). Composition of the TMR changed over the observation period. Crude protein, bypass protein, and the NE_L of TMR were kept relatively constant. The NE_L of TMR ranged between 7.0 and 7.2 MJ/kg of DM. Table 1 provides an overview of the TMR components and their variation.

The nutrient composition of TMR was calculated by using nutritional values of single components analyzed on a monthly basis (Spiekers et al., 2003). Intake of TMR per day (**TMI**) was recorded for each animal via single feeding troughs equipped with a weighing unit and automatic cow identification. Because cows were generally housed separately during the first 10 d of lactation, no feed intake data were available for this period. Individual TMI data were deleted for the first and last day with TMI information, for drying off days, culling days, and if cows were separated for insemina-