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Prediction and validation of residual feed intake and dry matter intake in Danish lactating dairy cows using mid-infrared spectroscopy of milk

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ABSTRACT

The present study explored the effectiveness of Fourier transform mid-infrared (FT-IR) spectral profiles as a predictor for dry matter intake (DMI) and residual feed intake (RFI). The partial least squares regression method was used to develop the prediction models. The models were validated using different external test sets, one randomly leaving out 20% of the records (validation A), the second randomly leaving out 20% of cows (validation B), and a third (for DMI prediction models) randomly leaving out one cow (validation C). The data included 1,044 records from 140 cows; 97 were Danish Holstein and 43 Danish Jersey. Results showed better accuracies for validation A compared with other validation methods. Milk yield (MY) contributed largely to DMI prediction; MY explained 59% of the variation and the validated model error root mean square error of prediction (RMSEP) was 2.24 kg. The model was improved by adding live weight (LW) as an additional predictor trait, where the accuracy R^2 increased from 0.59 to 0.72 and error RMSEP decreased from 2.24 to 1.83 kg. When only the milk FT-IR spectral profile was used in DMI prediction, a lower prediction ability was obtained, with $R^2 = 0.30$ and RMSEP = 2.91 kg. However, once the spectral information was added, along with MY and LW as predictors, model accuracy improved and R^2 increased to 0.81 and RMSEP decreased to 1.49 kg. Prediction accuracies of RFI changed throughout lactation. The RFI prediction model for the early-lactation stage was better compared with across lactation or mid- and late-lactation stages, with $R^2 = 0.46$ and RMSEP = 1.70. The most important spectral wavenumbers that contributed to DMI and RFI prediction models included fat, protein, and lactose peaks. Comparable prediction results were obtained when using infrared-predicted fat, protein, and lactose instead of full spectra, indicating that FT-IR spectral data do not add significant new information to improve DMI and RFI prediction models. Therefore, in practice, if full FT-IR spectral data are not stored, it is possible to achieve similar DMI or RFI prediction results based on standard milk control data. For DMI, the milk fat region was responsible for the major variation in milk spectra; for RFI, the major variation in milk spectra was within the milk protein region.
Key words: dry matter intake, residual feed intake, spectroscopy, prediction, validation

INTRODUCTION

Dry matter intake is a primary factor affecting animal performance. In cattle forage, DMI is integral in energy intake and production performance (Waldo and Jorgensen, 1981; Dado and Allen, 1994). Feed costs are the largest expense for dairy producers due to the energy required for lactation (Vallimont et al., 2011). Producers and nutritionists closely assess feeding programs to identify new opportunities to improve efficiency. Feed or DMI efficiencies have been applied to monitor dairy cattle performance. In dairy cows, feed efficiency is used as a measure to determine the capacity of lactating cows to convert feed nutrients into ECM or milk components. In simplest terms, feed efficiency equals kilograms of milk produced per kilogram of dry matter consumed (Hutjens, 2005). Feed efficiency measurements become increasingly important during periods of decreased profit margins; that is, high input and low return. Feed-efficient cows consume less energy and emit less methane (Connor et al., 2012). Thus, improving feed efficiency for dairy cows results in economic and environmental benefits (Basarab et al., 2013). Dairy cow efficiency can be defined in several ways. Among these, a commonly used method is residual feed intake (**RFI**). Residual feed intake is an alternative to the ratio-based (i.e., input:output) measure, because feed efficiency in lactating cows must consider the contribution of mobilization of body reserves to the cow's energy supply (Berry and Crowley, 2013). Residual feed intake is defined as the difference (in energy units) between feed intake energy and the sum of energy found in feed products and energy used in maintenance.

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The concept of selecting for improved feed efficiency or RFI is highly attractive, but practical implementation might be challenging, primarily because individual feed intake records are unavailable in commercial dairy herds. Dry matter intake is the key component to calculate feed efficiency. Genetic assessment of dairy cows requires reasonably large data sets. However, only small data sets are generally available for feed intake because of the difficulty and expense involved in measuring DMI. A promising option could be use of Fourier transform mid-infrared (**FT-IR**) spectroscopy on milk samples to predict DMI or RFI traits; FT-IR spectroscopy is a rapid and cost-effective tool for recording phenotypes at the population level and is already widespread for standard milk sample analysis.

Fourier transform mid-infrared spectroscopy studies the interactions between light and matter and is method of choice worldwide to quantify milk components, including fat, protein, and lactose during routine milk analyses. Recently, FT-IR spectroscopy was used to predict more detailed milk quality traits, such as individual milk fatty acids and proteins (Rutten et al., 2009, 2011; Bonfatti et al., 2011; Soyeurt et al., 2011; De Marchi et al., 2014). McParland et al. (2011, 2012, 2014) reported that energy status (intake and balance) and RFI can be predicted phenotypically using FT-IR. The additional benefit of using milk FT-IR is that spectral data are routinely generated for all individual milk samples, and DMI or RFI can be predicted on all milk-recorded animals at no additional cost.

In the present study, we elucidated the efficacy of FT-IR spectroscopy to predict DMI and RFI and evaluated the additional value of using FT-IR milk spectral profiles to improve DMI and RFI prediction models, along with other available informative traits. The objectives of this study were as follows: (1) to evaluate the potential of FT-IR to predict DMI and RFI using partial least squares regression (**PLSR**); (2) to identify and asses the most important FT-IR regions or wavenumbers in the prediction of DMI and RFI; and (3) to validate the developed prediction models for robustness.

MATERIALS AND METHODS

Data Collection

Data were collected from the Danish Cattle Research Centre (DKC, Foulum). Milk samples were collected 2 to 6 times per week (April to August 2015) and sent to the Eurofins-Steins laboratory (Vejen, Denmark) for FT-IR spectral analyses using MilkoScan FT+ (Foss, Hillerød, Denmark). Concurrently, milk yield (**MY**), fat, protein and lactose contents, DMI, live weight (**LW**), and BCS were recorded. The data analyzed included 1,044 DMI (kg/d) averaged per lactation week from 140 cows (97 Holstein and 43 Jersey). Corresponding weekly averages for daily MY (kg/d), LW (kg), and FT-IR–predicted fat, protein, and lactose contents were available for all these records. Body condition was scored to the nearest half unit on the Danish scale (Kristensen, 1986; derived from Lowman et al., 1976) from 1 to 5 on d 2, 14, 28, 42, 56, 84, 112, 168, and 224 after calving (Løvendahl et al., 2010). Body condition scoring was breed-specific and was scored every other week; BCS records were available as 596 records from 137 cows, because BCS records were missing for 3 cows. The 4,089 FT-IR spectral data records representing daily milk samples from the 140 cows were similarly averaged on a weekly basis, corresponding to the 1,044 DMI weekly average records. Dehareng et al. (2012) reported this approach, where each cow was milked twice daily and FT-IR spectral data were averaged to represent a daily milk spectrum, which was subsequently associated with recorded daily CH_4 data.

RFI Computation

We describe the feed efficiency measure, RFI, as the residual from a linear regression model, where DMI is regressed on ECM and metabolic body weight (**MBW**):

$$\mathrm{RFI} = \mathrm{DMI} - \beta 1 \times \mathrm{ECM} - \beta 2 \times \mathrm{MBW},$$

where ECM was calculated using the following formula proposed by Sjaunja et al. (1991):

$$\mathrm{ECM} = (\mathrm{yield}/3{,}140) \times [(383 \times \mathrm{fat}) + (242 \times \mathrm{protein}) + (157 \times \mathrm{lactose}) + 20.7].$$

Yield was in kilograms; fat, protein, and lactose contents are in percent; and MBW represents weekly metabolic BW (i.e., $\mathrm{LW}^{0.75}$).

Prediction Model Development

Prediction models were developed using the PLSR method (Wold et al., 1983; Martens and Naes, 1989). The method has been widely used in quantitative spectroscopy to determine a relationship between spectroscopic (predictors) and related chemical or physical data; that is, predictor(s). In the PLSR method, predictors are reduced to a smaller set of uncorrelated orthogonal components called latent variables, and a least squares regression is performed on the latent