J. Dairy Sci. 101:1–19
https://doi.org/10.3168/jds.2017-12636

Identification of biological traits associated with differences in residual energy intake among lactating Holstein cows

A. Fischer,*† R. Delagarde,† and P. Faverdin†[1]
*Institut de l'Élevage, F-75595, Paris, France
†PEGASE, Agrocampus-Ouest, INRA, F-35590, Saint-Gilles, France

ABSTRACT

Residual feed intake, which is usually used to estimate individual variation of feed efficiency, requires frequent and accurate measurements of individual feed intake to be carried out. Developing a breeding scheme based on residual feed intake in dairy cows is therefore complicated, especially because feed intake is not measurable for a large population. Another solution could be to focus on biological determinants of feed efficiency, which could potentially be directly and broadband measurable on farm. Several phenotypes have been identified in literature as being associated with differences in feed efficiency. The present study therefore aims to identify which biological mechanisms are associated with residual energy intake (REI) differences among dairy cows. Several candidate phenotypes were recorded frequently and simultaneously throughout the first 238 d in milk for 60 Holstein cows fed on a constant diet based on maize silage. A multiple linear regression of the 238 d in milk average of net energy intake was fitted on the 238 d in milk averages for milk energy output, metabolic body weight, the sum over the 238 d in milk of both, body condition score loss and gain, and the residuals were defined as REI. A partial least square regression was fitted over all biological traits to explain REI variability. Linear multiple regression explained 93.6% of net energy intake phenotypic variation, with 65.5% associated with lactation requirement, 23.2% with maintenance, and 4.9% with body reserves change; the 6.4% residuals represented REI. Overall, measured biological traits contributed to 58.9% of REI phenotypic variability, which were mainly explained by activity (26.5%) and feeding behavior (21.3%). However, apparent confounding was observed between behavior, activity, digestibility, and rumen-temperature variables. Drawing a conclusion on biological traits that explain feed efficiency differences among dairy cows was not possible due to this apparent confounding between the measured variables. Further investigation is needed to validate these results and to characterize the causal relationship of feed efficiency with feeding behavior, digestibility, body reserves change, activity, and rumen temperature.
Key words: feed efficiency, dairy cow, phenotype

INTRODUCTION

The world population is expected to increase by 32% by 2050 compared with 2015 (United Nations Department of Economic and Social Affairs Population Division, 2015). Demand for animal products is therefore expected to increase (IAASTD, 2009). To increase animal production, one possibility is to improve feed efficiency by selection, which means increased animal production or decreased use of resources. Selection for feed efficiency is complicated because individual variability of feed efficiency is not easily measurable on a large population. The classic indicator of individual variability in feed efficiency is residual feed or energy intake (**RFI** or **REI**; Dekkers and Gilbert, 2010; Aggrey and Rekaya, 2013; Berry and Crowley, 2013). By definition, RFI is the residual of a linear regression of feed intake fitted over a population, on the biological traits associated with the main energy expenditures.

Direct selection on RFI is often mentioned to improve feed efficiency (Pryce et al., 2015). Its heritability was moderate and variable in literature (Berry and Crowley, 2013; Yao et al., 2017); even when estimated over a large population (Tempelman et al., 2015), heritability was only 0.18. Given this moderate heritability, a large reference population is needed to develop a reliable EBV for RFI; at least 30,000 or 100,000 cows would be needed, respectively, with a heritability of 0.3 or 0.05 (Gonzalez-Recio et al., 2014). Because DM intake is difficult and expensive to measure on farm, especially in cattle, building a large reference population would therefore be difficult, and thus, developing EBV for RFI seems limited. To avoid measuring RFI in lactating cows, a possibility could be to measure it as grow-

Received January 24, 2017.
Accepted December 4, 2017.
[1]Corresponding author: philippe.faverdin@inra.fr

ing heifers if RFI is repeatable throughout age. When cows were identified as efficient or inefficient as calves, Macdonald et al. (2014) found that differences in DMI differed significantly but slightly between the most and the least efficient cows.

The major problem with RFI is that by definition of model residuals, RFI does not only reflect feed efficiency variability but also model fitting and measurement errors (Robinson, 2005). This sensitivity to model errors may contribute to the difficulty of building a reliable EBV of RFI. To have a better indication of feed efficiency variability, the possibilities are either to isolate RFI variability that is specific to animals and not to errors or to sum up feed efficiency in its main biological determinants. Literature poorly documents methods to identify animal-specific variability of RFI. Using frequent and accurate measurements of DMI and energy expenditure traits should reduce part of RFI associated with measurement errors (Robinson, 2005) and render RFI more representative of feed efficiency variability. Characterizing feed efficiency with its main biological determinants is an alternative to DMI modeling that could help to identify more heritable traits. Identification of feed efficiency biological determinants is largely documented in literature. Only Richardson and Herd (2004) have simultaneously analyzed the main biological traits expected to be involved in feed efficiency variability in beef cattle. In dairy cows, most studies have focused only on a group of these traits at the same time (Table 1). A more complete study with simultaneous measures of the identified biological traits is required to reach a conclusion on the biological determinants of RFI variability in dairy cows.

The present study is a preliminary analysis aiming at identifying potential determinants of long-term feed efficiency, estimated over the first 238 DIM, in dairy cow. Most potential determinants of feed efficiency cited in literature were therefore recorded for all cows to estimate the contribution of each determinant to residual energy intake phenotypic variability (Table 1). To reduce the part of REI variability that can be associated with measurement errors, REI was estimated with accurate and frequent measurements.

MATERIALS AND METHODS

An experiment on lactating dairy cows was established to frequently record as many phenotypes as possible among those that are potentially determinants of feed efficiency. Experimentation was carried out indoors to minimize the effect of changes in environmental conditions. This experiment was carried out from August 2014 to June 2015 in the INRA UMR PEGASE Méjusseaume (Le Rheu, France) experimental farm in western France. The data set consisted of 60 Holstein cows with 50% primiparous among them that were housed in a freestall barn. Data were available from calving to 238 DIM, which was the minimum number of DIM reached by all cows and will be referred to as the whole experimental period in the rest of the paper. Calving was seasonal, with a calving-season length of 56 d between August 27 and October 22, 2014.

A same TMR was fed from calving to the end of the experiment. The diet was offered ad libitum with a daily target level of 10% refusals per cow. Diet energy and protein densities were assessed according to the French system [INRA, 2010: UFL (unité fourragère lait) are amounts of NE_L, with 1 UFL equating to 7.1 MJ of NE_L, and PDIE (protein digested in the small intestine supplied by rumen-undegraded dietary protein and by microbial protein from rumen-fermented OM) are amounts of MP]. The TMR was based on maize silage, energy concentrate, soybean cake, dehydrated alfalfa, and minerals (Table 2). This diet had a net energy density of 0.936 UFL/kg of DM (6.65 MJ of NE/kg of DM) and a MP concentration of 94.3 g of PDIE/kg of DM. All cows were also fed the same diet at least 3 wk before calving. This precalving diet was based on a DM basis on corn silage (84.5%), soybean meal (9%), energy concentrate (4%), and straw (2.5%).

Feed Efficiency

Measurements to Calculate Feed Efficiency. Each cow had its own individual feed trough and was fed ad libitum. To enable feed distribution, access to the feed trough was closed from 0730 to 0900 h and from 1400 to 1600 h. Conversely, all cows were locked at the feed fence from 0900 to 1000 h and in the afternoon after milking, starting at 1530 until 1800 h; the rest of the day (17 h) they had free access to their feed trough, with a maximum of 10% refusals daily. Feed intake was measured daily for each cow as the difference between distributed and next morning refusals weight. A bulk sample of each ingredient was analyzed for composition. Analyses for DM were based on samples taken 5 times weekly for wet forages and once weekly for concentrates. Cows were gathered for milking around 0630 and 1530 h and were waiting in a standing position for milking. Milk yield was recorded at each milking. Twice a week, 2 consecutive milkings were analyzed for milk protein and fat concentrations. Milk net energy (**MNE**) was estimated according to the French standard energy requirement equation (INRA, 2010):

$$\mathrm{MNE} = 7.12 \times \{\mathrm{MY} \times [0.44 + 0.0055 \times (\mathrm{MFC} - 40) + 0.0033 \times (\mathrm{MPC} - 31)]\}, \quad [1]$$