COMPUTERS AND ELECTRONICS IN AGRICULTURE 60 (2008) 226–238

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Artificial neural network models of the rumen fermentation pattern in dairy cattle

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ARTICLE INFO

Article history:
Received 20 November 2006
Received in revised form
11 May 2007
Accepted 9 August 2007

Keywords:
Artificial neural networks
Milk fatty acids
Prediction
Rumen fermentation
Volatile fatty acids

ABSTRACT

The objectives of this study were: (1) to predict the rumen fermentation pattern from milk fatty acids using a machine learning technique, i.e. artificial neural networks (ANN) combined with feature selection and (2) to compare the prediction accuracy of the resulting model to that of a statistical multi-linear regression model, based on odd and branched chain milk fatty acids. Data were collected from 10 experiments with rumen fistulated dairy cows, resulting in a dataset of 138 observations. Feature selection was based on correlation and principal component analysis, and background physiological knowledge. Different ANN architectures and training algorithms were assessed. The evaluation of the model performance, based on the test dataset, showed a root mean square prediction error, expressed relative to the observed mean, of 2.65%, 7.67% and 7.61% of the observed mean for acetate, propionate and butyrate, respectively. Compared to a multi-linear regression model, the ANN revealed not to perform significantly better. However, the results confirm that milk fatty acids have great potential to predict molar proportions of individual volatile fatty acids in the rumen.

1. Introduction

Volatile fatty acids (VFA), produced by rumen microbes, are the major source of glucogenic and lipogenic nutrients to the ruminant. The relative proportions of the individual VFA, mainly acetate, propionate and butyrate, vary widely according to the animal's diet and influence the energy utilisation and the amount and composition of the milk produced (Sutton, 1985; Mc Donald et al., 1995). Prediction of the VFA proportions is therefore an important means of evaluating diets for milk production. Hence, much effort has already been done for the prediction of the VFA in the rumen. Mechanistic models (Baldwin et al., 1987; Dijkstra et al., 1992), based on feed characteristics and rumen conditions, were used, but the prediction accuracy of molar proportions VFA is low (Bannink et al., 1997). Friggens et al. (1998) used empirical regression equations, based on feed composition, but these regression models have not been tested on independent validation data. Also the gas production technique, another technique based on feed characteristics, was used to predict VFA proportions (Brown et al., 2002 and Rymer and Givens, 2002). However, the accuracy of these prediction models is still variable. This might be related to the fact that differences in the rumen fermentation pattern and bacterial population are not only affected by dietary composition but are also influenced by factors such as animal variability and feeding management (AFRC, 1998; Weimer et al., 1999; Vlaeminck et al., 2004). Hence, our laboratory approach is to use profiles of particular milk fatty acids (MFA) to improve rumen VFA predictions. Recently, Vlaeminck et al. (2006a) developed a multi-linear regression model based

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0168-1699/$ – see front matter
doi:10.1016/j.compag.2007.08.005

on odd and branched chain fatty acids (OBCFA) in milk for the prediction of VFA proportions, which revealed to perform better (root mean square prediction error <10% of the observed mean) compared to the existing models. The major source of these fatty acids in milk is from rumen bacterial origin rather than from animal synthesis (Vlaeminck et al., 2006b). Therefore, profiles of these MFA might be used as a tool to assess rumen function in terms of microbial populations, substrates and their interactions (Cabrita et al., 2003; Vlaeminck et al., 2006b). Prediction models, based on MFA, include animal variability because the MFA are measured for each individual cow and therefore can give information about individual rumen conditions.

Machine learning techniques, such as artificial neural networks (ANN), might further improve rumen VFA predictive models based on MFA through their capability of handling non-linear and complex data, even if these data are noisy and imprecise (Lek and Guégan, 1999). Moreover, ANNs have been shown to yield universal and highly flexible function approximates for any data (Lek and Guégan, 1999). Machine learning techniques are therefore increasingly used for classification and prediction purposes in agriculture (Salehi et al., 1998; Heald et al., 2000; Stefanon et al., 2001; Pietersma et al., 2003). This technique might be interesting when predictive MFA respond to rumen conditions in a non-linear way. C18-hydrogenation intermediates, especially *trans*-10 C18:1, are an example of a well-known non-linear response to rumen circumstances. *Trans*-10 C18:1 reflects more acidogenic rumen conditions, although the relationship with rumen pH is highly non-linear (Loor et al., 2005; Kalscheur et al., 1997). The use of ANN as modelling technique is therefore investigated in order to allow the inclusion of these non-linear relationships between MFA and rumen proportions of VFA.

The aim of this paper is to evaluate the use of ANN for the prediction of rumen proportions of VFA using MFA profiles. The prediction accuracy of the ANN is compared with that of a statistical multi-linear regression model based on milk OBCFA, using the same independent literature data.

2. Materials and methods

2.1. Data description

The current study combined data from 10 different experiments resulting in a dataset of 138 individual observations (Table 1) (Vlaeminck et al., 2006a).

2.1.1. Experiment 1 ($n = 17$)

Experimental design and diets were previously described by Dewhurst et al. (2003). This experiment was according to a four-period incomplete changeover design, in which six cows in the beginning of the lactation (76 ± 36 DIM) were used to test six dietary treatments. Each experimental treatment lasted for 3 weeks, of which the first 2 weeks were for adaptation. Each cow was offered four different diets. The cows received 8 kg/day of concentrate in three portions. Cows had ad libitum access to one of six silages: grass, red clover, white clover, alfalfa and 50/50 (DM basis) mixtures of grass and red clover and grass and white clover.

2.1.2. Experiment 2 ($n = 16$)

Experimental design and diets were described by Moorby et al. (2006) and Vlaeminck et al. (2006c). This experiment was according to a 4 × 4 Latin square design, in which four dairy cows (90 ± 34 DIM at the beginning of the experiment) were offered diets varying in forage to concentrate ratio. Each experimental period lasted for 4 weeks of which the first 2 weeks were for adaptation. Dietary treatments were based on ad libitum access to ryegrass silage and a dairy concentrate with forage to concentrate ratios of 80:20, 65:35, 50:50, 35:65 (DM basis). Fresh forage was distributed daily at 09.00 h whereas concentrates were distributed twice daily in equal portions at milking (Moorby et al., 2006; Vlaeminck et al., 2006c).

2.1.3. Experiment 3 ($n = 16$)

Experimental design and diets were described by Hindle et al. (2005). This experiment was a 4 × 4 Latin square design, in which four multi-cannulated dairy cows (80 ± 18 DIM at the beginning of the experiment) received a control diet, consisting of grass silage (43% of DM), ensiled sugar beet pulp (11% of DM) and a concentrate mixture with 70% dried sugar beet pulp. Dried sugar beet pulp of the concentrate was replaced either by native potato starch, cornmeal, or wheat meal in each of the three experimental diets. Each experimental period lasted for 4 weeks of which the first 2 weeks were for adaptation.

2.1.4. Experiment 4 ($n = 16$)

Experimental procedures are described in detail by Bruinenberg et al. (2004). Four rumen-cannulated multiparous Holstein cows (249 ± 76 DIM at the beginning of the experiment) were assigned to a 4 × 4 Latin square experiment. The experimental period lasted for 3 weeks, of which the first 2 weeks were for adaptation. The four dietary treatments consisted of different combinations of three grassland silages.

2.1.5. Experiments 5 and 6 ($n = 49$)

These experiments were both 5 × 5 Latin squares, with five dairy cows in early lactation at the beginning of experiment 5 (45 ± 14 DIM) and five dairy cows in late lactation at the beginning of experiment 6 (236 ± 14 DIM). The cows were offered diets varying in source of forage and concentrate (55/45 DM basis). Dietary treatments were based on ad libitum access to one of the five TMR: (1) a mixture (50/50, DM basis) of ryegrass silage and corn silage as forage and a mixture (50/50, DM basis) of two concentrates either rich in structural or in non-structural carbohydrates; (2) ryegrass silage as forage and the concentrate mixture (50/50, DM basis) as in diet 1; (3) corn silage as forage and the concentrate mixture (50/50, DM basis) as in diet 1; (4) a mixture (50/50, DM basis) of ryegrass silage and corn silage as forage and a concentrate rich in structural carbohydrates; (5) a mixture (50/50, DM basis) of ryegrass silage and corn silage as forage and a concentrate rich in non-structural carbohydrates. Each experimental period lasted for 3 weeks, of which the first 2 weeks were for adaptation.

2.1.6. Experiments 7 and 8 ($n = 17$)

These two experiments were both 3 × 3 Latin squares. Three dairy cows (294 ± 148 DIM at the beginning of the experiment) were offered diets with corn and grass silage as forage with a standard dairy concentrate. Corn silage was taken from two