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A new segmentation–clustering method to analyse feeding behaviour of ruminants from within-day cumulative intake patterns

S. Giger-Reverdin [a,b,*], E. Lebarbier [a,c], C. Duvaux-Ponter [a,b], M. Desnoyers [a,b]

[a] AgroParisTech, 16 rue Claude Bernard, 75005 Paris, France
[b] INRA UMR791 Modélisation Systémique Appliquée aux Ruminants, 16 rue Claude Bernard, 75005 Paris, France
[c] INRA UMR518 Mathématiques et Informatique Appliquées, 16 rue Claude Bernard, 75005 Paris, France

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ABSTRACT

Studying feeding behaviour of ruminants often implies the definition of eating bouts or the characterisation of meals. However, due to the difficulties encountered to define meal criteria there is a need for other ways of analysing feed intake. The aim of this paper was firstly to develop a new method to analyse feed intake without the need to define meals and secondly to use the obtained characteristics of the kinetic to discriminate between healthy animals and animals suffering from bouts of acidosis. The proposed method is broken down into two steps: a segmentation method is proposed first to detect changes in the slope of the kinetic representing changes in the feeding behaviour. Secondly, all the segments were clustered in eight groups according to the intake rate measured within the segment. This method was applied to the analysis of 15 h intake kinetics automatically recorded every 2 min in 12 goats in individual crates, during a period of 46 days. The present analysis showed that ruminal perturbations (acidosis) could influence the feeding pattern of goats and that it was possible to differentiate animals experiencing or not a bout of acidosis, through their feeding behaviour.

1. Introduction

Studying feeding behaviour in ruminants has often implied the definition of eating bouts or meals (Heinrichs and Conrad, 1987, Friggens et al., 1998, DeVries et al., 2003, Tolkamp and Kyriazakis, 1999, Abijaoudé et al., 2000a, Yeates et al., 2002, Kononoff and Heinrichs, 2003, Allcroft et al., 2004, Landau et al., 2000). The criteria used to identify these bouts or meals were, however, variable depending on authors and species. Some authors defined a priori the criteria to identify meals. For example, in sheep, Das et al. (1999) considered as an eating bout each period longer than 1 min during which time an animal was eating and which could include interruptions lasting less than 1 min. In goats, Abijaoudé et al. (2000a) used 20 min of chewing inactivity to define the end of a meal. In heifers, Landau et al. (2000) defined an eating bout as the period of time spent eating, including head raising interruptions shorter than 20 s in duration. In dairy cows, Kononoff and Heinrichs (2003) defined an eating bout as eating activity occurring for at least 5 min and which could include periods of maximum 10 min of inactivity. Other authors applied statistical methods to their data to define eating bouts and meals which were constituted of eating bouts separated by small time intervals. The simplest one categorised data according to the length of each eating bout, the amount consumed during each bout, and the interval between bouts (Heinrichs and Conrad, 1987). The set of data was ranked independently for each variate and the thresholds for each variate were chosen when between 90% and 95% of cumulated dry matter was accounted for, which meant for a dairy cow that minima of meal size of 0.2 kg, meal length of 2.5 min and intervals between meals of 8 min were selected (Heinrichs and Conrad, 1987). However, generally, proposed methods used frequency distributions showing a first peak corresponding to intervals between bouts, but within meals, and a second peak representing the intervals between meals. The meal criterion is based on the interval at which the two distributions intersect. These methods used combinations of either a Gaussian and a Weibull distribution, or two Gaussians and a Weibull distribution (Yeates et al. (2002)), or two log10-transformed frequency distributions (DeVries et al., 2003). Tolkamp and Kyriazakis (1999) aimed to determine if an eating bout constituted a meal by itself or was only part of a meal in cattle and compared five methods: frequency, log-survivorship, log-frequency, a two-Gaussian log-normal model and a three-Gaussian log-normal model. Another approach was proposed by Allcroft et al. (2004) who compared three statistical models (hidden Markov, latent Gaussian and semi-Markov) to predict feeding

* Corresponding author at: AgroParisTech INRA UMR791 Modélisation Systémique Appliquée aux Ruminants,16 rue Claude Bernard, F – 75 231 Paris Cedex 05, France. Tel.: +33 1 44 08 17 68; fax: +33 1 44 08 18 53.

E-mail addresses: sylvie.giger-reverdin@agroparistech.fr (S. Giger-Reverdin), lebarbie@agroparistech.fr (E. Lebarbier), christine.duvaux-ponter@agroparistech.fr (C. Duvaux-Ponter), mariondesnoyers@msn.com (M. Desnoyers).

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behaviour after defining feeding and non-feeding states. Most of the models were adapted to measurements obtained with automatic feeders recording the individual visits per animal Friggens et al. (1998) and were used mostly to study satiety with different diets or physiological stages. They generally gave the number and the mean length of either meals or eating bouts or visits. Some of them estimated the mean eating rate during the whole period of measurements (Landau et al., 2000, Yeates et al., 2002) or separated the initial meal from the spontaneous ones (Heinrichs and Conrad, 1987, Abijaoudé et al., 2000a), but none of them studied the variation in intake rates within a meal. The act of eating depends on the balance between motivations to eat and criteria of satiety which is an important notion used by Sauvant et al. (1996) in their model on intake and chewing activities in sheep. According to these authors, rumen loading is one of the main factors acting on satiety. In order to approach it rate, cumulative recording of feed intake could be relevant.

Off-feed periods due to subacute ruminal acidosis (SARA; mean rumen pH below 6.25 (Sauvant et al., 1999) are one of the major consequences of feeding high concentrate diets to high producing ruminants (Martin et al., 2006, Desnoyers et al., 2009). However, it is poorly detected in herds and has many consequences, such as decreased milk production, premature culling and increased mortality (Krause and Oetzel, 2005). Analysing feeding behaviour of ruminants during bouts of acidosis, via intake patterns, can help to better understand acidosis and to predict animal susceptibility to this metabolic disorder. It could also be of interest to test if an animal is able to modify not only its global feed intake, but also its feeding rate in case of rumen pH decrease, for example when this animal has eaten a large amount of fermentable feeds.

The aim of this paper was firstly to develop a new method to analyse feed intake and secondly to discriminate between intake patterns corresponding to days when animals were experiencing or not bouts of acidosis by using the obtained characteristics of the previous analysis. An intake pattern corresponds to the cumulative quantity of feed eaten during a given time. Changes in the feeding behaviour of the goat can be characterised by changes in the slopes of the intake pattern which correspond to the rate of eating. The statistical analysis aimed at detecting these changes through a segmentation method providing a partition of the data into segments (delimited by the change-points) with different characteristics. Piecewise regression models have been already studied by several authors, among them Toms and Lesperance (2003), Muggeo (2003) (and references therein). Two variants of this model can be distinguished: one involves a continuity constraint at the change-points instants and the other not. Chen et al. (2010) compared four methods for segmentation parameters estimation of these two kinds of models in both Bayesian and frequentist frameworks. In practice, the continuity constraint hampers the classical use of the Dynamic Programming algorithm (DP) to obtain the best segmentation with respect to this last criterion. To get around this problem, other approaches have been proposed, but they do not ensure to obtain the optimal solution (Muggeo, 2003, Chen et al., 2010). The reader can refer to Picard et al. (2005) for a description of the DP algorithm in the segmentation framework. As the number of segments for each intake pattern is unknown in practice, it must be estimated by using a model selection procedure Lavielle (2005). Each segment can be assigned to a "feeding behaviour" status by using a hierarchical clustering method that implies the choice of a distance between clusters, such as the one based on the log-likelihood ratio (Solomonoff et al., 1998). A segmentation/clustering procedure was applied to the analysis of 15 h within-day cumulative intake patterns automatically recorded every 2 min in 12 goats in individual crates, during a period of 46 consecutive days with rumen pH measurement. Bouts of acidosis were detected (Desnoyers et al., 2009) and within-day cumulative intake patterns with or without acidosis were compared according to the characteristics of each intake pattern obtained through the previous segmentation/clustering method.

2. Dairy goats within-day cumulative intake patterns and detection of acidosis

2.1. Animals and housing

Intake data were collected from 12 cannulated dairy goats (75 ± 4.0 days in milk, averaging 60 ± 6.8 kg body weight, producing 3.3 ± 0.59 kg milk per day at the start of the experiment). The present study was carried out according to French legislation on animal experimentation in line with the European Convention for the Protection of Vertebrates used for Experimental and other Scientific Purposes (European Directive 86/609).

Goats were housed in 1.20 m$\times$ 0.75 m individual pens with free access to water and received during 46 days a total mixed ration consisting in the proportion of the following components expressed on a dry matter basis: concentrate (50%), grass hay (35%) and sugar beet pulp (15%). Goats were fed twice daily after milking, in the proportion of two thirds at 4 p.m. and one third at 8 a.m., according to the intervals between milkings. Quantities of feed offered were adjusted weekly to ensure 10% refusals. The energy value of the diet (0.91 UFL/kg DM) was calculated according to the analytical method proposed by Vermorel (1988) and taking into account the digestive interactions due to both feeding level and concentrate percentage (Sauvant and Giger-Reverdin, 2009). The nitrogen value of the diet was calculated according to the additive method from the INRA tables (Baumont et al. (2007)) and was of 95 g PDI/kg DM. Animals were weighed weekly.

2.2. Intake measurements

Intake was recorded using a weigh-scale manufactured by Balea (Saint-Mathieu de Tréviers, France) fitted under the feed trough. This system recorded every 2 min the weight of the feed contained in the trough with a precision of 5 g and allowed simultaneous recording for the 12 goats. Data were downloaded every two or three days. Intake recordings were screened for errors by plotting cumulated intake and considering that a decrease in intake was impossible. Aberrant data due to a goat pressing on its trough were replaced by logical deduction from the preceding and following data. Cumulated dry matter intake (DMI) per kilogram of body weight (BW) was calculated after each feeding, using the body weight of the previous week and the dry matter percentage of the diet measured weekly from its water content (ISO, 1983). Analysis were performed separately on the intake patterns obtained after the morning feeding (6 h of measurement) and after the afternoon feeding (15 h of measurement). Only the data obtained between the afternoon feeding and the next morning feeding are presented and only the intake patterns from goats which have eaten more than 10 g of dry matter per kg BW after the afternoon feeding were used in the segmentation–clustering process described subsequently. Indeed, if the amount of feed eaten was too small, it was considered that intake behaviour was too disrupted to include the corresponding intake pattern in the overall process of clustering. Five intake patterns were therefore discarded for this reason. A goat died from acute acidosis during the trial, so that 18 days of measuring were missing for this goat, as well as 6 days due to technical problems with the scales. Finally, a total of 454 intake patterns were available. The cumulated DMI for a goat on a given day will be referred to as an intake pattern throughout the manuscript. For each intake pattern, the number of segments before reaching cluster 1 for the first time was calculated,