J. Dairy Sci. 99:1–15
http://dx.doi.org/10.3168/jds.2015-10162

Characterizing individual differences in animal responses to a nutritional challenge: Toward improved robustness measures

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ABSTRACT

The aim of this paper was to explore the variation between individuals in the response to and recovery from a nutritional challenge, the repeatability of responses between lactation stages, and the use of shape-clustering methods to classify similar individuals. Sixteen dairy goats were exposed to a 2-d nutritional challenge (underfeeding) at 2 different stages of lactation. Each challenge consisted of a 7-d control period with standard total mixed ration (TMR), 2 d of straw-only feeding, and a 10-d recovery period on the TMR. All feeds were offered ad libitum, as was water. The first challenge was in late lactation on primiparous goats (mean days in milk = 249), and the second challenge was carried out on the same goats early in the following lactation (mean days in milk = 28). The main energetic response traits dry matter intake (DMI), milk yield, body weight, milk fat and protein contents, and plasma glucose, fatty acids (NEFA), β-hydroxybutyrate (BHB), urea, and insulin, were measured daily throughout. A clustering procedure linked to a piecewise mixed model was used to characterize different types of response. As expected, straw feeding caused a large decline in DMI and milk yield, and substantial increases in milk fat and milk protein composition, relative to the prechallenge period on the control TMR. For both DMI and milk yield, the slope of the response, and hence the size of the drop, was strongly related to the prechallenge values, indicating that these 2 measures were tightly constrained by the challenge. Regression slopes between lactation stages for responses to the same nutritional challenge were significant for DMI, milk protein content, plasma BHB and urea, and body weight, indicating that within-animal responses in late and early lactation were repeatable. The clustering procedure generally performed well, classifying both scaling differences and differences in shape. The extent of reranking of cluster designations between late lactation and the following early lactation period was examined. For milk yield, DMI, body weight, and urea, relatively little reranking occurred; the numbers of goats not changing class number were 10, 12, 10, and 13, respectively. In contrast, for milk contents of fat and protein, and also for BHB, no clear association was found between late and early lactation class numbers. For NEFA and glucose, these comparisons were not relevant because either the vast majority of goats were in 1 cluster (NEFA) or because an outlier goat skewed the cluster designation (glucose in late lactation). For insulin, 9 out of 16 goats kept the same rank.
Key words: dairy goat, clustering method, adaptive capacity, resilience, lactation

INTRODUCTION

The ability of an animal to respond to, and recover from, environmental challenges is an increasingly important trait. This adaptive capacity is a key component of animal robustness [the ability to maintain life functions in the face of constraining environments (Kitano, 2004)] in the context of the challenges facing future livestock production. The diversity of environments to which livestock will be exposed is expected to increase as increasing food demand leads to further exploitation of marginal land (Bocquier and Gonzáles-Garcia, 2010). In addition, climate change is driving an increase in the variability over time in environmental conditions with a higher frequency of extreme conditions (Hansen et al., 2012). These 2 trends will place increasing demands on the animal's adaptive capacity.

Although there is now general agreement that adaptive capacity is a complex trait conferred by a combination of several underlying components (Strandberg, 2009), there is little agreement on how to quantify it, and on which are the key biological components (Friggens et al., 2010). This clearly presents a difficulty for characterizing both adaptive capacity and thus robust-

Received July 23, 2015.
Accepted December 5, 2015.
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ness. Marked differences are present between breeds and strains in performance responses to environmental challenges (Horan et al., 2005; Delaby et al., 2009). It has also been shown that individual variation in performance, and in the use of body reserves, can be adversely affected in harsh environments (Puillet et al., 2010). In this context, being able to characterize robustness at the level of the individual animal would be valuable for refining both management and selection strategies with respect to the anticipated increase in diversity of livestock systems.

The present study fits within an overall aim to develop ways to characterize the robustness and adaptive capacity of animals that can then be adapted to become operational methods for quantifying robustness on farm. [Robust animals are those that are able to be healthy and perform well under a wide range of environmental conditions (Amer, 2012)]. We believe that this is a timely and realistic aim given the increasing panel of automated measures that are becoming available on farm in the context of precision livestock farming (Rutten et al., 2013). Such measures provide the opportunity to describe the dynamic features of responses of individual animals to environmental perturbations (Codrea et al., 2011). The advances in on-farm technology also mean that such response dynamics can be measured across multiple performance and physiological traits. Preliminary studies indicate that it is possible to derive operational definitions of components of robustness that are quantifiable. For example, it has been shown that biological entities such as degree of infection can be derived from multivariate measures of the animal's disease response (Højsgaard and Friggens, 2010).

In the area of nutritional status and nutritional challenges, markers to monitor key metabolites such as BHB have been in use for a considerable time and now exist in automated systems (Nielsen et al., 2005). Several indexes are also now available for the purpose of monitoring to identify at-risk animals with respect to health status (Bramley et al., 2008; Moyes et al., 2013). In the present study, we wanted to extend this approach from a monitoring perspective toward phenotyping (i.e., to develop ways to better understand and characterize between animal variation in adaptive capacity using multivariate measures).

Accordingly, an experiment was carried out in which time-series measurements of behavior, performance, and metabolites were made in dairy goats exposed to a nutritional challenge, at 2 different stages of lactation. A major issue of this work relates to the exploration of the resulting data because the focus of this work is not to quantify the overall effect of the nutritional challenge but rather to examine individual differences in responses. Thus, we are interested in the portion of the variation that is usually eliminated (i.e., assigned to the error term) in standard ANOVA approaches. Given this, and the fact that there was no strong a priori rationale for which measures (or aspects of measures) are key components of adaptive capacity, an exploratory data analysis was used in this paper. Therefore, the aim of this paper was to prepare the ground (proof of concept) by providing the methodological basis for quantifying biologically meaningful descriptions of adaptive capacity phenotypes from multivariate measures. More specifically, the aim was to develop a methodology to explore the variation between individuals in the response and recovery to the challenge, the repeatability of responses, and shape-clustering methods to classify similar individuals.

MATERIALS AND METHODS

Animals, Feeds, and Design

Sixteen dairy goats, housed in individual pens (1.2 m by 0.75 m), were exposed to a 2-d nutritional challenge (underfeeding), at 2 different stages of lactation. Each challenge consisted of a 7-d control period with standard TMR, 2 d of straw only feeding, and a 10-d recovery period on the TMR. Prior to the start of each challenge period, the goats had received the standard TMR for at least 15 d. All feeds were offered ad libitum, as was water. The first challenge was in late lactation (mean DIM = 249, SD = 2.8, all goats were primiparous), and the second challenge was carried out on the same goats early in the following lactation (mean DIM = 28, SD = 3.3). The goats were housed in individual pens each with their own feed trough; they were milked twice per day and feed was distributed twice daily shortly after milking. Animals were cared for and handled in accordance with the French legislation on animal experimentation and European Convention for the Protection of Vertebrates Used for Experimental and Other Scientific Purposes (European Directive 86/609). The experiment was carried out between October 12, 2009, and February 14, 2010.

The standard TMR (on a DM basis) consisted of 20% chopped hay, 30% chopped dried alfalfa (Rumiluz, Désialis, Paris, France), 30% sugar beet pulp, and 20% of a commercial dairy concentrate (containing 18% maize, 14% sugar beet pulp, 12% sunflower meal, 10% wheat, 10% soybeans, 9% rapeseed meal, 6% soybean meal, 4% wheat distillers grains, 3.5% linseed, 3% pea seed, 1% rapeseed oil, 3% molasses, and 6.5% mineral and vitamin premix). The standard TMR (DM content 98.3%) had a measured content (on a DM basis) of 12.0% CP, 5.6% starch, 8.9% ash, 37.2% NDF, 20.0%