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The effects of feeding rations that differ in fiber and fermentable starch within a day on milk production and the daily rhythm of feed intake and plasma hormones and metabolites in dairy cows

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ABSTRACT

A daily pattern of feed intake, milk synthesis, and plasma metabolites and hormones occurs in dairy cows fed a total mixed ration once or twice a day. The object of this study was to determine if feeding multiple rations within a day, complementing these rhythms, would improve milk production. Twelve Holstein cows were used in a replicated 3 × 3 Latin square design with 21-d periods. Cows were housed in tie stalls with feed tubs, and feed weight was recorded every 10 s for observation of feeding behavior. Rations were a low fiber and high fermentable starch ration [LFHS; 27.4% neutral detergent fiber (NDF) and 31.7% starch based on 55.7% corn silage and 14.1% steam-flaked corn], a high fiber and low fermentable starch ration (HFLS; 31.7% NDF and 22.3% starch based on 44% corn silage, 26.3% alfalfa haylage, and no steam-flaked corn), and a total mixed ration that was a 1:3 ratio of LFHS and HFLS (30.7% NDF, 24.5% starch). The control treatment (CON) cows were fed the total mixed ration at 0700 h, the high/low treatment (HL) fed HFLS ration at 0700 h and LFHS ration at 2200 h, and the low/high (LH) treatment fed LFHS ration at 0700 h and HFLS ration at 1100 h (LFHS and HFLS rations fed at a 1:3 ratio). No effect was found of treatment on daily milk, but LH decreased milk fat concentration and yield compared with HL (0.2 percentage units and 0.24 kg, respectively). Daily dry matter and NDF intake and total-tract digestibility did not differ between treatments. The HL treatment reduced intake at the morning-conditioned meal after feeding and reduced intake before the evening feeding. A treatment by time of day interaction was found for fecal NDF and indigestible NDF concentration, blood urea nitrogen (BUN), plasma insulin, and fatty acid concentration, and body temperature. CON and LH increased the daily amplitude of fecal NDF by 1.0 and 1.1 percentage units compared with HL. Plasma insulin was higher in HL than CON at 0100 and 0400 h, but lower at 1300 and 1900 h. Plasma fatty acids were higher for CON than HL at 0700 h and HL was lower than LH at 0400 and 1900 h. Plasma BUN was higher for HL than control at 0100 h, but lower at 1000 h. Body temperature in CON and HL treatments followed a similar diurnal pattern, whereas body temperature for LH was lower than that of HL treatment at 1300 and 2300 h. No daily rhythm was found of fecal indigestible NDF concentration, plasma glucose, or fatty acids detected in the HL treatment, and the amplitude of plasma insulin and BUN was lower for HL compared with CON (70 and 60% decrease, respectively). In conclusion, feeding 2 rations that differ in fiber and fermentable starch modifies diurnal rhythms in dairy cows. Furthermore, feeding a high fiber and low fermentable starch ration during the high intake period of the day may stabilize nutrient absorption across the day.
Key words: circadian, diurnal, feed intake, milk fat

INTRODUCTION

Circadian rhythms are repeating 24-h cycles exhibited by most physiological functions in animals and these rhythms are entrained by numerous environmental cues including strong entrainment by light-dark cycles and entrainment by feed availability in some situations (see review Schibler et al., 2003). Giannetto and Picciano (2009) reported that 12 of 25 variables observed in dairy cows followed a circadian pattern. Additionally, circadian rhythms in plasma cortisol, growth hormone, insulin, fatty acids, BUN, locomotor activity, and body temperature of dairy cows have been reported (Lefcourt et al., 1995, 1999; Giannetto and Picciano, 2009).

Daily rhythmicity of feed intake has been well described including conditional meals related to feed delivery and a daily pattern of spontaneous meals with higher intake during the afternoon and lower intake during the overnight period (e.g., DeVries et al., 2005). Total mixed rations are a feeding technology developed

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more than 30 yr ago and are widely used in the dairy industry. The advantage of TMR feeding is that it supplies a consistent ration composition at each meal, with the goal of reducing fluctuations in the entry of rapidly fermentable substrate into the rumen across the day (Coppock et al., 1981). However, ruminal fermentation of cows fed TMR is not consistent because the daily pattern of feeding across the day results in fluctuations in starch entry into the rumen and rumen digesta composition (e.g., Ying et al., 2015). Specifically, the natural daily pattern of intake results in a higher flux of fermentable substrate entering the rumen during the higher intake period, and a lower flux of fermentable substrate entering the rumen during the lower intake period. This variation in intake combined with the large differences in the rate of digestion of starch and fiber results in ruminal digesta being higher in starch during the active feeding period of the day and lower in starch overnight. Additionally, Fickett and Allen (2002) reported lower ruminal amylolytic capacity before feeding compared with after feeding in cows fed a TMR once per day.

Rottman et al. (2015) investigated the effect of feeding 2 rations differing in forage to concentrate ratio at different times within a day in an attempt to complement the daily pattern of intake and stabilize rumen fermentation and reported that feeding a low forage diet in the morning increased feed efficiency and milk fat yield compared with feeding the low forage diet at night, presumably because of a priming effect allowing a more rapid increase in rumen starch from the low levels overnight. Feeding a high forage diet in the morning and a low forage diet at night unexpectedly reduces DMI and reduced milk fat yield. The objective of the current study was to determine the effect of offering 2 rations differing in both fiber and fermentable starch concentration during the high intake or low intake periods of the day on milk production and the daily rhythm of feed intake and key plasma hormones and metabolites. The hypothesis was that feeding a higher fiber and lower fermentable starch ration during the high intake period of the day would stabilize rumen fermentation and the circadian rhythms of plasma metabolites and metabolic hormones, whereas feeding a low fiber and high fermentable starch ration during the high intake period of the day would have the opposite effect.

MATERIALS AND METHODS

Experimental Design and Treatments

The experiment was conducted from April to May of 2012 at the Pennsylvania State University Dairy Production Research and Teaching Center. Twelve noncannulated multiparous Holstein cows (2.5 ± 0.21 parities; 128 ± 8 DIM; mean ± SD) were housed in a tie-stall barn with mattresses and sawdust bedding and randomly assigned to treatment sequences in a replicated 3 × 3 Latin square design with 21-d periods (sequenced balanced for carry-over effects). One cow was removed at beginning of the experiment due to mastitis. Rations were a low fiber and high fermentable starch ration (**LFHS**; 27.4% NDF, 31.7% starch, 55.7% corn silage, and 14.1% steam-flaked corn), a high fiber and low fermentable starch ration (**HFLS**; 31.7% NDF, 22.3% starch, 44% corn silage, and no steam-flaked corn), and a control TMR that was a 1 to 3 ratio of LFHS to HFLS. The 3 treatments were feeding (1) the control TMR at 0700 h (**CON**), (2) HFLS ration at 0700 h and LFHS ration at 2200 h (**HL**), or (3) LFHS ration at 0700 h and HFLS ration at 1100 h (**LH**). The LFHS and HFLS rations were offered in a 1 to 3 ratio, respectively. The 7-h starch fermentability of ground corn was 45.4, steam-flaked corn was 69.8%, and corn silage was 73.6%. The control TMR (1:3 ratio of LFHS:HFLS) was formulated to meet or exceed NRC (2001) recommendations. Although formulated for equal CP, the HFLS ration was 0.7 percentage units higher than the LFHS ration, but both are above expected RDP requirements (Table 1). A NPN source was used in the LFHS ration to balance for the NPN found in alfalfa haylage in the HFLS ration.

Cows were individually fed ad libitum at 110% of expected daily intake. All rations were mixed at 0600 h, stored at ambient temperature compacted in plastic bins, and covered with plastic to reduce exposure to air. Refused feed was removed and weighed once per day before feed delivery at 0700 h in all treatments. A light sensing data logger verified a consistent 18 h light to 6 h of dark schedule (dark ~2300 to 0500 h) and environmental temperature averaged 18.7 ± 4.8°C (mean ± SD).

Data and Sample Collection and Analysis

Nine cows were housed in tie stalls equipped with a feed intake observation system using feed tubs hanging from load cells as described by Niu et al. (2014). Briefly, feed weight was recorded every 10 s from d 15 to 21 of each period. Feed intake over 2-h intervals over the day was calculated based on running averages. Meals were determined through a multi-step process. The running average and standard deviation of the feed tub weight was determined over 2 min ever 10 s. First, possible eating activity was flagged when the running standard deviation of feed weight was greater than the 80th percentile. Meal size was determined based on the stable