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The effects of feeding a partial mixed ration plus a top-dress before feeding on milk production and the daily rhythm of feed intake and plasma hormones and metabolites in dairy cows

M. Niu[1] and K. J. Harvatine[2]
Department of Animal Science, Penn State University, University Park 16802

ABSTRACT

Total mixed rations (TMR) are commonly fed to dairy cows with a goal of reducing ruminal acidosis, but the daily pattern of feed intake has major implication for rumen fermentation and postabsorptive physiology. Generally there is low feed intake during the overnight period and high intake after feeding and during the afternoon. The objective of this study was to determine if feeding a partial mixed ration (PMR) plus a high starch top-dress before feeding of the PMR would improve production and modify key daily rhythms. The top-dress was fed before feeding as ruminal starch is at a nadir and amylolytic capacity is expected to be low. Ten Holstein cows were used in a crossover design with 14-d periods. Cows were housed in tie stalls with feed tubs and feed weight was recorded every 10 s for observation of feeding behavior. Treatments were a control TMR fed once per day at 0900 h or a partial mixed ration plus a top-dress (PMR+TD). The top-dress was fed at 9.5% of DMI offered at 0800 h and contained steamflaked corn, canola meal, and nonprotein nitrogen. No interaction was observed between treatment and milking time. Milk yield tended to be decreased 1.1 kg and milk fat yield was decreased 70 g/d by PMR+TD. Milk fat preformed fatty acids were decreased and no effect was observed of treatment on *trans*-10 C18:1 or other indicators of biohydrogenation-induced milk fat depression. No effect was observed of treatment on meal parameters including meal size and number. The PMR+TD increased total-tract neutral detergent fiber (NDF) digestibility by 1.2 percentage points. Treatment changed the daily pattern of fecal NDF and indigestible NDF, indicating changes in rumen function over the day. No effect was observed on plasma glucose, but the amplitude of the daily rhythm of insulin was increased by PMR+TD. The PMR+TD also increased plasma nonesterified fatty acids and decreased blood urea nitrogen across the day. Core body temperature is entrained by the central biological clock and its phase was advanced 42 min and its amplitude slightly increased by PMR+TD. In conclusion, the top-dress appears to have modified the central circadian rhythm and plasma insulin and blood urea nitrogen. This demonstrates that timing of feeding can be used to manage daily rhythms of the dairy cow, although the optimal timing requires further investigation.
Key words: circadian, diurnal, partial mixed ration, total mixed ration

INTRODUCTION

Total mixed rations are commonly fed to modern dairy cows, but a daily pattern of feed intake results in over a 3-fold change in the rate of fermentable substrate entering the rumen over the day (Niu et al., 2014, 2017). Additionally, cows within a herd or group differ in their nutrient needs, making balancing a single TMR for all cows difficult. Supplementation with a high starch top-dress may be advantageous and feasible in some situations such as tie-stalls, robotic feeding, and groups on small dairies mixing a single batch of TMR. However, the optimal timing of the supplementation is not clear.

Most physiological processes follow a circadian rhythm entrained by the light-dark cycles and other environmental cues including feed availability (see review Schibler et al., 2003). Plasma cortisol, growth hormone, insulin, nonesterified fatty acids (**NEFA**), blood urea nitrogen (**BUN**), locomotor activity, and body temperature have been reported to follow a circadian rhythm in the dairy cow (Lefcourt et al., 1995, 1999; Giannetto and Picciano, 2009). We recently have reported circadian rhythms in feed intake and milk synthesis (Niu et al., 2014; Rottman et al., 2014).

Generally, feed intake is low overnight, increases drastically after fresh feed delivery, and is higher in during the afternoon and early evening with TMR feeding (e.g., DeVries et al., 2005). This daily pattern

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[1]Current address: Farmers Business Network, San Carlos, CA 94070.
[2]Corresponding author: kjh182@psu.edu

has an effect on rumen digesta composition and the ruminal starch pool is lowest in the morning because of low intake during the night and the high rate of starch digestion. Additionally, lower ruminal amylolytic capacity before feeding compared with after feeding has been reported (Fickett and Allen, 2002). Because rumen starch pool and amylolytic capacity are lowest in the morning before TMR delivery, we proposed that this might be an optimal time to provide a high-starch supplement, as it would decrease starch intake during the high-intake period of the day. Supplementation strategies have been well investigated in the context of pasture (Auldist et al., 2016), component feeding (Auldist et al., 2016), and robotic milking (Bach and Cabrera, 2017), but timing supplementation relative to rumen dynamics has not been well investigated. The hypothesis was that feeding a high starch top-dress in the morning would decrease peak starch intake during the afternoon and modify daily rhythms of plasma metabolites and hormones.

MATERIALS AND METHODS

Experimental Design and Treatments

The experiment was conducted at the Pennsylvania State University Dairy Production Research and Teaching Center. Twelve noncannulated multiparous Holstein cows (2.5 ± 0.69 parities; 163 ± 35.8 DIM; mean ± SD) were housed in a tie-stall barn with mattresses and sawdust bedding and randomly assigned to treatment sequences in a crossover design with 14-d periods, but 2 cows were removed from data analysis as they refused to consume more than 10% of the top-dress. Rations were a TMR or a partial mixed ration (**PMR**) with a top-dress fed a 9.5% of DMI fed at 0800 h (1 h before the feeding of PMR; Table 1). The top-dress contained steamflaked corn, canola meal, and NPN and was balanced to be isonitrogenous with the TMR. The TMR delivered the same nutrient composition as the PMR plus the top-dress. Cows were individually fed the TMR and PMR ad libitum at 110% of expected daily intake. A light-sensing data logger verified a consistent 18 h light to 6 h of dark schedule (dark ~2300 to 0500 h).

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 as described by Niu et al. (2017).

Each ration and individual feed ingredients were sampled on d 8, 11, and 14 and orts (12.5%) were sampled before the morning feeding from d 8 to 14 of each period. Feed and orts samples were composited by period. Forages and a mix of concentrate feeds representing what was mixed were analyzed for DM, NDF, indigestible NDF (**iNDF**; 240 h in vitro), CP, and ash by wet chemistry procedures (Cumberland Valley Analytical Services Inc., Hagerstown, MD) and starch concentration by an enzymatic method according to Karkalas (1985). Orts samples were analyzed for DM, NDF, and ash by the same procedures.

Cows were milked twice daily at 0500 and 1700 h, and milk yield was determined by an integrated milk meter (AfiMilk; SAE Afikim, Israel) and analyzed as the average of d 12, 13, and 14 of each period. Milk

Table 1. Ingredients and chemical composition of treatment diets[1]

Item	TMR	PMR	Top-dress
Ingredient, % of DM			
Corn silage[2]	34.4	38.0	—
Alfalfa haylage[3]	22.9	25.2	—
Grass hay	3.57	3.95	—
Ground corn	7.25	8.03	—
Steam-flaked corn[4]	7.80	—	81.9
Canola meal	6.61	5.48	17.4
Soybean roasted	7.28	8.05	—
Bakery byproduct	3.66	4.05	—
Molasses	3.21	3.56	—
Vitamin-mineral mix[5]	3.04	3.36	—
NPN[6]	0.32	0.29	0.66
Chemical composition, % of DM			
DM	52.0	49.8	89.4
NDF	32.2	34.7	10.7
ADF	20.9	21.5	7.0
CP	16.6	16.6	15.4
Starch	24.0	21.2	57.4
Ash	8.7	9.3	2.8

[1]Treatments were a TMR or a partial mixed ration (PMR) and a top-dress fed at 9.5% of daily DMI.

[2]Contained 34% DM and 8.9% CP, 39.2% NDF, and 30.6% starch on a DM basis.

[3]Contained 54% DM and 19.2% CP, 49.3% NDF, and 1.1% starch on a DM basis.

[4]Contained 89% DM and 74.9% starch on a DM basis. Seven-hour starch digestibility of 69.8% (Pennfield Feeds, Mount Joy, PA).

[5]Contained (%, as-fed basis): 45.8 dried corn distillers grains with solubles; 35.8 limestone (38% Ca); 8.3 magnesium oxide (54% Mg); 6.4 salt; 1.73 vitamin A, D, E premix; 1.09 selenium premix (0.06% selenium); and 0.88 trace mineral mix. Composition (DM basis): 11% CP; 18% NDF; 5.2% fat; 14.9% Ca; 0.35% P; 4.58% Mg; 0.41% K; 0.31% S; 357 mg/kg of Cu; 1,085 mg/kg of Zn; 181 mg/kg of Fe; 6.67 mg/kg of Se; 125,875 IU/kg of vitamin A (retinyl acetate); 31,418 IU/kg of vitamin D (activated 7-dehydrocholesterol); and 946 IU/kg of vitamin E (DL-α-tocopheryl acetate). Purchased from Cargill Animal Nutrition (Minneapolis, MN).

[6]Coated urea (Optigen, Alltech Inc., Lexington, KY; 256% CP on DM basis).