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The control of short-term feed intake by metabolic oxidation in late-pregnant and early lactating dairy cows exposed to high ambient temperatures

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HIGHLIGHTS

- Feeding behavior differed in pre- and postpartum cows exposed to heat-stress.
- Heat stressed cows in early lactation had slower postprandial fat oxidation.
- Heat stress in early lactation delayed postprandial RQ increase.
- Heat stress prolonged feed digestion and shifted fat to glucose utilization.

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ABSTRACT

The objective of the present study was to integrate the dynamics of feed intake and metabolic oxidation in late pregnant and early lactating Holstein cows under heat stress conditions. On day 21 before parturition and again on day 20 after parturition, seven Holstein cows were kept for 7 days at thermoneutral (TN) conditions (15 °C; temperature–humidity-index (THI) = 60) followed by a 7 day heat stress (HS) period at 28 °C (THI = 76). On the last day of each temperature condition, gas exchange, feed intake and water intake were recorded every 6 min in a respiration chamber. Pre- and post-partum cows responded to HS by decreasing feed intake. The reduction in feed intake in pre-partum cows was achieved through decreased meal size, meal duration, eating rate and daily eating time with no change in meal frequency, while post-partum cows kept under HS conditions showed variable responses in feeding behavior. In both pre- and post-partum cows exposed to heat stress, daily and resting metabolic heat production decreased while the periprandial respiratory quotient (RQ) increased. The prolonged time between meal and the postprandial minimum in fat oxidation and the postprandial RQ maximum, respectively, revealed that HS as compared to TN early-lactating cows have slower postprandial fat oxidation, longer feed digestion, and thereby showing a shift from fat to glucose utilization.

1. Introduction

Heat stress in dairy cows is becoming an increasing concern of milk producers in Europe due to the ongoing climate change in the current century. Recent climate models indicate an increasing frequency of warm days and nights and near-term increases in the duration, intensity and spatial extent of heat-waves resulting in pronounced increase in high-percentile summer temperatures in almost all parts of Europe [1]. Under extreme ambient temperatures, particularly in association with high relative humidity that exceed the thermal comfort zone, dairy cows respond among many others by a reduction of feed intake, milk yield and reduced concentrations of milk constitutes [2,3]. Particularly, cows with high production traits possess a greater susceptibility towards high environmental temperatures due to the close relationship between metabolic heat and milk production. When milk production increases e.g. from 35 to 45 kg/day the temperature threshold for intermediate heat stress decreases by 5 °C [4,5].

When compared to their ancestors, modern Holstein dairy cows have become much greater [6] and possess therefore a much smaller surface:volume ratio which reduces the ability to dissipate heat load (Bergmann's rule). Dry cows as compared to lactating cows produce less metabolic heat [7] and are less susceptible to environmental heat as indicated by their greater critical temperature–humidity-index (THI) for heat stress [8]. However, when late-gestating cows are exposed above their critical THI, negative heat stress effects may carry

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over to the next lactation compromising not only milk performance but also intermediary metabolism, health and immune function [9].

The reduction of feed intake during environmental heat is one of the main contributors reducing endogenous heat production [10]. The decline in dry matter intake (DMI) must ultimately be mediated by some alterations in short-term feeding behavior because feed intake is a function of feeding behavior variables such as meal size, meal frequency, and inter-meal interval [11]. Just recently it has been shown that short-term feed intake is regulated by carbohydrate oxidation (**COX**) and fat oxidation (**FOX**) in dairy cows [12] and that the reduction of DMI in response to heat stress is accompanied by marked alterations in the carbohydrate, protein, and fat metabolism which differ from changes in animals kept on a reduced plane of nutrition [13,14].

How increased ambient heat affects dynamics of feeding behavior and nutrient oxidation, and how short-term feed intake is controlled by macronutrient oxidation under heat-stress conditions still remain to be elucidated. Understanding these relationships is a prerequisite for developing managerial and feeding strategies aligned to maintain DMI, milk-yield and reproductive function under high ambient temperatures [9]. Therefore, the aim of the present study was to determine dynamic changes in feeding pattern and metabolic oxidation of late gestation and early lactation cows exposed to high ambient temperatures.

2. Material and methods

2.1. Animals and experiments

The animal experiment was conducted between November 2012 and September 2013. Seven German Holstein dairy cows from the herd of Leibniz Institute for Farm Animal Biology (FBN, Dummerstorf, Germany) were used in this experiment. All cows were at the end of their 2nd parity, not milked within the 7 weeks prior to the expected calving date, and comparable in milk yield during first lactation (7629.6 ± 111.8 kg), as well as body weight (BW) (684.9 ± 37.1 kg) and back fat thickness (BFT, 12 ± 2 mm) determined in week 3 prior to calving (data presented as mean ± SEM). Prior to the experiment, animals were halter-trained and well adapted to climatic chambers and respiration chambers located at the Tiertechnikum of the FBN. To reduce seasonally-driven temperature differences between the open free-stall barn and the climate chamber, animals were transferred to the climate chamber two days before the experimental protocol was started to allow for the adaptation to the housing (tie-stall) and climate (15 °C, 63% humidity) conditions. Cows were kept in pairs of two per block. The experimental protocol consisted of two consecutive 7 day periods (TN and HS), each before and after parturition. On day 21 ± 2.8 before parturition and again on day 20 ± 5.7 (mean ± SE) after parturition, cows were kept in tie-stall in a climate chamber at thermal neutral conditions for 5.5 days and for another 1.5 days in an adjacent respiration chamber at 15 °C, 63% humidity (**TN** period; THI = 60 calculated according to National Research Council, 1971 [15]). On the following transition day (day 8), cows were transferred back to the climatic chamber in which the air temperature was continuously increased over a period of 12 h to 28 °C and the humidity adjusted to 52% (THI = 76). Under these conditions cows were kept for further 5.5 days and subsequently for another 1.5 days in the adjacent respiration chamber (**HS** period). Postpartum cows were milked twice daily at 0630 and 1630 h without interfering gas exchange measurement. Milk yield was recorded daily and milk samples were taken for analysis.

Between the pre- and post-partum experimental periods cows were kept in the experimental free stall barn at the institute. Due to severe sickness of two cows after calving, only five cows were included in the post-partum stage.

During the TN and HS periods, cows were kept at a light cycle ranging from 0600 to 1900 h and were fed ad libitum a TMR according to the recommendations [16] in meals of equal sizes at 0700 and 1500 h. The components and chemical analysis of the diets are shown in Table 1.

Table 1
Composition and chemical analysis of TMR diets fed pre- and post-partum.

Item	Diet	
	Pre-partum	Post-partum
Components, g/kg DM		
Grass silage	171	224
Corn silage	438	349
Hay	62	49
Straw	62	0
Concentrate	256	364
Mineral feed	11	14
DM, %	45.6	47.4
Chemical analysis		
Crude protein, g/kg DM	155.7	167.8
Crude fiber, g/kg DM	190.1	157.8
Crude fat, g/kg DM	27.3	39.0
Utilizable protein, g/kg DM	148.7	154.2
Metabolizable energy, MJ/kg DM	10.6	11.1
Net energy lactation, MJ/kg DM	6.36	6.66

Animals had free access to water, pre-warmed to 28 °C to prevent behavioral cooling by drinking. During lactation, cows were milked at 0630 and 1630. The experimental procedures were in accordance with the German animal protection law and were approved by the relevant authorities of the state government in Mecklenburg-West Pommerania (Registration No. LALLF M-V/TSD/7221.3-1.1-074/12).

2.2. Measurements in respiration chambers

After the 5.5 days stay in the climate chamber, the body weight was determined and animals were brought into the open-circuit respiration chambers to allow gas concentrations to equilibrate for 12 h (0.5 day). Subsequently, the dynamic of feed and water intake, gas exchange, and physical activity was recorded for 24 h as described recently [12]. Briefly, feed intake was measured every 6 min by feed disappearance from the feeding bin located on a scale and connected to an electronic registration device. Water intake was measured by a water meter connected to an electronic registration device. Standing and lying of the animals (position changes) were registered by a photoelectric switch (SA1E, Idec Elektrotechnik GmbH, Hamburg, Germany) emitting a light beam perpendicular to the longitudinal axis of the animal. Other physical activities were detected by a modified infrared-based motion detector (IS 120, Steinel, Herzebrock-Klarholz, Germany) converting movements of the animal to impulses. Thereby, movements lasting for 1 s are converted to 10 electric impulses. Thus, constant movement during a 6 min interval may result in a maximum of 3600 impulses.

Concentrations of CO_2 and CH_4 in the chamber were analyzed by infrared-absorption and the concentration of O_2 paramagnetically (SIDOR, SICK MAIHAK GmbH, Reute, Germany) every 6 min. Based on the measurements of O_2 consumption and CO_2 and CH_4 production, daily heat production (HP) calculated according to Brouwer [17] was normalized by metabolic BW (mBW) to obtain metabolic HP (mHP):

$$\text{mHP}\left(\text{kJ/kg}^{0.75}\right) = \left(16.18\,V_{O_2}(\text{L}) + 5.02\,V_{CO_2}(\text{L}) - 2.17\,V_{CH_4}(\text{L}) - 5.99\,N_u(\text{g})\right) / \,\text{mBW}\left(\text{kg}^{0.75}\right). \quad (1)$$

The average of the 10 lowest HP values determined during the nocturnal period (1900 to 0600 h) was computed as resting HP according to Derno et al. [12].

Because total CO_2 production (V_{CO_2}) measured is the sum of fermentative ($CO_{2\,\text{ferm.}}$) and metabolic CO_2 ($CO_{2\,\text{metab.}}$). $CO_{2\,\text{ferm.}}$ was estimated according to Chwalibog et al. [18]:

$$V_{CO_{2\text{ferm.}}}(\text{L}) = 1.7 \times V_{CH_4}(\text{L}) \quad (2)$$

in which the factor 1.7 is constant for a variety of diet compositions [20]. Accordingly, $V_{CO_{2\,\text{metab.}}}$ was calculated by subtracting $V_{CO_{2\,\text{ferm.}}}$ from V_{CO_2}