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Transient changes in milk production efficiency and bacterial community composition resulting from near-total exchange of ruminal contents between high- and low-efficiency Holstein cows

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ABSTRACT

The objectives of this study were to determine if milk production efficiency (MPE) is altered by near-total exchange of ruminal contents between high- (HE) and low-MPE (LE) cows and to characterize ruminal bacterial community composition (BCC) before exchange and over time postexchange. Three pairs of ruminally cannulated, third-lactation cows were selected whose MPE (energy-corrected milk per unit of dry matter intake) differed over their first 2 lactations. Approximately 95% of ruminal contents were exchanged between cows within each pair. Ruminal pH and volatile fatty acid (VFA) profiles, along with BCC (characterized by sequencing of the variable 4 region of 16S rRNA genes), were assessed just before feeding on d −8, −7, −5, −4, −1, 1, 2, 3, 7, 10, 14, 21, 28, 35, 42, and 56, relative to the exchange date. High-MPE cows had higher total ruminal VFA concentrations, higher molar percentages of propionate and valerate, and lower molar percentages of acetate and butyrate than did LE cows, and re-established these differences 1 d after contents exchange. Across all LE cows, MPE increased during 7 d postexchange but declined thereafter. Two of the 3 HE cows displayed decreases in MPE following introduction of the ruminal contents from the corresponding LE cow, but MPE increased in the third HE cow, which was determined to be an outlier. For all 6 cows, both liquid- and solids-associated BCC differed between individuals within a pair before contents exchange. Upon exchange, BCC of both phases in all 3 pairs was more similar to that of the donor inoculum than to preexchange host BCC. For 5 of 6 cows, the solids-associated community returned within 10 d to more resemble the preexchange community of that host than that of the donor community. Individual variability before the exchange was greater in liquids than in solids, as was the variability in response of bacterial communities to the exchange. Individual cows varied in their response, but generally moved toward re-establishment of their preexchange communities by 10 d after contents exchange. By contrast, ruminal pH and VFA profiles returned to preexchange levels within 1 d. Despite the small number of cows studied, the data suggest an apparent role for the ruminal bacterial community as a determinant of MPE.
Key words: milk production efficiency, ruminal contents exchange, ruminal microbiome

INTRODUCTION

Breeding of ruminants for improved production, combined with improvements in feeding and management, have resulted in tremendous gains in livestock productivity and efficiency. Although it is difficult to directly compare efficiency within the dairy industry over long time periods due to changes in feeding and production practices, dairy cows in the United States in 2007 were more efficient and environmentally benign than dairy cows in 1944 (Capper et al., 2009), despite undesirable negative trends in cow longevity and fertility (Dobson et al., 2007). Additional improvements in feed efficiency are considered essential to promote economically and environmentally sustainable dairy production in the future (Connor, 2015), and this might be accomplished in a variety of ways. Experiments with groups of animals fed the same diet indicate substantial differences in production efficiency among animals for both beef cattle (Hernandez-Sanabria et al., 2010, 2012; Carberry et al., 2012) and dairy cows (Connor et al., 2012; Arndt et al., 2015). Although these differences are often ascribed to differences in animal genetics (Pryce et al., 2012; VandeHaar et al., 2016), evidence is accumulating that differences in efficiency are associated with

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Table 1. Cows used for ruminal contents exchange experiments

Pair	Cow	Efficiency status[1]	DIM[2]	BW[3] (kg)	Contents removed[4] (kg)	Contents received[5] (kg)
1	4255	High	123	676	84.6	82.5
	4261	Low	238	833	83.4	84.4
2	4273	High	279	729	81.4	94.7
	4282	Low	151	725	95.9	80.4
3	4262	High	164	679	65.8	85.4
	4297	Low	79	725	86.2	65.0

[1]Milk production efficiency status (low = less efficient; high = more efficient) based on within-pair comparisons over 2 previous lactations (Jewell et al., 2015; see text).

[2]Days in milk on day of contents exchange.

[3]Mean BW (d −5, 6, and 7 relative to date of contents exchange).

[4]Fresh weight of liquid and solid ruminal contents removed for transfer to other cow within pair.

[5]Fresh weight of liquid and solid ruminal contents received from other cow within pair.

differences in the composition of the ruminal microbial community, interactions between the microbiome and host genetics, or both (Jami et al., 2014; Jewell et al., 2015; Shabat et al., 2016).

The objective of this study was to determine if differences in milk production efficiency (**MPE**) are mediated by (rather than merely correlated or associated with) the host bacterial community. We examined changes in ruminal microbial composition and MPE following near-total exchange of ruminal contents between pairs of third-lactation cows that had displayed differences in feed intake at the same within-pair level of milk production over their first 2 lactations. Our hypothesis was that MPE of the cow receiving the ruminal contents would change, at least transiently, to be similar to that of the donor animal, until the original ruminal community composition reverted to more closely resemble that of the cow before contents exchange.

MATERIALS AND METHODS

Animal Trial

The study was conducted at the US Dairy Forage Research Center (**USDFRC**), Prairie du Sac, Wisconsin, under protocol A01427, approved by the College of Agricultural and Life Sciences Animal Care and Use Committee, University of Wisconsin–Madison (**UW**). Three pairs of ruminally cannulated Holstein cows in their third lactation (cannulated before their first lactation according to a separate protocol, A01307) were used (Table 1). These pairs were previously identified (Jewell et al., 2015) as divergent in DMI at similar levels of ECM production over 3 discrete ranges of DIM (76–82, 151–157, and 251–257 DIM) over both their first and second lactations. At the start of the present experiment, the 6 cows were allocated to 3 pairings, each containing 1 cow with high MPE (**HE**) and 1 with low MPE (**LE**) based on the previous determinations (see Figure 1 of Jewell et al., 2015). The cows were offered the same TMR once daily at ∼0900 h to achieve ∼10% refusals. The ration was formulated to meet NRC guidelines for high-producing dairy cows (NRC, 2001), and contained (per kg of DM): 277 g of corn silage, 244 g of finely ground high-moisture shell corn, 265 g of alfalfa silage, 84 g of canola meal, 76 g of roasted soybeans, 41 g of distillers dried grains, and 25 g of vitamin/mineral mix. Upon analysis the ration contained (per kg of DM) 288 g of NDF (including 208 g of ADF and 26.7 g of ADL), 440 g of NFC (including 267 g of starch), 55 g of fat (ether extract), and 169 g of CP. The DMI (feed presented minus residual feed at the next feeding) and milk yields (kg) were determined daily, and milk samples were collected at each of 3 milkings on all days between −8 and +7 d relative to the date of ruminal contents exchange, and at each ruminal sampling day between 10 and 56 d postexchange (see below).

Ruminal Contents Exchange

Just before the morning feeding (February 10, 2015), ruminal contents were almost completely (subjectively estimated at ∼95%) removed from each cow through the ruminal cannula, and transferred to a tared container. Fluid-saturated solid digesta were first removed by handfuls, and finally liquid was removed using a small (∼100 mL) cup. Care was taken to locate and at least partially empty folds and pockets within the rumen to increase the extent of digesta removal, but with the intent of leaving a small fraction of the microbiome behind to serve as competitors for the introduced inoculum, as described previously (Weimer et al., 2010a). The solids, liquids, and tared bin were weighed. As soon as both rumens within a pair of cows were emptied, the contents were transferred between