Addition of straw to the early-lactation diet: Effects on feed intake, milk yield, and subclinical ketosis in Holstein cows

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ABSTRACT

This study evaluated feed intake, milk yield, and subclinical ketosis in dairy cows in early lactation fed 2 different diets postpartum. Cows are typically offered a high-energy ration immediately after calving. We compared a conventional high-energy total mixed ration (TMR) with a transition ration that contained chopped straw. We predicted that adding chopped straw would increase dry matter intake, milk production, and indicators of energy metabolism during the first 3 wk of lactation compared to cows fed a conventional high-energy TMR. We also predicted that carryover effects would be likely for at least 2 wk after treatment ended. A total of 68 mixed-age Holstein cows were enrolled in the study 3 wk before their expected calving. All cows were managed on a single high-forage diet during the dry period. At calving, cows were allocated to 1 of the 2 diets: half to the conventional high-energy TMR (CTMR; n = 34; net energy for lactation = 1.61 Mcal/kg; neutral detergent fiber = 31.7%), and the other half to a high-forage TMR containing chopped wheat straw, equivalent to 4.27% dry matter (STMR; n = 34; net energy for lactation = 1.59 Mcal/kg; neutral detergent fiber = 33.7%) for 3 wk after calving. Cows on STMR were then shifted to CTMR for the next 2 wk to study short-term residual effects on the performance of cows. Treatments were balanced for parity, body condition score, and body weight. Feed intake was measured daily from 2 wk before to 5 wk after calving using automatic feed bins. Blood was sampled twice weekly from 2 wk before to 5 wk after calving, and β-hydroxybutyrate and glucose were measured in serum samples. Subclinical ketosis was identified using a threshold of β-hydroxybutyrate ≥1.0 mmol/L in wk 1 after calving and ≥1.2 mmol/L in wk 2 to 5 after calving. Cows were milked twice daily, and weekly samples (composite samples of morning and afternoon milkings) were analyzed to determine total solids, fat, protein, lactose, and somatic cell count. Data were analyzed in 2 separate periods: the treatment phase (wk +1, +2, and +3) and the post-treatment phase (wk +4 and +5). The addition of straw to the TMR negatively affected the dry matter intake of STMR cows during wk 2 and 3 of lactation. Daily milk yield during the first 5 wk of lactation was lower in STMR cows than in CTMR cows. Concentrations of β-hydroxybutyrate were higher in CTMR cows than in STMR cows during wk 1, but this effect was reversed during wk 2 and 3 of lactation. By 21 d in milk, STMR cows had a greater risk of developing subclinical ketosis than CTMR cows. Adding chopped wheat straw to the TMR during the first 21 d after calving lowered dry matter intake and provided no metabolic or production benefits to lactating dairy cattle.

Key words: transition cow, high forage, dry matter intake, energy balance

INTRODUCTION

Early lactation is marked by a sudden increase in nutrient demands to support lactation, accompanied by low feed intake around calving (Drackley, 1999); this combination results in almost all cows entering a period of negative energy balance that is most pronounced during the first few weeks of lactation (Grummer et al., 2004). The weeks following calving are characterized by increased lipolysis (Allen et al., 2009), high circulating concentrations of nonesterified fatty acids (NEFA), and increased the risk of subclinical ketosis and ketosis (Bradford et al., 2015).
Increasing the concentrate content of the diet immediately postpartum has been associated with greater DMI and milk production (Rabelo et al., 2003). However, increasing concentrate inclusion relative to forage in the TMR can lead to an accumulation of volatile fatty acids in the rumen, reducing its buffering capacity (McCann et al., 2016) and increasing the risk of subacute ruminal acidosis (Gozho et al., 2005), displaced abomasum, ruminal ulcer, and liver abscess (Allen et al., 2009; Bradford et al., 2015; Lacasse et al., 2018).

Interest has been increasing in the use of straw in dry-cow diets (Vickers et al., 2013; Mann et al., 2015), but to our knowledge no study has addressed whether there are benefits to continuing to feed a less energy-dense diet during the first weeks postpartum. Including limited amounts of straw in milking rations has been advocated by some (Ferris et al., 2000; Oba and Allen, 2003). Furthermore, the inclusion of straw in the diet of early-lactation dairy cows as a source of physically effective fiber may improve digestion and the absorption of nutrients by promoting a stable rumen environment (e.g., less fluctuation in rumen pH), achieved by increasing chewing and salivary buffer secretion (Nandra et al., 1993; Mertens, 1997; Beauchemin et al., 2008). We hypothesized that the addition of chopped straw would reduce the energy density and increase the physically effective fiber of the TMR. We predicted that cows given this ration during the first 3 wk of lactation would show improved DMI, milk production, and indicators of energy metabolism during the first 3 wk of lactation compared to cows fed a conventional high-energy TMR. We also predicted that carryover effects would be likely once treatment had ended, so we followed the cows for an additional 2 wk.

**MATERIALS AND METHODS**

### Experimental Animals

This study was conducted at The University of British Columbia’s Dairy Education and Research Centre (Agassiz, British Columbia) from January to July 2012. The study was approved by The University of British Columbia Animal Care Committee (Application A10–0162) and performed in accordance with the guidelines outlined by the Canadian Council on Animal Care (2009). A total of 68 Holstein dairy cows (21 primiparous and 47 multiparous) were enrolled in this study. At enrollment, cows were randomly assigned to 1 of 2 treatments: a high-energy lactation TMR [CTMR; n = 34; 10 primiparous and 24 multiparous cows (average parity ± standard deviation: 3.2 ± 1.7)]; or a high-forage TMR containing chopped wheat straw [STMR; n = 34; 11 primiparous and 23 multiparous cows (average parity ± standard deviation: 3.4 ± 1.9)].

### Housing, Management, Dietary Treatments, and Feed Monitoring System

Cows were moved into an experimental prepartum pen at approximately 3 wk before their expected calving date. The prepartum pen consisted of 24 freestalls fitted with a mattress (Pasture Mat, Promat Inc., Woodstock, ON, Canada) covered with 5 cm of sand bedding, 12 feed bins (Insentec, Marknesse, Netherlands), and 2 water troughs (Insentec). The Insentec feeding system used in the present study has been described in previous studies (Chapinal et al., 2007; Neave et al., 2018). Stocking density in the pretreatment (prepartum pen; period 1), treatment (1–20 DIM; period 2), and post-treatment (period 3) periods remained constant throughout the study. As experimental cows moved from one period to the next (i.e., from the prepartum pen to the postpartum pen), an equivalent number of cows were removed to maintain stocking density. Cows that were moved out of the pens were either experimental cows that were eligible to move or “filler cows” (non-experimental cows that were housed in the pen to maintain stocking density). During the prepartum period, all cows were fed the same dry-cow TMR (DTMR), and all 24 cows in the pen had access to all 12 feed bins (Table 1). When cows showed signs of imminent calving (i.e., udder enlargement, milk let-down, relaxation of the tail ligament) they were relocated to an individual maternity pen (located in the same barn as the other experimental pens, directly adjacent to the prepartum pen) for the calving event and then moved to an experimental postpartum pen within 24 h after calving. The postpartum pen was located adjacent to the prepartum pen and also consisted of 24 free stalls, 12 Insentec feed bins, and 2 Insentec water troughs; it was stocked with 24 animals per pen. The system allowed cows on both treatments to be housed in the same group pen. Cows remained in the treatment postpartum pen for 3 wk (d 0 to 21 relative to calving) and were then relocated to an adjacent postpartum pen consisting of 12 free stalls, 6 Insentec feeders, and 1 Insentec water trough; stocking was maintained at 12 cows in the pen for an additional 2 wk of observation (d 22 to 35), during which all cows were provided with the same diet (CTMR). Before and after calving, cows were fed twice daily (0700 h and 1700 h).

### Measurements and Data Collection

Data generated by the Insentec feeders were used to calculate daily as-fed feed intake for individual cows.
Samples of TMR feed (fresh feed and orts) were collected weekly throughout the study. A consistent feed formulation of forage and concentrates from the same source and batches was used throughout the study, so the composition of the feeds offered during the study had little variation. Feed samples were used to determine the percent DM of each TMR and for later nutrient analysis; samples were dried at 60°C for 48 h to determine DM content, which was then used to adjust as-fed intakes reported by the Insentec system to DMI. Dried weekly feed samples (DTMR, CTMR, and STMR) were pooled into monthly samples, and 3 samples of each diet were sent to Cumberland Valley Analytical Services Inc. (Maugansville, MD) for analysis of DM (135°C; AOAC International, 2000: method 930.15), ash (535°C; AOAC International, 2000: method 942.05), ADF (AOAC International, 2000: method 973.18), NDF with heat-stable α-amylase and sodium sulfite (Van Soest et al., 1991), CP (N × 6.25; AOAC International, 2000: method 990.03), Leco FP-528 Nitrogen Analyzer, Leco, St. Joseph, MI), and starch (Hall, 2009). Net energy of lactation was calculated based on NRC (2001) equations.

All cows’ BW were measured weekly from 2 wk before calving to wk 5 postpartum, as well as on the day of calving. Cows’ BCS were measured weekly from 2 wk before calving to 5 wk postpartum and at calving using the 5-point scale described by Ferguson et al. (1994).

Cows were milked twice per day at approximately 0600 and 1600 h using a parallel milking parlor (12 cows per side). Daily milk production was recorded using milk meters interfaced with DairyComp305 herd management software (Dairy One Cooperative Inc., Lansing, NY). In each of the 5 wk postpartum, a milk sample was obtained from 1 morning and 1 afternoon milking. A composite milk sample was sent to Pacific Milk Analysis Labs/Can. (Chilliwack, BC, Canada) and analyzed for total solids (%), fat (%), protein (%), lactose (%), and SCC using a MilkoScan FT 6000 (Foss Electric, Hillerød, Denmark). The ECM yield was calculated as [(0.3246 × milk yield) + (12.86 × fat yield) + (7.04 × protein yield)] × (0.75). Postpartum energy balance was calculated daily for each cow using NRC (2001) calculations for energy requirements. We determined net energy intake (NEI; Mcal/d) by multiplying DMI by the calculated mean energy density of lactation diet estimated from feed analysis. Energy requirements for maintenance (NEM; Mcal/d) were calculated as follows: NEI = 0.080 Mcal/kg × BW0.75. Net energy for milk production (NEL; Mcal/d) was calculated as NEL = (0.0929 × fat %) + (0.0563 × protein %) + (0.0395 × lactose %) × milk yield (kg/d). Postpartum energy balance (NE) was calculated as follows: NE = NEI – (NEM + NEL).

### Data Analysis

Individual feed intake was calculated from data provided by the Insentec system. Due to the differences

### Table 1. Composition and component analysis (% of DM unless otherwise noted) of composite samples of 3 TMR types fed to transition cows: dry-cow TMR (DTMR), conventional postpartum TMR (CTMR), and postpartum TMR with added wheat straw (STMR; fed only during the 3-wk postcalving treatment period)^1^

<table>
<thead>
<tr>
<th>Composition</th>
<th>DTMR</th>
<th>CTMR</th>
<th>STMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass silage</td>
<td>13.07</td>
<td>22.25</td>
<td>21.0</td>
</tr>
<tr>
<td>Corn silage</td>
<td>30.25</td>
<td>16.64</td>
<td>15.93</td>
</tr>
<tr>
<td>Alfalfa hay</td>
<td>16.43</td>
<td>11.72</td>
<td>11.22</td>
</tr>
<tr>
<td>Concentrate mix^2^</td>
<td>14.17</td>
<td>40.38</td>
<td>47.27</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>26.08</td>
<td>0</td>
<td>4.27</td>
</tr>
<tr>
<td>Component</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM</td>
<td>49.28</td>
<td>52.45</td>
<td>53.41</td>
</tr>
<tr>
<td>NE^3^ (Mcal/kg)</td>
<td>1.41</td>
<td>1.61</td>
<td>1.59</td>
</tr>
<tr>
<td>CP</td>
<td>16.09</td>
<td>17.54</td>
<td>16.92</td>
</tr>
<tr>
<td>NDF</td>
<td>42.76</td>
<td>31.73</td>
<td>33.75</td>
</tr>
<tr>
<td>ADF</td>
<td>28.13</td>
<td>19.08</td>
<td>20.40</td>
</tr>
<tr>
<td>Effective NDF</td>
<td>40.93</td>
<td>24.04</td>
<td>26.38</td>
</tr>
<tr>
<td>Starch</td>
<td>13.16</td>
<td>26.75</td>
<td>25.80</td>
</tr>
<tr>
<td>Sugar</td>
<td>7.13</td>
<td>5.41</td>
<td>5.25</td>
</tr>
<tr>
<td>Ca</td>
<td>1.30</td>
<td>0.92</td>
<td>0.89</td>
</tr>
<tr>
<td>P</td>
<td>0.31</td>
<td>0.40</td>
<td>0.39</td>
</tr>
<tr>
<td>Na</td>
<td>0.15</td>
<td>0.37</td>
<td>0.36</td>
</tr>
<tr>
<td>Cl</td>
<td>0.53</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>K</td>
<td>1.65</td>
<td>1.68</td>
<td>1.67</td>
</tr>
<tr>
<td>Mg</td>
<td>0.42</td>
<td>0.28</td>
<td>0.28</td>
</tr>
<tr>
<td>S</td>
<td>0.30</td>
<td>0.24</td>
<td>0.23</td>
</tr>
</tbody>
</table>

^1^All cows were fed the CTMR after the treatment period (n = 34 cows per treatment).

^2^For DTMR, the major ingredients included 45% Amino Plus (Ag Processing Inc., Omaha, NE), 12% corn gluten meal, 11% soybean meal, 7.36% fine limestone, 5% ground beet pulp, 5% dry cow mineral, 4.32% calcium sulfate, 3.54% distillers corn wheat blend, 1% molasses. CTMR and STMR: 34% rolled barley, 26% fine ground barley, 10% distillers corn wheat blend, 7.3% ground wheat, 6% soybean meal, 6% Amino Plus (Ag Processing Inc.), 5% canola meal, 2.22% fine limestone, 1.18% mill run pellets.
between expected and actual calving dates (i.e., cows calving early) we analyzed feed intake up to 14 d prepartum only; all experimental cows had data recorded on these days. If a cow had less than 24 h of recorded data on a particular day, that day was excluded from further analysis. This generally occurred when cows were moved out of the experimental pens into an individual maternity pen for calving. All data from d −1 and d 0 were excluded from the analyses for every cow, because these days were almost always associated with pen changes, resulting in incomplete feed intake data. On the day a cow was moved between pens to accommodate the experimental design, feed intake data for that day were also removed. Following these adjustments to the feed intake data, we defined 7 experimental periods for feed intake: wk −2 (d −14 to −8), wk −1 (d −7 to −2), wk +1 (d 1 to 7), wk 2 (d 8 to 14), wk 3 (d 15 to 21), wk 4 (d 22 to 28), wk 5 (d 29 to 35). The statistical analysis was performed only for postpartum experimental periods.

Statistical analyses were performed with SAS (version 9.4; SAS Institute Inc., Cary, NC), using cow (n = 68) as the experimental unit. The MIXED procedure of SAS was used to analyze differences in DMI, milk yield and components, ECM, energy balance, and BHB and glucose concentrations. Data were analyzed in 2 separate periods: treatment (over 21 d of lactation) and post-treatment (following 2 wk).

The MIXED models included the fixed effects of treatment (STMR vs. CTMR), parity group (primiparous or multiparous), and BCS class (cows with a BCS ≤2.75 were classified as thin; cows with a BCS of 3–3.5 were classified as fair; and cows with a BCS ≥3.75 were classified as fat), with period (weekly periods for DMI, energy balance, milk yield and components, and ECM) or day (for BHB and glucose) specified as repeated measures and the period (or day) × treatment interaction. Cow was treated as a random effect. Data from 68 cows in the first 35 d of lactation were available for evaluation of the treatment effect on SCC. The final model for SCC included treatment (STMR vs. CTMR), day and treatment × day interaction, parity group, BCS class and disease, and the random effect of cow. The distributions of BHB, glucose, and milk fat and protein were skewed to the right and were transformed using the natural logarithm to achieve a normal distribution. All models used an autoregressive covariance structure except BHB, which used a Toeplitz covariance structure (selected on the basis of the smallest Bayesian information criterion). All variables were offered to each model and then removed in a backward stepwise elimination of nonsignificant (P > 0.05) variables. Interactions between treatment and significant covariates were included in the final model. If we found a significant interaction between time and treatment, we reanalyzed the data after stratification by the sample time.

One of our aims was to determine the effect of adding straw to the early-lactation diet on the prevention and treatment of subclinical ketosis. We evaluated this effect with multivariable logistic regression models using the GENMOD procedure in SAS. The models included treatment, parity group, and BCS class. The wk 1 samples served as the referent for the incidence of subclinical ketosis. The effects of treatment on prevention (cows with BHB <1 mmol/L at wk 1 that remained non-ketotic in the following weeks) and cure (those with subclinical ketosis at wk 1 that were normal when tested in the following weeks) were modeled separately using logistic regression as described above.

**RESULTS**

**BCS**

At enrollment, BCS ranged from 2.5 to 4.25 (mean 3.18) for STMR cows and 2.75 to 4.25 (mean 3.26) for CTMR cows. Throughout the study, the range and mean BCS by treatment were as follows: 2 to 4.25 (3.05) for STMR cows and 2.25 to 4.75 (3.15) for CTMR cows.

**DMI**

We found a period × treatment interaction for DMI (P = 0.01), indicating that differences in DMI between treatments varied by week relative to calving. Treatment differences were most pronounced in wk 3 after calving, with STMR cows consuming less feed (Figure 1). In addition, STMR cows tended to have a lower DMI during the post-treatment period (P = 0.08).

**Production**

Milk yield and ECM yield were not affected by treatment during the first 3 wk postpartum; however, the residual effects (i.e., during wk 4 and 5 of lactation) of treatment on milk yield and ECM yield were significant (P = 0.01; Figure 2 and 3). During the first 3 wk of lactation, milk fat percentage tended to be higher for STMR cows than for CTMR cows. We found no differences in protein or lactose between treatments (Table 2), and no interaction between treatment and day for milk components. We also found no effect of treatment on SCC (STMR: 393,000 cells/mL; CTMR: 378,000 cells/mL; P = 0.92).
Energy Balance

During the first 5 wk of lactation, all cows experienced negative energy balance (Figure 4). We found no effect of diet on energy balance ($P = 0.42$) during the first 21 d of lactation, but we did find a post-treatment difference ($P = 0.01$) between treatments. The STMR cows had improved energy balance from d 21 to 35 of lactation, after they were switched to the CTMR.

BHB and Glucose Concentrations

Concentrations of BHB were higher in STMR cows than in CTMR cows on d 14 and 17 after calving, driving a treatment × time interaction ($P = 0.05$; Figure 5). We found no group or group × time interaction on BHB in the post-treatment period ($P > 0.05$). We observed no effect of parity or BCS on BHB concentrations ($P > 0.05$).

Multiparous CTMR cows had higher blood glucose concentrations than multiparous STMR cows (51.4 ± 0.03 vs. 46.5 ± 0.03 mg/dL, respectively; $P = 0.02$; Figure 6) during the 21-d treatment period. This difference was not present in primiparous cows, contributing...
to a treatment × parity interaction for this measure ($P < 0.01$). We found no effect of treatment on glucose concentrations in the post-treatment period ($P > 0.05$).

### Subclinical Ketosis

We identified 28 cases of subclinical ketosis. Overall, during the first 5 wk of lactation, we observed no difference in the prevalence of subclinical ketosis between STMR and CTMR cows; each treatment had the same number of subclinical ketosis cases ($n = 14$). However, the prevalence gradually increased in the STMR group over the course of the experiment. Among the 58 cows that did not have ketosis during wk 1 after calving, the STMR cows had a higher risk of developing subclinical ketosis than CTMR cows by wk 3 after calving (odds ratio 4.9, 95% CI: 0.95–25.47; $P = 0.06$). The STMR diet had no effect on the incidence of subclinical ketosis during wk 2, 4, or 5 of lactation (Table 3). Only 10 cows had ketosis during wk 1 after calving—too few to meaningfully test the therapeutic effect of the STMR diet on subclinical ketosis.

### DISCUSSION

The main findings of the present study were that the addition of wheat straw to the TMR of cows in early lactation provided no beneficial effects for feed intake, milk yield, or preventing subclinical ketosis. Our results indicated that adding a small amount of chopped straw to the postpartum diet during the 21 d after calving depressed DMI. Wheat straw has lower NDF degradability than many other forages (Spanghero et al., 2010), and inclusion in the diet has been reported to increase rumen fill and limit DMI, resulting in a slower

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**Table 2. Least squares means (± SE) for DMI, milk production and components, energy balance, and serum constituents in the 7 wk around calving (prepartum: wk −2 and −1; treatment phase: wk +1, +2, and +3; post-treatment phase: wk +4 and +5)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Phase</th>
<th>CTMR</th>
<th>STMR</th>
<th>$P$-value</th>
<th>Group$^2$</th>
<th>Time</th>
<th>Group × time</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI (kg/d)</td>
<td>Treatment</td>
<td>17.3 ± 0.3</td>
<td>16.7 ± 0.4</td>
<td>0.26</td>
<td>0.01</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-treat</td>
<td>20.3 ± 0.4</td>
<td>19.3 ± 0.4</td>
<td>0.08</td>
<td>0.77</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Milk production (kg/d)</td>
<td>Treatment</td>
<td>31.6 ± 1.0</td>
<td>29.7 ± 0.9</td>
<td>0.14</td>
<td>0.76</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-treat</td>
<td>40.1 ± 1.1</td>
<td>35.9 ± 1.0</td>
<td>0.01</td>
<td>0.37</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>ECM (kg/d)</td>
<td>Treatment</td>
<td>33.2 ± 1.1</td>
<td>31.7 ± 1.1</td>
<td>0.32</td>
<td>0.13</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-treat</td>
<td>40.5 ± 1.1</td>
<td>36.8 ± 1.1</td>
<td>0.01</td>
<td>0.94</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td>Milk fat (%)</td>
<td>Treatment</td>
<td>4.26 ± 0.03</td>
<td>4.53 ± 0.03</td>
<td>0.10</td>
<td>0.54</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-treat</td>
<td>3.86 ± 0.02</td>
<td>3.90 ± 0.02</td>
<td>0.69</td>
<td>0.28</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Milk protein (%)</td>
<td>Treatment</td>
<td>3.29 ± 0.01</td>
<td>3.29 ± 0.01</td>
<td>0.94</td>
<td>0.27</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-treat</td>
<td>2.92 ± 0.01</td>
<td>2.94 ± 0.01</td>
<td>0.40</td>
<td>0.01</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>Milk lactose (%)</td>
<td>Treatment</td>
<td>4.47 ± 0.04</td>
<td>4.45 ± 0.03</td>
<td>0.68</td>
<td>0.86</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-treat</td>
<td>4.61 ± 0.04</td>
<td>4.58 ± 0.03</td>
<td>0.61</td>
<td>0.27</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>Energy balance (Mcal/d)</td>
<td>Treatment</td>
<td>−7.81 ± 0.60</td>
<td>−7.19 ± 0.57</td>
<td>0.42</td>
<td>0.30</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-treat</td>
<td>−6.11 ± 0.49</td>
<td>−4.32 ± 0.47</td>
<td>0.01</td>
<td>0.83</td>
<td>0.57</td>
<td></td>
</tr>
<tr>
<td>BHB (mmol/L)</td>
<td>Treatment</td>
<td>0.56 ± 0.08</td>
<td>0.61 ± 0.08</td>
<td>0.49</td>
<td>0.05</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-treat</td>
<td>0.58 ± 0.11</td>
<td>0.58 ± 0.10</td>
<td>0.93</td>
<td>0.16</td>
<td>0.79</td>
<td></td>
</tr>
<tr>
<td>Glucose (mg/dL)</td>
<td>Treatment</td>
<td>52.5 ± 0.03</td>
<td>50.4 ± 0.03</td>
<td>0.21</td>
<td>0.97</td>
<td>&lt;0.0001</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Post-treat</td>
<td>53.5 ± 0.03</td>
<td>54.6 ± 0.03</td>
<td>0.52</td>
<td>0.17</td>
<td>0.57</td>
<td></td>
</tr>
</tbody>
</table>

$^1$CTMR = conventional postpartum TMR; STMR = postpartum TMR with added wheat straw ($n = 34$ cows per treatment).

$^2$Group of treatment (STMR and CTMR).

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**Figure 4. Least squares means (± SE) for postpartum energy balance (Mcal/d) over 5 wk after parturition (treatment phase, shaded area). CTMR = conventional postpartum TMR; STMR = postpartum TMR with added wheat straw ($n = 34$ cows per treatment).**

*Significant difference between groups ($P < 0.05$).
passage rate (VandeHaar and St. Pierre, 2006; Coon et al., 2018). Cows on the STMR diet tended to have a lower DMI during the post-treatment period ($P = 0.08$), likely an associated adaptation with the transition to the high-energy diet.

Allen et al. (2009) stated that diets with moderate forage fiber concentrations benefit cows in early lactation. Some studies have shown that adding finely chopped straw to a TMR at 4% of DM made no difference to feed intake and milk yield in multiparous lactating cows (Humphries et al., 2010), and that the inclusion of small quantities of straw in the diets of dairy cows in mid-lactation resulted in small increases in DMI (Ferris et al., 2000). These differences in DMI response to straw could be attributed to differences in stage of lactation. In early lactation, cows are in a lipolytic state associated with low blood insulin and decreased insulin sensitivity of tissues (Bell, 1995). This state increases the demand for glucose precursors; adding straw to the ration in early lactation limits propionate production and promotes ketogenesis, potentially exacerbating negative energy balance. Elevated plasma ketone concentrations indicate a lipolytic state likely to suppress feed intake (Allen and Piantoni, 2013), and we also found that the lower DMI in STMR versus CTMR cows in wk of treatment coincided with higher levels of BHB.

Milk and ECM yield in the STMR cows were numerically lower than in the CTMR cows during the treatment period and significantly lower into the post-treatment period when all cows were fed the CTMR. These reductions in milk yield with the inclusion of straw were consistent with the work of Ferris et al. (2000) on cows in mid-lactation. The lower yield of the STMR cows was due to their lower DMI, because feed intake is a major determinant of milk yield (VandeHaar and St-Pierre, 2006). The elevated risk of subclinical ketosis may have also played a role, given that it can decrease milk yield in early lactation (Dohoo and Martin, 1984; Ospina et al., 2010; McArt et al., 2012). Further, the STMR cows were transitioned to the CTMR diet at 21 DIM, resulting in reduced milk production over the next 2 wk. This change in diet likely negatively influenced the rumen environment (Humer et al., 2018) and thus the cows’ ability to consume, ferment, and use nutrients from the diet (Rabelo et al., 2003). Higher milk fat percentage in STMR versus CTMR cows could be attributed to differences in dietary effective NDF (reviewed by Eastridge, 2006). Feeding a low-fiber diet can lead to declines in rumen pH, resulting in incomplete biohydrogenation of fatty acids and increases in trans-octadecenoic acids, ultimately causing milk fat depression (Grüninger et al., 1998). Alternatively, the addition of straw might have promoted acetate production and an improved acetate-to-propionate ratio in the rumen, which in turn increased the supply of substrate for milk fat synthesis (Rabelo et al., 2003).

Energy balance during the 21 d after calving was similar between the 2 experimental groups. Two major determinants of energy balance are DMI and milk yield. Because DMI was reduced in the STMR cows (particularly in wk 3 of treatment), energy intake was

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**Figure 5.** Least squares means (± SE) for BHB (mmol/L) for 2 wk before calving and 5 wk after (prepartum: d $-14$ and $-1$; treatment phase, shaded area: d $+1$ to $+21$; post-treatment phase: d $+22$ and $+35$). CTMR = conventional postpartum TMR; STMR = postpartum TMR with added wheat straw (n = 34 cows per treatment). Pretreatment (precalving) period data were used as baselines and were not analyzed. *Significant difference between groups ($P < 0.05$).
lower, but the lower milk yield in these cows mitigated the gap in energy balance. After the STMR cows were switched to the CTMR at 21 DIM, they continued to have lower DMI but improved energy balance compared with the CTMR cows, likely because of their lower milk yield.

Cows on the STMR experienced elevated BHB and increased risk of subclinical ketosis. Reduced DMI postpartum is associated with increased risk of metabolic disorders (Ingvartsen et al., 2003). Reduced DMI in the days after calving can negatively affect energy metabolism later in lactation (Baird et al., 1972; Drackley, 1999). Cows in early lactation experience lipolysis, which in turn can limit DMI, increasing the mobilization of body tissues and production of ketones (Roberts et al., 1981; Drackley, 1999). When stratified by health status, our results indicated that cows that did not have ketosis during wk 1 postpartum had a higher risk of developing subclinical ketosis when fed the STMR, but this difference was evident only in wk 3 after calving. We speculate that because the STMR group consumed less feed in early lactation, they were at increased risk for greater ketogenesis and thus increased incidence of subclinical ketosis (Drackley et al., 2001). The increased risk of subclinical ketosis is concerning given that it is associated with increased risk of abomasal displacements (LeBlanc et al., 2005; Seifi et al., 2011), decreased probability of pregnancy at first AI (Walsh et al., 2007), decreased milk production (Duffield et al., 2009), and increased duration and severity of mastitis (Suriyasathaporn et al., 2000).

Adding straw to the fresh cow diet lowered blood glucose concentrations. Glucose demand for milk production increases in early lactation (Oba and Allen, 2003). This demand is greater for multiparous cows than for primiparous cows, likely due to increased milk

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**Table 3.** Results of logistic regression models testing the effect of postpartum TMR on incidence of subclinical ketosis (serum BHB ≥1 mmol/L in wk 1 and BHB ≥1.2 mmol/L in wk 2 to 5)\(^1\)\(^2\)

<table>
<thead>
<tr>
<th>Time after treatment</th>
<th>Treatment</th>
<th>β estimate</th>
<th>Robust SE</th>
<th>Odds ratio</th>
<th>95% CI</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wk 2</td>
<td>STMR</td>
<td>-0.5390</td>
<td>0.8173</td>
<td>0.58</td>
<td>0.12-2.89</td>
<td>0.51</td>
</tr>
<tr>
<td>Wk 3</td>
<td>STMR</td>
<td>1.5950</td>
<td>0.8380</td>
<td>4.93</td>
<td>0.95-25.47</td>
<td>0.06</td>
</tr>
<tr>
<td>Wk 4</td>
<td>STMR</td>
<td>1.2528</td>
<td>0.8543</td>
<td>3.5</td>
<td>0.66-18.67</td>
<td>0.14</td>
</tr>
<tr>
<td>Wk 5</td>
<td>STMR</td>
<td>0.8329</td>
<td>0.8851</td>
<td>2.3</td>
<td>0.41-13.04</td>
<td>0.35</td>
</tr>
</tbody>
</table>

\(^1\)CTMR (conventional postpartum TMR) specified as the reference group; STMR = postpartum TMR with added wheat straw; models accounted for the effects of parity and BCS.

\(^2\)Among cows with BHB <1 mmol/L at wk 1 (n = 58).
yield (Ferris et al., 2000). Forage fiber increases the production of acetate more than propionate, the latter being the major precursor of glucose. Although some observations suggest that acetate spares glucose utilization by extrahepatic tissues for mid-lactation, decreasing the rate of glucose clearance from the blood (Head et al., 1964; Oba and Allen, 2003), acetate might spare glucose to a lesser extent in early lactation compared with mid-lactation (Oba and Allen, 2003).

CONCLUSIONS

Feeding a TMR containing a small amount of wheat straw during the 3 wk immediately after calving offered no metabolic or production benefits for lactating dairy cattle. Under the conditions used in this study, the addition of wheat straw to TMR reduced feed intake and milk yield and increased the incidence of subclinical ketosis.

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