Effect of replacement of barley meal with crude glycerol on lactation performance of primiparous dairy cows fed a grass silage-based diet

Marko Kass a,b,*, Tiia Ariko a, Tanel Kaart a,b, Eve Rihma a,b, Meelis Ots a,b, David Arney a, Olav Kärt a,b

a Institute of Veterinary Medicine and Animal Sciences, Estonian University of Life Sciences, 62 Kreutzwaldi Street, 51014 Tartu, Estonia
b Bio-Competence Centre of Healthy Dairy Products LLC, 1 Kreutzwaldi Street, 51014 Tartu, Estonia

ARTICLE INFO

Article history:
Received 29 June 2012
Received in revised form 5 September 2012
Accepted 8 September 2012

Keywords:
Crude glycerol
Barley meal
Grass silage
Rumen environment
Mid-lactation

ABSTRACT

The use of increasingly available glycerol, from the biodiesel industry, in dairy cow diets was assessed. The effects of replacement of barley meal by crude glycerol in a total mixed ration based on the grass silage on dry matter intake, milk yield and composition, rumen pH, silage degradability and metabolic status in mid-lactation Holstein dairy cows were evaluated. Eight, tie-stalled, primiparous cows were assigned to a $4 \times 4$ Latin square experimental design with two cows per treatment. Cows were paired according to milk yield and body weight, with one ruminally cannulated cow in each pair. The treatment period lasted 21 days of which 16 days were for adaptation. Cows were given a total mixed ration where barley meal was replaced isoenergetically by 0 kg (control), 1 kg, 2 kg and 3 kg crude glycerol per day per cow. An increased level of crude glycerol in the diet increased total intake ($P < 0.001$). Milk yield and composition were not affected by glycerol inclusion to the diet, with the exception of an increase in the milk protein content ($P < 0.001$). Cows given the glycerol diet had lower concentrations of blood nonesterified fatty acids ($P = 0.038$) and a higher concentration of blood urea ($P < 0.001$). Partial replacement of barley meal with crude glycerol in a total mixed ration affected the rumen environment, as the proportions of volatile fatty acids changed. There were no effects of treatment on the effective degradability of silage nutrients. These results indicate that crude glycerol is a suitable replacement for barley meal in a total mixed ration based on grass silage with no detrimental effect on lactation performance or rumen parameters.

© 2012 Elsevier B.V. All rights reserved.

1. Introduction

Biodiesel, an alternative fuel for diesel engines, produced from the reaction between a vegetable oil or animal fat with an alcohol, results in the production of crude glycerol as a by-product (Van Gerpen, 2005). The increase in biodiesel production has increased the availability of crude glycerol (European Biodiesel Board Statistics, 2010), making it attractive to farmers as a livestock feed. In early studies, glycerol was used as an aid in the treatment of ketosis (Fisher et al., 1971; Johnson, 1951). More recent studies have evaluated its glucogenic potential for dairy cows, particularly in the transition period (Bodarski et al., 2005; DeFrain et al., 2004; Ogborn, 2006) or in early lactation (Chung et al., 2007; Wang et al., 2009b). Other studies have focused on glycerol as an energy source, replacing starch in the diet of dairy cows (Donkin et al., 2009; Khalili et al., 1997; Schröder and Südekum, 1999).

*Corresponding author at: Institute of Veterinary Medicine and Animal Sciences, Estonian University of Life Sciences, 62 Kreutzwaldi Street, 51014 Tartu, Estonia. Tel.: +372 731478; fax: +372 7313477.
E-mail address: marko.kass@emu.ee (M. Kass).

http://dx.doi.org/10.1016/j.livsci.2012.09.007

Please cite this article as: Kass, M., et al., Effect of replacement of barley meal with crude glycerol on lactation performance of primiparous dairy cows fed a grass silage-based diet. Livestock Science (2012), http://dx.doi.org/10.1016/j.livsci.2012.09.007
Schröder and Südekum (1999) suggested that glycerol of different purities could replace rapidly fermentable starches in diets for ruminants at up to 10% of the diet DM with no adverse effect on either intakes or the ruminal environment. Donkin et al. (2009) reported that glycerol is a suitable replacement for maize grain in rations up to a level of 15% of dry matter without detrimental effects on milk yield or composition. Similar results were found with lower amounts of glycerol (3.6% of diet DM) replacing a barley-based concentrate (Khalili et al., 1997).

There are conflicting results on the effect of glycerol feeding on glycerol metabolism in the rumen. Early studies concluded that glycerol was entirely fermented to propionate (Garton et al., 1961; Johns, 1953). More recent studies indicated that in addition to propionate there were also increases in the concentrations of acetate (Wright, 1969) and butyrate (Linke et al., 2004; Rémond et al., 1993; Schröder and Südekum, 1999). When replacing starch sources with glycerol, Khalili et al. (1997) noted an increase in the proportions of propionate and butyrate at the expense of acetate, while Mach et al. (2009) found no effect on rumen molar proportions of volatile fatty acids. Such differences in results may be attributable to amounts fed, but also to the other dietary components affecting the complex metabolic pathways within the rumen.

Barley meal as a primary starch source and grass silage-based diets are common feedstuffs in Europe (Todorov, 1988). Most glycerol-feeding studies have focused on the replacement of maize-based concentrate with glycerol in the diet, and there has been a focus on the feeding of glycerol in early lactation. There is a lack of data on barley meal- and grass silage-based rations, and effects in mid-lactation. The objective of this study was to determine the optimum replacement level of barley meal with crude glycerol in grass silage diets fed to dairy cows. The experiment was designed to analyse effects in mid-lactation in order to provide guidance for the practical application of glycerol feeding to dairy farmers throughout lactation, and in the context of northern Europe.

2. Material and methods

2.1. Animals and diets

Eight primiparous Holstein cows were used in a 4 × 4 Latin square trial with two replicates. The cows were housed individually, tethered in stalls, in which they were fed and milked. Cows with mean days in milk (DIM) of 134 ± 15 were divided into pairs according to milk yield (24.7 ± 1.0 kg/d) and body weight (535 ± 13.5 kg). Within each pair, one cow was fitted with a rumen fistula. Each experimental period lasted 21 days; an adaption period of 16 days and five days of data collection.

Cows were fed a total mixed ration (TMR) twice a day at 06.00 and 16.00 on an ad libitum intake basis, the amounts offered adjusted to ensure a 5–10% feed refusal. Feed residuals were removed and weighed before fresh feed was offered. TMR was hand-mixed for each individual cow before feeding. The basal diet (control, C) contained grass silage, barley meal, soybean meal, limestone, sodium chloride and a mineral mix (Table 1). Treatment diets consisted of the basal diet in which 1 kg (low glycerol, LG), 2 kg (medium glycerol, MG) or 3 kg (high glycerol, HG) of crude glycerol replaced an isoeneric amount of barley meal in the daily ration. The experimental diets were isonitrogenously balanced by the addition of a commercially available protected urea (Optigen II; Alltech, USA).

The study was carried out at the Eerika Experimental Farm of the Estonian University of Life Sciences. The study was run in accordance with the Animal Protection Act of the Republic of Estonia.

2.2. Sample collection and analysis

The cows were weighed in a crush at the beginning of the trial and on two consecutive days at the end of each experimental period. The cows were milked twice a day, in their stalls. Milk yield was recorded in the last five days of each experimental period at every milking, and samples were taken for analyses on the last two days (days 20 and 21). Milk samples were stabilized with bronopol (Broad Spectrum Microtabs, D & F Control Systems Inc., Norwood, USA). Milk fat, protein, lactose and urea concentrations and somatic cell counts were measured using an automated infrared milk analyzer (System 4000, Foss Electric, Hillerød, Denmark).

Table 1 Ingredients and chemical composition of experimental diets in g/kg dry matter.

<table>
<thead>
<tr>
<th>Item</th>
<th>C</th>
<th>LG</th>
<th>MG</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass silage</td>
<td>469</td>
<td>470</td>
<td>471</td>
<td>472</td>
</tr>
<tr>
<td>Soybean meal</td>
<td>111</td>
<td>112</td>
<td>112</td>
<td>112</td>
</tr>
<tr>
<td>Barley meal</td>
<td>394</td>
<td>339</td>
<td>283</td>
<td>227</td>
</tr>
<tr>
<td>Crude glycerol&lt;sup&gt;a&lt;/sup&gt;</td>
<td>52</td>
<td>104</td>
<td>156</td>
<td></td>
</tr>
<tr>
<td>Optigen II&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mineral mix&lt;sup&gt;c&lt;/sup&gt;</td>
<td>11</td>
<td>11</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Metabolizable energy (MJ)</td>
<td>11.1</td>
<td>11.2</td>
<td>11.2</td>
<td>11.2</td>
</tr>
</tbody>
</table>

<sup>a</sup> Crude glycerol = BioOil Ltd., Estonia, 82.6% glycerol, 9.3% salts, 7.1% water, 0.6 crude fat and 0.4% methanol.

<sup>b</sup> Optigen II (Alltech, USA) = nitrogen 410 g/kg, crude fat 114 g/kg.

<sup>c</sup> Mineral mix (Veskimõiste Ltd., Estonia; contained CaCO<sub>3</sub> 30%, NaCl 20%, Ca(H<sub>2</sub>PO<sub>4</sub>)<sub>2</sub> 20%, Mg(PO<sub>4</sub>)<sub>2</sub> 19.5%).

Please cite this article as: Kass, M., et al., Effect of replacement of barley meal with crude glycerol on lactation performance of primiparous dairy cows fed a grass silage-based diet. Livestock Science (2012), http://dx.doi.org/10.1016/j.livsci.2012.09.007
Extraction Unit (FOSS, Hillerød, Denmark). Crude protein content was analysed by the Kjeldahl method with a Kjeltec 2300 analyser (FOSS, Hillerød, Denmark). ADF and NDF concentrations were determined with a fibre analyzer ANKOM220 (ANKOM Technology, Macedon NY, USA) (Van Soest et al., 1991). Dry matter intakes (DMI) were calculated based on daily intake of TMR and the DM content of the feed.

Crude glycerol contents were analyzed as follows: Na and K analyses by a flame atomic absorption spectrometer Solar M6 (Thermo Electron Co., USA); Pb by an atomic absorption spectrometer Solar M6 with graphite furnace (Thermo Electron Co., USA); P with a DR4000/U spectrometer (Hach Company, USA); moisture content by gravimetric analysis at 102°C; crude fat content by gravimetric analysis; glycerol content with a Liquid Chromatography HPLC Agilent 1200 Series Refractive Index Detector, using colon Zorbax carbohydrate (Agilent Technologies, USA) and methanol content was analysed with the Gas Chromatography Agilent 7890A GC System using capillary colon CP-WAX 57CB; 50 m × 320 μm × 0.2 μm (Agilent Technologies, USA).

Rumen pH was measured from one of each pair of cows on alternate days, with an indwelling pH metre (PHCN-37 Microprocessor-based pH Controller, Omega Engineering Inc., USA) once every hour from the beginning of the morning feeding to the beginning of the afternoon feeding. Rumen fluid was collected from the ventral area of rumen of all fistulated cows on each day of the final two days of the experimental period, in the morning (10.00). Samples were mixed and drained through cheesecloth and taken immediately to the laboratory for analysis of volatile fatty acid (VFA) and NH3-N contents.

For rumen VFA analyses, 1 ml of the strained rumen fluid was pipetted into a centrifuge tube and 0.2 ml of a metaphosphoric acid (at a concentration of 25%) and pivalic acid mixture (3/1, v/v) was added. After 30 min the acid (VFA) and NH3-N contents were mixed and drained through cheesecloth and taken immediately to the laboratory for analysis of volatile fatty acid (VFA) and NH3-N contents.

Effective degradabilities of silage nutrients were calculated based on daily intake of TMR and the DM content of the feed. Statistical significance was declared at 0.001; Table 2). All statistical analyses were performed with SAS 9.1 (SAS Institute Inc., 2003).

3. Results

Dry matter intake was significant (P < 0.001; Table 2) with glycerol inclusions, the mean increase being 0.97 kg. Cows given the HG diet had a significantly higher DMI.
Table 2
Effects of dietary treatments on DMI, milk yield and milk composition.

<table>
<thead>
<tr>
<th>Variable</th>
<th>C</th>
<th>LG</th>
<th>MG</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMI (kg/d)</td>
<td>18.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>18.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>18.4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>19.9&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>Milk yield (kg/d)</td>
<td>22.6</td>
<td>22.7</td>
<td>23.1</td>
<td>22.7</td>
</tr>
<tr>
<td>ECM&lt;sup&gt;1&lt;/sup&gt; (kg/d)</td>
<td>25.4</td>
<td>25.4</td>
<td>25.6</td>
<td>25.0</td>
</tr>
<tr>
<td>Fat (g/kg)</td>
<td>46.7</td>
<td>46.4</td>
<td>46.1</td>
<td>45.3</td>
</tr>
<tr>
<td>Protein (g/kg)</td>
<td>36.0&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>36.9&lt;sup&gt;d&lt;/sup&gt;</td>
<td>37.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>37.6&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Lactose (g/kg)</td>
<td>48.0&lt;sup&gt;c&lt;/sup&gt;</td>
<td>47.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>47.9</td>
<td>48.0&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fat (kg/d)</td>
<td>1.07</td>
<td>1.06</td>
<td>1.07</td>
<td>1.03</td>
</tr>
<tr>
<td>Protein (kg/d)</td>
<td>0.83</td>
<td>0.84</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
<td>Lactose (kg/d)</td>
<td>1.11</td>
<td>1.10</td>
<td>1.11</td>
<td>1.09</td>
</tr>
<tr>
<td>FP ratio&lt;sup&gt;2&lt;/sup&gt;</td>
<td>1.29&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.26</td>
<td>1.24</td>
<td>1.21&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>PL ratio&lt;sup&gt;1&lt;/sup&gt;</td>
<td>0.75&lt;sup&gt;abc&lt;/sup&gt;</td>
<td>0.78&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.78&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.79&lt;sup&lt;c&gt;</td>
</tr>
<tr>
<td>SCC × 1000 cells/mL</td>
<td>60.7</td>
<td>46.2</td>
<td>64.4</td>
<td>44.4</td>
</tr>
<tr>
<td>Milk urea (mg/L)</td>
<td>221</td>
<td>220</td>
<td>235</td>
<td>229</td>
</tr>
<tr>
<td>FE (kg/kg&lt;sup&gt;3&lt;/sup&gt;)</td>
<td>1.27&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.25&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.27&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>1.15&lt;sup&gt;ac&lt;/sup&gt;</td>
</tr>
<tr>
<td>BW change (kg)</td>
<td>14.9</td>
<td>2.05</td>
<td>--</td>
<td>2.73</td>
</tr>
</tbody>
</table>

<sup>a–c</sup> Least square means within rows with the same superscripts are different at P<0.05.
<sup>1</sup> Calculated according to Sjaunja et al. (1990) based on milk composition: ECM, kg = milk yield, kg × (383 × fat% + 242 × protein% + 165.4 × lactose% + 20.7)/3140.
<sup>2</sup> FP ratio = Milk fat/protein ratio.
<sup>3</sup> PL ratio = Milk protein/lactose ratio.
<sup>4</sup> Feed efficiency = milk, kg/d: DMI, kg/d.
<sup>5</sup> P-values of treatment effect.

Table 3
Effects of crude glycerol on blood plasma composition.

<table>
<thead>
<tr>
<th>Variable</th>
<th>C</th>
<th>LG</th>
<th>MG</th>
<th>HG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose (mg/dl)</td>
<td>84.8</td>
<td>81.8</td>
<td>81.6</td>
<td>87.2</td>
</tr>
<tr>
<td>Insulin (mIU/l)</td>
<td>14.1</td>
<td>15.1</td>
<td>12.3</td>
<td>15.0</td>
</tr>
<tr>
<td>BHB (mmol/l)</td>
<td>1.16</td>
<td>1.10</td>
<td>1.15</td>
<td>1.10</td>
</tr>
<tr>
<td>NEFA (mmol/l)</td>
<td>91.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>79.3</td>
<td>81.2</td>
<td>68.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Urea (mg/dl)</td>
<td>38.6&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>42.8&lt;sup&gt;c&lt;/sup&gt;</td>
<td>49.8&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>44.8&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a–c</sup> Least square means within rows with the same superscripts are different at P<0.05.
<sup>1</sup> P-values of treatment effect.

compared to the other groups (Table 2). Milk yield, ECM yield and composition were not affected by treatment, with the exception of the milk protein content which was significantly increased (P<0.001) with glycerol inclusion to the diet. Cows given the HG diet had a significantly lower value feed efficiency compared to the other groups (Table 2).

There was a significant difference between the milk fat/protein ratio of the control and glycerol treatment groups (P=0.042); the HG cows had a lower ratio compared to the C cows. The ratio of milk protein to lactose was also affected by the treatment (P=0.001), with higher values for the cows in the glycerol groups compared to the cows fed the control diet (Table 2).

The treatment effects on blood parameters are shown in Table 3. The blood plasma concentrations of glucose, insulin and BHB were not affected by treatments. There were decreases (P=0.038) in plasma concentrations of NEFA when compared with the control and increases in urea concentrations (P=0.001) in all treatment groups. HG cows had a significantly lower plasma NEFA concentration compared to controls (P=0.004).

The rumen VFA and rumen pH values are presented in Table 4. Treatment diets did not affect rumen pH at any measuring time between 6:00 and 16:00. Dietary treatments did not affect total concentrations of rumen fluid VFAs. The proportions of individual VFAs altered (P<0.001), there was an increase in the proportion of propionate and butyrate, and a decrease in the proportion of acetate in rumen fluid compared to the control diet (P<0.001). The ratios of VFA were also affected by treatment (P<0.001). However, the changes in ratios were not linear with respect to the increasing glycerol level in the diet.

Rumen NH₃–N was significantly higher in the two higher glycerol treatments (MG and HG; P<0.05).

The effective degradability of silage DM, CP, NDF and ADF were not affected by the addition of glycerol to the TMR (Table 5).

4. Discussion

Including crude glycerol in the TMR of lactating dairy cows increased DMI. This supports the potential of replacing...
Barley meal with glycerol as an energy source in the lactating dairy cow. Glycerol levels up to a very high proportion, 15% of the diet DM, were found to have no negative effect on intakes. Such high levels have also previously been found to have no deleterious effect on intakes in mid-lactation (Donkin et al., 2009), in transition cows (Carvalho et al., 2011) or in early lactation (Bodarski et al., 2005). In the current trial, crude glycerol was used, which might be thought to have adverse effects because of impurities, such as methanol and various salts (Thompson and He, 2006). Fisher (1999) and Werner Omazic et al. (2011). The increased feed intake may therefore be expected to be in the body tissue, which would be at less risk of energy deficiency. The decrease in plasma NEFA levels might be a consequence of either, or both of, the increase in intake and the addition of a specific provision of an energy-rich component to the diet (Drouillard, 2008).

The lack of an effect of crude glycerol on both milk yield and ECM-yield in mid-lactation cows is consistent with previous studies (Boyd et al., 2011; Donkin et al., 2009; Khalili et al., 1997). The increase in intake did not have a consequential effect on milk yield. One reason could be that the use of propionate for gluconeogenesis in the liver is inhibited by butyrate (which increased significantly in the treatment cows) which reduces the production of glucose and increases the utilization of amino acids for gluconeogenesis, which leads to a reduction in the available amino acids for lactogenesis in the mammary gland (Huhtanen et al., 1993).

There was a reduced feed efficiency for milk production. The target for deposition of the increased nutrient intake may therefore be expected to be in the body tissue, although BW changes were not affected by treatments, as was also found by Boyd et al. (2011) with mid-lactation dairy cows and Mach et al. (2009) with beef cattle. Nevertheless, BWs of high glycerol treatment cows were significantly higher at the end of each treatment period than control and other treatment cows. Donkin et al. (2009) found that replacing corn grain with 15% of glycerol in diet increased BW in dairy cows during mid-lactation. It would seem reasonable to assume that the glycerol in diet increased BW in dairy cows during mid-lactation. It would seem reasonable to assume that the glycerol supplementation could ameliorate the problems of negative energy balance.

Plasma NEFA concentrations were reduced in the treatment cows, indicating reduced lipid mobilisation (Drackley, 1999). It was hypothesized that glycerol administration increased the supply of energy, with increased DMI, and therefore reduced the concentration of NEFA circulating in the blood. With increased energy availability the cows would be at less risk of energy deficiency. The decrease in NEFA levels might be a consequence of either, or both of, a DMI increase with added glycerol, and the addition of a specific provision of an energy-rich component to the diet.
(glycerol). The decrease of plasma NEFA concentration was not found in earlier research with mid-lactation (Khalili et al., 1997) and transition (Carvalho et al., 2011; DeFrain et al., 2004) cows.

Glycerol is either fermented in the rumen, largely to propionate, or absorbed through the rumen wall, and to a lesser extent escapes rumen fermentation (Remond et al., 1993). It could therefore increase the availability of glucose to the cow. In the current study, the change in glucogenic precursor in the diet had no effect on plasma glucose concentration, as previously observed by others (Boyd et al., 2011; Khalili et al., 1997; Mach et al., 2009). This may be related to the kinetics of glucose, which remained elevated for 8 h after rapid delivery and returned to basal values within 24 h (Goff and Horst, 2001; Linke et al., 2004), so within the parameters of sampling in the current study any increase might have been missed. Similarly, plasma insulin concentration was unaffected by glycerol inclusion in the diet as reported in studies with transition (Chung et al., 2007) and post partum dairy cows (DeFrain et al., 2004). Differences in blood glucose and insulin may be associated with many issues such as the method of glycerol feeding, quantity, delivery period or blood sampling.

The change in energy source in the TMR did not affect the rumen total VFA concentration, as previously found by Carvalho et al. (2011), DeFrain et al. (2004), Khalili et al. (1997) and Mach et al. (2009). Wang et al. (2009a) reported that a linear increase in glycerol in the diet linearly increased the ruminal VFA concentration, but this was not observed in current trial. This may have been because of the differences in the basal diet, and the amounts of glycerol used by Wang et al. (2009a, 2009b) were much less than the current study.

The proportions of individual VFAs in the rumen were affected by glycerol inclusion. The higher levels of glycerol in the diet increased the proportions of propionate and butyrate at the expense of acetate. This is in agreement with several other in vivo studies (Carvalho et al., 2011; Khalili et al., 1997; Linke et al., 2004) and in vitro (Avila et al., 2011). One study found that feeding transition cows glycerol increased the proportion of propionate in the rumen, but only in the post partum period (DeFrain et al., 2004). Glycerol was expected to have influenced milk constituents, but milk fat was not significantly lower in the treatment cows, and there was only a tendency, on milk lactose in the LG treatment.

In the current study there was a decrease in the ratios of acetate to propionate and acetate+/butyrate to propionate, when feeding MG or HG diets, reflecting the variation in VFA concentrations. The decrease in ratios of acetate to propionate was supported by earlier studies (Carvalho et al., 2011; Wang et al., 2009a), but not by Mach et al. (2009).

The milk protein content was greater for the treatment cows than the control cows. An increased protein content in milk is associated with increased energy and crude protein intakes (Emery, 1978). The increased milk protein could be related to the use by rumen microorganisms of glycerol as an energy source for microbial protein synthesis. And indeed the increase in ruminal \(\text{NH}_3\)–N that was found with increasing glycerol added, and the increase in blood urea, supports this. However, these increases may have been caused by the slow-release non-protein nitrogen product used to balance the crude protein content in the treatment diets.

The increase in milk protein caused reductions in the fat/protein and also in the milk protein/lactose ratios in the glycerol treatment cows. The latter may also have been caused by reduced lactose content, as there was a tendency for a decrease in milk lactose in cows given the LG diet. The increase in blood urea concentrations with glycerol feeding confirms the findings of Khalili et al. (1997). Since blood urea and milk urea concentrations are well correlated (Roseler et al., 1990) milk urea could indicate nutritional status. In this study, blood urea was raised but milk urea was not affected. This lack of an effect on milk urea may be related to the fact that the experimental diets were formulated to be isonitrogenous, and milk urea is mainly influenced by dietary concentrations of crude protein and protein balance in the rumen (Nousiainen et al., 2004).

The lack of a glycerol effect on rumen \(\text{pH}\) is consistent with the previous studies of Khalili et al. (1997) and Goff and Horst (2001). Similar results were also reported when feeding glycerol to transition cows (Carvalho et al., 2011; DeFrain et al., 2004). A reduction in ruminal \(\text{pH}\) was expected when more easily metabolisable energy was introduced. This was not observed in the present trial. However, other studies found that glycerol supplementation decreased rumen \(\text{pH}\) (Kijora et al., 1998; Mach et al., 2009; Wang et al., 2009b). One reason for these seemingly contradictory findings could have been the high content of starch in the maize silage that was fed in these other studies, which is known to decrease the rumen \(\text{pH}\).

The type of forage used in the TMR may well affect the beneficience of glycerol addition. In the current study, grass-based silage was fed to cows, but several others have fed corn silage-based diets (Carvalho et al., 2011; Donkin et al., 2009). Corn silage contains higher amounts of starch, but lower concentrations of crude protein and NDF compared to grass silage (NRC, 2001). Also, the forage particle size is essential as this has been related to the chewing time (Beauchemin et al., 1994; Grant and Weidner, 1992), and reduced acid production in the rumen (Allen, 1997). Therefore, the effect of the forage component of the diet with glycerol feeding on feed intake and lactation performance generally remains unclear. Nevertheless, this study has demonstrated that the beneficial effects found from adding glycerol to corn silage-based diets are also found with a grass silage-based diet.

The \textit{in sacco} degradation of silage nutrients was not affected by treatment. This is new information regarding the glycerol-feeding effect on degradation values in cows fed a grass silage-based diet. This lack of an effect is supported by the other ruminal parameters that were unchanged by treatment: \(\text{pH}\) and total VFA concentration. Reduced fibre degradation (Ørskov and Fraser, 1975) and reduced ruminal microbial cellulolytic activity (Russell and Wilson, 1996) might have been expected in lower ruminal \(\text{pH}\) conditions. However, in the current study, the
rumen pH was over 6.0 and was unaffected by treatment. Wang et al. (2009a) reported improved in situ ruminal NDF degradation of corn stover as the main roughage in the diet, but this would appear not to be so for grass silage.

5. Conclusion

These experimental results indicate that even impure forms of glycerol at quite high levels are acceptable replacements for rapidly fermentable starch in the mixed diets of lactating dairy cows. The inclusion of crude glycerol as an energy source into TMR improved DMI, but did not affect either milk yields or milk composition, except milk protein content, which was higher. The reduced plasma NEFA concentration suggested that lipid mobilisation was reduced in the glycerol treatment cows. It is suggested that glycerol is a suitable partial replacement for a starch source in dry matter and milk production of dairy cows under project EU30002 carried out by the Bio-Competence Community’s Regional Development Fund in the framework of the Final frontier? J. Dairy Sci. 82, 2259–2273.

Conflict of interest statement

The authors of the manuscript entitled: “Effect of replacement of barley meal with crude glycerol on lactation performance of primiparous dairy cows fed a grass silage-based diet” declare that there is no conflict of interest in the subject matter, results presented or publication of the research described.

Acknowledgements

We are grateful to Mrs. Ülle Lätt and Mrs. Sirje Kuusk for technical assistance and to other colleagues for fruitful discussions. We also thank the staff of Eerika Experimental Farm for their kind cooperation. The research leading to these results was co-financed also by the European Community’s Regional Development Fund in the framework of the Competence Centre Programme of Enterprise Estonia under project EU30002 carried out by the Bio-Competence Centre of Healthy Dairy Products LLC (Tartu, Estonia).

References


Please cite this article as: Kass, M., et al., Effect of replacement of barley meal with crude glycerol on lactation performance of primiparous dairy cows fed a grass silage-based diet. Livestock Science (2012), http://dx.doi.org/10.1016/j.livsci.2012.09.007