

USE OF GLYCEROL IN DAIRY RATIONS

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Increased cost of common feedstuffs and increased availability of coproducts from plant-based biofuel manufacturing has enhanced interest in the use of these coproducts in rations for dairy cattle (Donkin and Doane, 2007). Glycerol (commonly marketed as crude glycerine with a glycerol content of approximately 80%) is a coproduct produced during biodiesel production from soybean oil and is becoming available as a feedstuff within the dairy industry. The purpose of this paper will be to review the metabolism of glycerol in the cow, to review recent research focused on feeding glycerol as a glucogenic supplement to transition cows, and to review use of glycerol in rations for lactating dairy cows.

GLYCEROL METABOLISM IN THE COW

Most early research that involved feeding or bolus-administration of glycerol to dairy cows was focused on the potential role of glycerol as a glucogenic precursor or treatment for ketosis (Johnson, 1953; Fisher et al., 1971; Fisher et al., 1973; Sauer et al., 1973). This was based on the premise that any absorbed glycerol would be converted readily to glucose in the liver, as glycerol is one of the potential glucogenic substrates in ruminants (Seal and Reynolds, 1993). More recent information suggests that net absorption of glycerol from the gastrointestinal tract of cows is quite small. Kristensen and Raun (2007) measured glycerol absorption and liver utilization of glycerol in cows administered 925 g/d of 85% glycerol once daily via the rumen cannula. Approximately 10% of the glycerol infused was recovered as glycerol in the portal vein, and nearly all of the glycerol absorbed was extracted by the liver where it would be potentially available for gluconeogenesis.

The low net absorption of glycerol does not necessarily preclude it from being an effective glucogenic precursor. Propylene glycol makes a contribution to overall glucogenic substrate supply either absorbed as propylene glycol or fermented to propionate in the rumen and subsequently absorbed (Nielsen and Ingvarsen, 2004). Although ruminal metabolism of glycerol has not been fully characterized, available information suggests that ruminal fermentation of glycerol differs from that of propylene glycol. Linke et al. (2004) reported that feeding or oral administration via drench or stomach tube of 1 kg of glycerine (80% glycerol) decreased molar percentages of acetate and increased molar percentages of propionate and butyrate at 4 h after feeding or oral administration (Table 1), although the increase in molar percentage of butyrate was much larger than that for propionate. Similarly, Kristensen and Raun (2007) determined that glycerol infusion decreased molar percentages of acetate and increased butyrate without affecting the molar percentage of propionate in rumen fluid. Trabue et al. (2007) compared ruminal fermentation characteristics of propylene glycol

and glycerol added as single substrates in vitro. They found that propylene glycol addition resulted in much larger increases in propionate concentration over time compared with glycerol, and that glycerol addition increased concentrations of butyrate, valerate, and caproate compared to the control or propylene glycol addition. Based upon this collective information, one would expect that glycerol administration via feeding or oral bolus administration would contribute to ruminal fermentation as an energy substrate, but likely would not make as large a contribution as propylene glycol to net glucogenic substrate supply.

Limited research also has focused on other aspects of ruminal availability of glycerol on ruminal fermentation. Roger et al. (1992) studied the effects of glycerol addition in vitro on growth, adhesion, and cellulolytic activity of two major cellulolytic bacterial species (*Ruminococcus flavefaciens* and *Fibrobacter succinogenes*). They determined that low concentrations (0.1 to 1% of volume) did not affect any of the aspects studied; however, addition of glycerol at 5% of volume had strong negative effects on growth and cellulolytic activity of these organisms. Given that ruminal liquid volume of lactating dairy cows typically ranges from 50 to 60 L, these results suggest that inclusion of glycerol at low inclusion rates (~250 g or less at one time) is unlikely to result in negative effects; however, greater amounts (~1.25 kg at one time) could result in some negative effects on ruminal cellulolytic activity.

Table 1. Ruminal fermentation characteristics at 4 h postadministration for cows administered 1 kg of glycerine (80% glycerol). From Linke et al. (2004).

VFA	Treatment				P value
	Control	Fed	Drench	Tube	
Acetate, mol %	53.3	44.9	44.6	43.0	0.05
Propionate, mol %	26.4	28.7	30.4	30.4	0.05
Butyrate, mol %	14.1	20.0	20.3	21.5	0.05

GLYCEROL AS A SUPPLEMENT FOR TRANSITION COWS

As mentioned above, much of the early research involving glycerol focused on its potential for use as a glucogenic supplement or ketosis treatment, with modestly favorable results. Consistent with these observations, Goff and Horst (2001) determined that administration of 1, 2 or 3 L of glycerol (80% glycerol) via esophageal pump increased plasma glucose by 16, 20 and 25%, respectively, over pretreatment values.

DeFrain et al. (2004) evaluated glycerol supplementation in the diet of transition cows. Glycerol (0, 0.43, or 0.86 kg/d) was topdressed on to the top one-third of a total mixed ration (TMR) and fed to transition cows (n=10 per treatment) from 14 d prepartum to 21 d postpartum. Glycerol treatments did not affect prepartum concentrations of glucose, insulin, NEFA or BHBA; however, postpartum concentrations of plasma glucose tended to be higher for the cows fed the control diet compared to those fed

glycerol (65.8 vs. 63.0 and 60.1 mg/dL). Glycerol administration had little effect of postpartum blood metabolites. Cows fed either 0.43 or 0.86 kg/d of glycerol had decreased prepartum DMI compared with the control cows, but postpartum DMI was not affected by treatment. Energy-corrected milk yield tended to be decreased in cows fed glycerol compared with the control.

We conducted a study several years ago focused on the potential to use glycerol either as a dietary supplement or short-term postcalving drench (Ogborn et al., 2004; Ogborn, 2006). We assigned 48 Holstein cows entering second or greater lactation to two prepartum treatments beginning at 21 d before expected calving and subsequently to four postpartum treatments after calving. Prepartum treatments consisted of a control or dietary addition of crude glycerine (80.6% glycerol) at 5% of diet DM. Postpartum treatments consisted of a control, dietary addition of glycerine (3.3% of diet DM), oral glycerine drench (500 ml; 625 g) once daily for the first 5 d postcalving, or a combination of diet addition and oral drench of glycerine. Postpartum dietary addition of glycerine continued through 21 d postcalving; thereafter, all cows were fed the same diet.

Cows fed glycerol during the prepartum period consumed on average 0.59 kg/d of glycerol (0.74 kg/d of crude glycerine). In contrast to the DeFrain et al. (2004) study, prepartum glycerol feeding increased prepartum DMI (14.8 vs. 13.2 kg/d); however, this increase in prepartum DMI did not translate into any effects on postpartum DMI or milk yield and composition. Furthermore, prepartum dietary glycerol did not affect plasma metabolites (glucose, NEFA, BHBA) and liver composition (triglycerides and glycogen) during either the prepartum or postpartum periods.

Cows fed glycerol during the postpartum period consumed on average 0.50 kg/d of glycerol (0.63 kg/d of crude glycerine). Postpartum performance data over the first 63 DIM for cows fed or drenched glycerol during the early postpartum period are presented in Table 2. Glycerol feeding tended to decrease postpartum DMI (~ 1 kg/d) and drenching glycerol had a pronounced negative effect on postpartum DMI (~1.5 kg/d) that was consistent across the dietary treatments. Feeding glycerol postpartum did not affect milk yield or composition (Table 2), BW and BCS change, or plasma metabolites and liver composition during the postpartum period. Drenching glycerol did not affect milk yield or major aspects of milk composition (Table 2), but did result in greater BW and BCS loss during early lactation. Overall concentrations of plasma metabolites and liver composition were not affected by drenching glycerol.

We also studied short-term responses of plasma metabolites on d 5 postcalving to glycerol drench, and results are presented in Table 3. Glycerol drench tended to increase plasma glucose and decrease plasma NEFA concentrations during the first 6 hours postdrench. These results suggest that glycerol is glucogenic; however, metabolite responses are weaker than those typically expected when propylene glycol is drenched (Pickett et al., 2003; Neilsen and Ingvarsen, 2004).

Table 2. Postpartum DMI and milk yield and composition for the first 63 DIM as affected by incorporation of glycerol¹ into the postpartum TMR and short-term oral administration² of glycerol beginning at parturition (Ogborn et al., 2004).

Item	Treatment				SEM	P-value		
	Control TMR		Glycerol TMR			TMR	Drench	TMR x drench
	Water drench	Glycerol drench	Water drench	Glycerol drench				
Number per treatment	11	12	12	11	---	---	---	---
DMI, kg	22.5	21.2	21.9	19.9	0.5	0.08	0.001	0.48
Milk, kg/d	42.8	42.7	41.2	41.7	2.0	0.53	0.90	0.89
3.5% FCM, kg/d	42.3	42.3	40.7	41.1	2.0	0.50	0.91	0.90
Fat %	3.49	3.5	3.49	3.5	0.09	0.99	0.85	1.00
Fat, kg/d	1.46	1.47	1.41	1.42	0.07	0.48	0.93	0.97
True protein, %	2.9	2.85	2.98	2.79	0.08	0.91	0.15	0.42
True protein, kg/d	1.2	1.19	1.19	1.13	0.07	0.61	0.64	0.75
Lactose, %	4.73	4.70	4.73	4.56	0.05	0.18	0.04	0.16
Lactose, kg/d	2.01	2.00	1.95	1.91	0.09	0.36	0.79	0.87
MUN,mg/dl	13.8	13.2	13.6	13.3	0.5	0.85	0.36	0.76
SCC, x 1000	201	267	276	258	89	0.71	0.79	0.63

¹Postpartum diet included glycerol at a rate of 3.3% of DM.

²500 ml of crude glycerine was administered for 5 consecutive days following parturition.

Recently, Chung et al. (2007) topdressed 250 g/d of a blended glycerin source (65% glycerol) from calving through 21 d postpartum. Postpartum DMI and metabolic responses during the first 21 d postcalving were not affected by treatment. Milk yield and composition was largely not affected by treatment, although there was a trend for increased milk yield of cows fed glycerin during the last week studied (wk 6 of lactation).

Collectively, results suggest that there are not specific advantages as a glucogenic precursor of supplementing glycerol to transition dairy cows. Part of the reason for this likely coincides with the overall lack of positive responses of glucogenic supplementation either through diet or routine bolus administration on aspects of metabolism and performance of transition cows (Overton and Waldron, 2004). A second reason for this likely relates to the differences in metabolism (ruminal and

absorptive) of glycerol and propylene glycol as discussed in the first section of this paper.

Table 3. Effects of oral glycerol drench on short-term responses of plasma metabolites and insulin (Ogborn, 2006).

Item	Drench		SE	P-value
	Glycerol	Water		
Number per treatment	23	23	---	---
Glucose, mg/dl	48.9	46.7	1.5	0.11
NEFA, uEq/L	206	313	25	0.06
BHBA, mg/dl	10.7	10.3	0.9	0.41
Insulin, ng/ml	0.11	0.12	0.01	0.098

Blood samples were obtained prior to drench and at 1, 2, 4, and 6 hours post drench.

GLYCEROL AS A DIETARY INGREDIENT FOR LACTATING COWS

Although there appear to be few, if any, specific advantages to supplementing glycerol as a potentially glucogenic substrate for transition cows, the ready fermentation of glycerol in the rumen suggests that it could make a contribution as a rapidly fermentable energy source for the rumen microbes. This would result in direct contributions to energy and metabolizable protein supply to the cow.

Donkin et al. (2007) evaluated glycerol as an ingredient in dairy rations by replacing corn grain with a combination of glycerol and corn gluten feed. They fed Holstein cows (n = 60) diets containing 0, 5, 10, and 15% glycerol on a DM basis. Glycerol plus corn gluten feed (6.25:1) ratio replaced ground shelled corn in the ration. One potentially important consideration from this experiment is that kosher-grade glycerol (99.5%) was used rather than crude glycerine. All other dietary ingredients remained in the diet at the same percentage of diet DM across the four experimental diets. Results from this experiment are presented in Table 4. Feeding glycerol up to 15% of diet DM did not affect overall DMI or milk yield, although the authors reported that cows fed the 15% glycerol diet had decreased DMI for the first 7 d of the experiment. Feeding glycerol did not affect milk fat or protein content, but decreased milk urea N content, suggesting that the glycerol was more fermentable in the rumen than ground shelled corn. Cows fed glycerol had larger increases in BW during the experiment. Although more research is needed to determine the energy value of glycerol and appropriate rates for use in models such as CNCPS and CPM Dairy, this existing information suggests that the energy value and ruminal fermentability significantly exceeds that of ground shelled corn.

Table 4. Effects of feeding increasing amounts of glycerol on performance of lactating dairy cows (Donkin et al., 2007; Donkin and Doane, 2007).

Item	Glycerol, % of diet DM				SEM	P value
	0	5	10	15		
DMI, kg/d	24.0	24.5	24.6	24.1	0.5	0.82
Milk, kg/d	37.0	36.9	37.3	36.4	0.6	0.71
Milk fat, %	3.70	3.52	3.58	3.58	0.11	0.69
Milk protein, %	2.79	2.84	2.86	2.89	0.06	0.62
MUN, mg/dl	12.5 ^a	10.9 ^b	10.7 ^b	10.2 ^b	0.4	<0.05
BW change, kg	31.5 ^a	40.6 ^{ab}	49.6 ^b	51.5 ^b	4.6	<0.05

^{ab}Means within a row with different superscripts differ, P < 0.05.

SUMMARY AND CONCLUSIONS

Glycerol is a sugar alcohol that is readily fermented in the rumen and is absorbed at relatively low proportions from the gastrointestinal tract of dairy cattle. Available information suggests that glycerol fermentation in the rumen favors butyrate production, although some increase in propionate production may occur. Although older research suggested that glycerol can be an effective glucogenic precursor for transition dairy cows and for treatment of ketosis, more recently conducted research suggests that glycerol is a much weaker glucogenic precursor than propylene glycol and does not appear to provide specific benefits when supplemented to diets fed to transition cows. Recent work evaluating glycerol as a dietary ingredient for lactating cows suggests that glycerol can be fed as a replacement for ground shelled corn at rates up to 15% of dietary DM without apparent negative effects on performance. Associated decreases in milk urea N and increased BW of cows fed increasing amounts of glycerol suggests significantly higher ruminal fermentability and energy content than ground shelled corn.

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