A Field Study of Dietary Interactions with Monensin on Milk Fat Percentage in Lactating Dairy Cattle

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ABSTRACT

Ninety-one Ontario Holstein dairy herds were surveyed about their lactating cow ration and use of a premix containing monensin to identify possible dietary interactions with monensin on milk fat suppression. All herds were enrolled in Ontario Dairy Herd Improvement (DHI) milk recording, and results from four DHI tests were used. Herd mean fat tests were calculated only for cows between 100 and 200 d in milk to avoid potential confounding due to stage of lactation. Wet forage and total mixed ration (TMR) samples from all herds were evaluated for particle size using the Penn State Particle Size Separator. Of the herds using monensin ($n = 58$), the dose (per kg of dry matter) ranged from 9 to 14 mg/kg in TMR-fed herds and from approximately 9 to 23 mg/kg in herds in which concentrates were fed separately from forages (component-fed). Of the samples submitted for particle size evaluation, 15% of the haylage ($n = 80$), 14% of the corn silage ($n = 79$), and 42% of the TMR ($n = 58$) samples were classified as having low fiber. There was a significant negative univariable association between monensin and mean milk fat percentage. Monensin significantly reduced milk fat percentage in TMR-fed but not component-fed herds. Fiber length significantly interacted with monensin in TMR-fed herds: Herds that had low fiber in their TMR ($\leq 6.0\%$ in the top screen) were susceptible to milk fat decrease by monensin, whereas herds that had adequate fiber ($> 6.0\%$) were not. Monensin also significantly reduced milk fat percentage in herds receiving diets low in nonstructural carbohydrate ($< 40.2\%$) but not in those receiving diets high in NSC ($\geq 40.2\%$). The results of this study suggest that there are significant interactions between monensin and certain dietary factors on milk fat suppression in Holstein dairy herds.

(**Key words:** monensin, milk fat, diet, lactating dairy cow)

INTRODUCTION

The administration of monensin to lactating dairy cattle has a number of potential advantages, including improved energy metabolism, increased milk production, and reduced incidence of subclinical ketosis and periparturient diseases such as clinical ketosis and abomasal displacement (Duffield and Bagg, 2000).

A number of studies have shown that monensin can also result in the depression of milk fat (Symanowski et al., 1999; Phipps et al., 2000). However, this finding does not appear to be consistent because other investigations have failed to demonstrate milk fat depression following administration of monensin (Lean et al., 1994; Duffield et al., 1999).

A variety of factors have been demonstrated or hypothesized to account for observed variations in this fat depressing effect. The effect appears to be dependent on the dose of monensin administered (Symanowski et al., 1999) and possibly the method of delivery and stage of lactation (Duffield and Bagg, 2000).

Variability in the fat-depressing effect of monensin may also result from dietary interactions (Duffield and Bagg, 2000). Suppression of milk fat production by monensin is thought to be mediated in part through a shift in the rumen microflora in favor of increased production of propionic acid and decreased production of acetic acid—a primary fat precursor. The mechanism of lowered milk fat by monensin may also be mediated through interference with biohydrogenation of long-chain fatty acids within the rumen, possibly through its effects on rumen bacteria. Metabolism of volatile and long-chain fatty acids within the rumen is also influenced by dietary changes, particularly changes in intake and characteristics of dietary fiber (Bauman and Griinari, 2000).

The objective of this study was to identify possible interactions in milk fat suppression between dietary factors and inclusion of monensin in the diet of lactating dairy cattle.

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MATERIALS AND METHODS

Dairy herds ($n = 199$) in southwestern and eastern Ontario were nominated for entry into this study by veterinarians in the province who had a special interest in dairy nutrition. The mean herd size was 57 milking cows, with a range from 26 to 212 milking cows. All herds were enrolled in Ontario DHI milk recording. Data were initially provided by 111 herds. Those with average milk fat tests over 4.0% were excluded (based on criteria developed a priori) because they are uncommon in Ontario and could have unduly influenced the results of the data analysis. The majority of the herds with higher fat tests contained cows of breeds other than Holsteins. Twenty herds were excluded on this basis, leaving a final enrollment of 91 Holstein-only herds. The average fat test for the 20 excluded herds was 4.51%, with a range of 4.04 to 5.16%.

Participating veterinarians collected one wet forage and one TMR sample once from each participating farm between March and June, 1999. Samples from each herd were submitted to the Ontario Veterinary College for evaluation of particle size using a Penn State particle size separator according to the technique described by Lammers et al. (1996). The separator consisted of two screens, with varying hole sizes, and a bottom pan. The first screen collected forage particles greater than 19 mm in length. Forage particles that were between 8 and 19 mm were collected on the second screen, and particles smaller than 8 mm fell to the bottom pan. Based on the Penn State particle size separator recommendations (Heinrichs, 1996), forage samples were classified as having low or adequate levels of particles on each screen. These data were used as an indicator of physically effective fiber.

At the time of sample collection, participating veterinarians conducted a producer survey to collect information on lactating cow rations and the use of a premix containing monensin (Rumensin Premix; Elanco Animal Health, Division Eli Lilly Canada Inc., Guelph, ON) in lactating cow diets. The compositions of lactating cow rations were estimated for each herd, including NDF, ADF, NSC, CP, soluble protein, kilograms of forage, and kilograms of concentrate. In most cases these data were derived directly from the questionnaire responses. In some cases this information was supplemented by data supplied by the veterinarian from their respective ration balancing programs, with inputted values from feed analysis (forages) and from book values (concentrates and supplements). Budgetary and resource restrictions prohibited multiple on-farm sampling of the forages and TMR or multiple laboratory analyses of feedstuffs during the study period. Thus, because rations were likely to change dur-

ing the 4-mo period of sampling and the lack of precise feed analysis, this study should be considered a preliminary investigation of dietary interactions with monensin on milk fat percentage.

Milk production data were obtained for each herd from the computerized DHI data storage system. Herd-level data were created for production variables such as mean percent milk fat, mean milk yield, mean percent milk protein, and mean DIM by averaging individual cow results for the four DHI tests that occurred closest to the March-to-June time frame of the feed submission for each herd. In Ontario, DHI tests occur every 30 to 40 d. In most cases, the four DHI tests closest to March to June would have occurred in March, April, May, and June. However, because of the varying range in intervals of sampling, some herds would have had either a February test or a July test included. To avoid the potential confounding effects of stage of lactation, the herd mean fat test was calculated using data only for those cows that were between 100 and 200 DIM on a given DHI test date.

Analysis of variance was used to systematically study the relationship between herd-level percentage milk fat and 1) herd-level use of monensin, 2) herd-level ration variables, and 3) the interaction between herd-level use of monensin and ration variables. This was accomplished by constructing a hierarchy of models consisting of 1) the univariable association between use of monensin and milk fat percentage, 2) a series of bivariable models consisting of monensin accompanied by each of the feed-type variables in turn, 3) multivariable models based on the results of 2, 4) a series of bivariable models consisting of monensin accompanied by each of the feed-composition variables in turn, and 5) multivariable models based on the results of 3 and 4. Feed composition in this context refers to results of chemical analysis of feedstuffs, whereas feed type refers to the general nature of the feed administered (e.g., TMR, hay, silage) and measures of physically effective fiber. Statistical analyses were conducted using analysis of variance within Proc GLM in the SAS system (SAS Institute, 1997).

RESULTS

In total, 33 dairy herds did not include monensin in the lactating cow diet. For the 58 herds that did include monensin, the dose ranged from 9 to 14 mg/kg in TMR herds, and from 200 to 500 mg/cow per day as a top-dress (approximately 9 to 23 mg/kg) in component-fed herds.

Of the 91 herds used in this study, 80 were fed haylage, 79 were fed corn silage, and 58 were fed a TMR. A summary of available herd and ration information

Table 1. Herd and ration descriptions for 91 participating herds in a study of the effect of dietary interactions with monensin premix on milk fat percentage in lactating Holstein dairy cows.

Variable	Mean	Minimum	Maximum
Herd size	57	26	212
Number of midlactation cows	16	5	67
Herds feeding haylage (%)	80 (88)	NA	NA
Herds feeding corn silage (%)	79 (87)	NA	NA
Herds feeding hay (%)	67 (74)	NA	NA
Forage:concentrate ratio	49	40	62
Herds feeding TMR (%)	58 (64)	NA	NA
CP (%)	17.6	15.6	20.3
Soluble protein (% of CP)	32.6	19.4	59.6
ADF (%)	18.4	15.2	27.2
NDF (%)	31.7	25	46
NSC (%)	40.2	33.8	47
Lactation number	2.4	1.6	3.7
Milk yield (kg)	33.8	22.2	46.2
Milk fat percentage	3.5	3.1	4.0
Milk protein percentage	3.2	3.0	3.6

is depicted in Table 1. The percentages of herds that had low particle sizes for haylage, corn silage, and TMR, based on the Penn State separator guidelines are shown in Table 2. Low particle size was most common in TMR diets, regardless of whether forages comprising the TMR were of normal particle size.

There was a significant ($P = 0.003$) negative univariable association between feeding monensin and mean milk fat percentage. The relationship between monensin dose and mean milk fat percentage is shown in Table 3. Based on this simple association, use of monensin explained 12.5% of the herd variation in milk fat percentage.

In a series of bivariable models containing monensin and each of the feed-type variables in turn (with the exception of measures of effective fiber), both TMR (i.e., TMR vs. component feeding) and hay were significantly ($P < 0.05$) associated with decreased milk fat percentage. In addition, there was a significant ($P < 0.05$) interaction between TMR and monensin in a

three-variable model combining TMR, monensin, and hay. Thus, the analysis was stratified by feeding method. Monensin had a significant ($P < 0.05$) effect on reducing milk fat percentage in TMR-fed herds but not in herds in which grain was fed separately from forage (component-fed herds). However, there was no interaction between hay and monensin in either of those models. Least squares means of milk fat percentages associated with the presence or absence of monensin in feed, stratified by TMR and component-fed herds, and controlling for the effect of hay in the diet are shown in Table 4. Milk fat percentage in cows within TMR-fed herds not receiving monensin was 3.61% compared with 3.39% in cows within TMR herds receiving monensin in the diet ($P = 0.002$). This contrasts with milk fat percentages of 3.62% for cows not receiving monensin and 3.58% for cows receiving monensin, within component-fed herds ($P = 0.58$).

Because of the interaction between use of monensin and TMR, the interaction between measures of effective fiber and monensin was evaluated after stratifying the data on TMR. No variables that were measures of effective fiber interacted significantly with monensin in the component-fed (i.e., non-TMR) herds. Over 90% of those herds fed long-stem hay.

In TMR herds, there was a significant interaction between TMR fiber length and monensin after adjusting for hay feeding. In TMR herds that had low TMR fiber ($\leq 6\%$ on the top screen of the Penn State particle separator), use of monensin resulted in a significant ($P < 0.05$) decrease in milk fat percentage, whereas in normal TMR fiber herds ($> 6\%$ on top screen) the effect of monensin on decreasing milk fat percentage tended to be lower, but this was not statistically significant ($P = 0.06$; Table 5). Within the low fiber TMR herds, milk fat percentage was 3.68% in diets without monensin versus 3.36% in diets containing monensin. For herds with normal fiber in the TMR, milk fat percentage was 3.60% in cows receiving

Table 2. Number (n) and percentage of herds with low particle size in haylage, corn silage, or TMR based on Penn State Particle Size Separator recommendations.¹

	Top screen n (%)	Middle screen n (%)	Both top and middle screens n (%)	Bottom pan n (%)
Haylage	12 (15.0)	11 (13.7)	2 (2.5)	22 (27.5)
Corn silage	11 (13.9)	5 (6.3)	2 (2.4)	9 (11.4)
TMR				
All samples	24 (41.4)	21 (36.2)	19 (15.5)	23 (39.6)
Samples with normal forages ²	13 (41.9)	8 (25.8)	3 (9.6)	9 (29.0)

¹Percentages are based on lower Penn State guidelines for top and middle screens and upper guidelines for bottom pan.

²Herds with normal forage particle size, but low TMR particle size (31 herds).

Table 3. Mean milk fat percentage for varying doses of monensin.

Monensin ¹ mg/kg	Mean milk fat percentage
0	3.62
>0 to 13.6	3.53
>13.6	3.44

¹Effect of monensin was statistically significant ($P = 0.003$) using an analysis of variance model.

diets without monensin compared with 3.44% in cows receiving monensin in their diets. In addition, the magnitude of the decrease in milk fat with inclusion of monensin in low fiber TMR herds (−0.32 percentage units) was twice the response of inclusion of monensin in normal-fiber TMR herds (−0.16 percentage units). In these models, feeding hay tended to be associated with lower milk fat percentage ($P = 0.09$) in low-fiber TMR herds but was not significantly associated with milk fat percentage in normal-fiber TMR herds ($P = 0.20$). Hay feeding did not interact with monensin on milk fat percentage in TMR diets. Low fiber on the top screen of the particle separator was the only measure of effective fiber that interacted with monensin. The average feeding frequency for TMR herds was twice per day and varied from once to four times per day. Feeding frequency was not associated with milk fat percentage.

Finally, in a series of bivariable models containing monensin and each of the feed composition variables in turn, there was an interaction with monensin use only for NSC. Results of the final model containing monensin, hay, TMR, and NSC and the two-way interactions between NSC and each of the other three variables are shown in Table 6. In high NSC herds ($\geq 40.2\%$ NSC), there was no significant effect of monensin on milk fat percentage in this model. However, for low

Table 4. Least squares means of milk fat percentages from an analysis of variance model consisting of monensin, TMR, and hay¹ in a study of the effect of dietary interactions with monensin premix on milk fat percentage in lactating Holstein dairy cows stratified by herd feeding type (component² or TMR).

	Mean milk fat percentage	<i>P</i> Value for monensin effect
TMR-fed herds		
No monensin	3.61	0.002
Monensin	3.39	
Component-fed herds		
No monensin	3.62	0.58
Monensin	3.58	

¹Feeding of hay in diet included as a covariate but did not interact with monensin.

²Component feeding involves feeding forages separate from concentrates.

Table 5. Least squares means of milk fat percentages in TMR-fed herds from an analysis of variance model consisting of monensin, TMR fiber¹ and hay. Analysis was stratified by low vs. normal fiber.

	Mean milk fat percentage	
	Low-fiber herds ²	Normal-fiber herds ³
Monensin-fed		
No	3.68	3.60
Yes	3.36	3.44
<i>P</i> value ⁴	0.0004	0.06
Hay-fed		
No	3.59	3.57
Yes	3.45	3.47
<i>P</i> value ⁵	0.09	0.20

¹Based on the lower recommended limit of the top screen of the Penn State Particle Separator.

² $\leq 6\%$ on top screen of Penn State Particle Separator.

³ $> 6\%$ on top screen of Penn State Particle Separator.

⁴*P*-value for monensin effect.

⁵*P*-value for hay effect. Hay included as a covariate but did not interact with monensin.

NSC herds ($< 40.2\%$ NSC), feeding monensin significantly ($P = 0.0001$) reduced milk fat percentage.

DISCUSSION

The results of this study are consistent with previous investigations that have demonstrated a dose-dependent suppression of milk fat production by monensin (Symanowski et al., 1999; Phipps et al., 2000) in Holstein cows. Further, our results show that this effect is dependent on diet. Suppression of milk fat percentage by monensin occurred in herds fed a TMR but not

Table 6. Least squares means of milk fat percentages from an analysis of variance model consisting of monensin, NSC, TMR, and hay.

	Mean milk fat percentage	
	Low NSC herds ¹	High NSC herds ²
Monensin-fed		
No	3.77	3.60
Yes	3.42	3.61
<i>P</i> value ³	0.0001	0.92
Hay-fed		
No	3.60	3.71
Yes	3.59	3.50
<i>P</i> value ⁴	0.96	0.01
TMR-fed		
No	3.67	3.68
Yes	3.52	3.53
<i>P</i> value ⁵	0.05	0.03

¹ $< 40.2\%$ NSC.

² $\geq 40.2\%$ NSC.

³*P*-value for monensin effect.

⁴*P*-value for hay effect.

⁵*P*-value for TMR effect.

in component-fed herds. Furthermore, among TMR herds, a significant suppression of milk fat by monensin occurred only in those fed a low-fiber ration, as determined by the Penn State particle separator. However, there was a tendency for reduced milk fat with monensin in normal-fiber TMR herds, but the magnitude of the response was considerably less. Finally, milk fat suppression by monensin occurred in herds fed low NSC (<40.2%) but not in those fed high NSC (>40.2%).

A number of factors may explain these observed interactions between administration of monensin and diet. In TMR, the entire ration is dosed with monensin, whereas with component feeding, administration of monensin is periodic, corresponding to feeding of concentrates. These two methods of monensin delivery may have different effects on the rumen microflora. Furthermore, TMR is susceptible to over mixing, which might reduce effective fiber. Component-fed diets are more likely to include long-stem hay as a major ration component that should provide adequate levels of effective fiber. There is evidence that there could have been overmixing in the TMR herds, considering that over 40% of the low fiber TMR herds had normal-fiber forages going into the TMR mix. It is also interesting to note that hay fed in a TMR diet was associated with a lower milk fat percentage. There are several explanations for this. Herds that chronically have low milk fat may feed hay as an attempt to increase milk fat percentage. Alternatively, cows in these herds may sort their TMR and not eat the hay. In any case, there was no interaction observed between hay feeding and monensin in herds using TMR.

The propensity of monensin to suppress milk fat in TMR herds fed a low fiber ration, but not a high fiber ration might be explained as follows. Diets high in fiber stimulate cud chewing, resulting in increased production and ingestion of salivary bicarbonate. The resulting increase in rumen pH supports the growth of bacteria responsible for biohydrogenation of long-chain fatty acids. This results in a decrease in production of trans fatty acids and consequently an increase in milk fat percentage (Bauman and Griinari, 2000).

The observed interaction between NSC and monensin is more difficult to explain. It may have been the result of unrecognized confounding variables or interactions with factors (for example, hay feeding or dietary fiber) that could not be identified, perhaps as a result of the relatively small sample size of this investigation. Elevated levels of dietary unsaturated vegetable oils are known to promote a decrease in milk fat percentage (Bauman and Griinari, 2000). However, levels of these oils could not be determined in this investigation.

It is worth noting that these associations among diet, monensin, and milk fat were found despite the limitations of the data. Only one sample of feed was taken to evaluate particle size. Although the lactating cow rations are more stable at this time of year than in the fall, there is a good chance the rations on many dairies could have changed over the 4-mo observation period. The focus of the original project was on forages. However, it would have been useful to have more detailed ration information on such things as types and form of grain fed, nature, and concentration of unsaturated oils, and presence of sodium bicarbonate or other buffers in the diet. Information on the use of other by-product feeds that might be fed in Ontario, such as wet brewers grain, beet pulp, corn gluten meal, or wet corn distillers would have also been helpful. In addition, the ration data would have been much more complete if funds were available to analyze all feeds used in this study. However, budgetary restrictions allowed only for collection of much of these data through survey. The fact that significant associations were found among dietary factors, milk fat, and monensin in this field study suggests that a more controlled approach to investigating these interactions is warranted.

Because of the nature of the study design, interpretation of results of this study is limited to Holstein herds administering monensin at or below 14 mg/kg of feed and having milk fat averages below 4.0%, and to cows between 100 and 200 DIM.

This study thus supports the results of previous investigations that demonstrate a dose-dependent effect of monensin in suppressing milk fat percentage. However, it also provides evidence that this effect is dependent on other dietary characteristics. Specifically, our results suggest that the effect is most profound in TMR-fed herds, particularly those having low dietary fiber. Ensuring adequate dietary fiber might be one means of minimizing the milk fat suppression mediated by monensin while maintaining the beneficial effects of feeding monensin.

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