Effect of salinomycin or monensin on performance and feeding behavior of cattle fed wheat- or barley-based diets

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Gibb, D. J., Moustafa, S. M. S., Wiedmeier, R. D. and McAllister, T. A. 2001. **Effect of salinomycin or monensin on performance and feeding behavior of cattle fed wheat- or barley-based diets.** Can. J. Anim. Sci. **81**: 253–261. Feeding behavior and growth performance of cattle fed diets containing monensin or salinomycin were assessed in two trials. In trial 1, 36 Hereford × Angus steers (267.7 ± 4.3 kg) were individually fed (n = 12) wheat-based transition and finishing diets containing no ionophore (control, C), 26 mg monensin (M) or 13 mg salinomycin (S) per kg of dietary dry matter (DM). Cattle fed M consumed less than those fed C or S, and their intake was more stable during the transition to the finishing diet. Overall, steers fed M exhibited lower dry matter intake (DMI) (8.0 vs. 9.2 and 9.2 kg d^{-1}) and rates of gain (1.21 vs. 1.62 and 1.56 kg d^{-1}) than those fed C or S. Cattle fed S required fewer days (93.3) to reach the targeted finish (5 mm backfat) than those fed C or M (105.8 d). Monensin reduced slaughter weight and carcass weights, relative to controls (414.3 vs. 480.5 kg, and 231.2 vs. 245.8 kg, respectively). In trial 2, M (25 ppm) or S (13 ppm) were included in barley-based diets for 72 yearling steers placed in four pens equipped with radio frequency identification systems. Individual bunk attendance patterns were monitored during transition to a finishing diet, during 11 d of limit feeding the finishing diet twice daily (LF2/d), 13 d of limit feeding once daily (LF1/d), and 21 d of feeding once daily to ad libitum intake (AL1/d). Ionophore type did not affect (P > 0.10) DMI, rate of gain or efficiency of feed conversion. Bunk visits were more frequent (P < 0.05) with M than with S during transition and limit-feeding. With M, total daily attendance (TDA) at the bunk during LF1/d and AL1/d, was higher (P < 0.05) than with S, and variability in TDA was lower (P < 0.05) during LF1/d. In the present study, there was no performance advantage in providing S or M in wheat-based finishing diets. Monensin moderated feeding intensity, but this effect may have been strong enough to suppress intake and even reduce gain on the wheat-based diet.

Key words: Ionophores, feeding behavior, feedlot cattle, salinomycin, monensin

Gibb, D. J., Moustafa, S. M. S., Wiedmeier, R. D. et McAllister, T. A. 2001. **Incidence de la salinomycine ou du monensin sur le rendement et les habitudes alimentaires des bovins nourris d'une ration à base de blé ou d'orge**. Can. J. Anim. Sci. **81**: 253–261. Les auteurs ont étudié les habitudes alimentaires et le taux de croissance de bovins à qui on avait servi une ration r enfermant du monensin ou de la salinomycine dans le cadre de deux essais. Lors du premier essai, 36 bouvillons Hereford × Angus (267 ± 4,3 kg) ont chacun reçu (n = 12) une ration de transition et de finition à base de blé qui ne contenait pas d'ionophores (groupe témoin, T) ou contenait 26 mg de monensin (M) ou 13 mg de salinomycine (S) par kg de matière sèche. Les animaux du groupe M ont moins consommé de nourriture que ceux des groupes T et S, et l'indice de consommation était plus stable avec les rations de transition et de finition. Dans l'ensemble, les bovins du groupe M ont enregistré un taux de consommation de matière sèche (CMS) (8,0 kg contre 9,2 kg et 9,2 kg par jour) et un gain de poids (1,21 kg contre 1,62 kg et 1,56 kg par jour) plus faibles que ceux des groupes T ou S. Les bovins du groupe S ont pris moins de temps (93,3 jours) pour atteindre le poids de finition souhaité (5 mm de gras dorsal) que les animaux des deux autres groupes (105,8 jours). Le monensin diminue le poids à l'abattage et le poids de la carcasse comparativement aux animaux du groupe témoin (414,3 kg contre 480,5 kg, et 231,2 kg contre 245,8 kg, respectivement). Lors du deuxième essai, on a ajouté du monensin (25 ppm) ou de la salinomycine (13 ppm) à la ration à base d'orge de 72 bouvillons d'un an répartis dans quatre enclos dotés d'un système d'identification radio. On a surveillé les habitudes de chaque animal pendant la période où les mangeoires étaient remplies de la ration de transition puis de finition selon trois régimes : quantité restreinte de la ration de finition servie deux fois par jour pendant 11 jours (RF2/j), quantité restreinte de la ration de finition servie une fois par jour pendant 13 jours (RF1/j) et ration servie à satiété une fois par jour pendant 21 jours (AS1/j). Le type d'ionophore n'affecte pas le CMS (P > 0,10), le gain de poids ni la valorisation des aliments. Les animaux se rendent moins souvent à la mangeoire (P < 0,05) quand les aliments renferment du monensin plutôt que de la salinomycine durant la période de transition et quand il y a restriction de la quantité d'aliments. Le nombre total de visites quotidiennes (NTV) à la mangeoire lors de la RF1/j et de la AS1/j est plus élevé (P < 0,05) avec le monensin que la salinomycine et la NTV varie moins (P < 0,05) pendant la RF1/j. Dans la présente étude, l'addition de salinomycine ou de monensin à la ration de finition à base de blé n'a amélioré le rendement en aucune façon. Le monensin modère la fréquence de l'alimentation, effet qui pourrait avoir été assez puissant pour stopper l'ingestion voire réduire le gain de poids venant de la ration à base de blé.

Mots clés: Ionophores, habitudes alimentaires, bovins d'engrais, salinomycine, monensin

Abbreviations: **C**, basal diet containing no ionophore (control); **DM**, dry matter; **DMI**, dry matter intake; **M**, basal diet containing 26 ppm (Trial 1) or 25 ppm (Trial 2) monensin; **S**, basal diet containing 13 ppm salinomycin; **TDA**, total daily attendance

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Ionophores increase production of propionate and decrease production of methane (Schelling 1984) in the rumen, thereby improving energy utilization by ruminants. Monensin is also known to reduce eating rates (Chirase et al. 1992), to decrease variation in intake (Stock et al. 1995b), and to moderate fluctuations of ruminal pH (Nagaraja et al. 1982) in feedlot cattle. Assuming that rapid eating and fluctuating intake contribute to increased acidosis, these modifications in eating behavior may also contribute to ionophore efficacy. In addition, moderate intake would promote a more stable ruminal fermentation. This may in part account for the reductions in bloat that have been attributed to ionophores (Nagaraja 1994). Ionophore-induced changes in feeding behavior may be influenced by the feeding strategies employed (Fanning et al. 1999). For example, limit-feeding can increase eating rates (Prawl et al. 1997) and reduce ruminal pH (Fanning et al. 1999), which could negate or potentiate the ionophore effect. This study was undertaken to investigate the effects of monensin and salinomycin on eating behavior of feedlot cattle through transition and finishing, and to determine if feeding strategies (e.g., frequency or level of feeding) counteract or enhance potential positive effects of these ionophores on feeding behavior.

MATERIALS AND METHODS

Trial 1

Thirty-six Hereford × Angus steers (267.7 × 4.3 kg) were weighed on 2 consecutive days, blocked by weight, and randomly assigned to three dietary treatments: no ionophore (C), monensin (M) or salinomycin (S) included in wheat-based transition and finishing diets (Table 1). The steers were housed and fed in individual pens (n = 12) at the Lethbridge Research Centre, weighed at 14-d intervals, and were given free access to feed and water throughout the trial, which was conducted from March through June. Diets (Table 1) consisted of dry-rolled wheat, barley silage, and one of three wheat-based supplements provided at 10% of ad libitum intake (as-fed). The supplements supplied minerals and vitamins to meet National Research Council (NRC 1984) recommendations, and no ionophore (for C diets) or sufficient monensin or salinomycin to yield 26 ppm or 13 ppm ionophore in the M and S treatments, respectively (DM basis). The proportion of wheat in the diets was increased incrementally from 36.3% in the initial diet to 86.5% in the finishing diet. Each of the seven diets was fed for 4 d in the 28-d transition period, then the finishing diet (97.4% concentrate) was fed until steers attained a targeted finish of 5 mm backfat thickness between the 12th and 13th ribs, as determined by ultrasonography. Feed deliveries and refusals were recorded daily for 28 d and weekly thereafter. For each steer, feed intake was calculated as feed delivered less orts, and variation in intake of each diet was calculated as the average daily deviation from the 4-d mean intake of that diet (Stock et al. 1995a).

At slaughter, ribeye area and marbling were determined once the longissimus muscle was exposed by incising the carcasses between the 12th and 13th ribs. Back fat, carcass weights and carcass grades were also recorded.

Trial 2

Seventy-two exotic cross yearling steers (412 ± 23.6 kg) were blocked by weight, tagged with electronic ID ear tags (Allflex USA, Dallas-Ft. Worth, TX) and randomly assigned to four outdoor pens at the Lethbridge Research Centre each equipped with a GrowSafe antenna in the feedbunk. The GrowSafe system allows continuous monitoring

Table 1. Composition of diets fed to 36 crossbred steers in Trial 1

	Percentage of concentrate in diet[z]						
	51.8	61.9	70.8	78.6	85.5	91.7	97.4
Ingredients (%, DM basis)							
Wheat, dry-rolled	36.3	47.4	57.2	65.8	73.5	80.3	86.5
Barley silage	48.2	38.1	29.2	21.4	14.5	8.0	2.6
Supplement[y]	15.5	14.5	13.6	12.8	12.1	11.4	10.9
Chemical analyses (%)							
Dry matter	60.7	14.2	69.3	73.6	77.9	82.2	86.5
Crude protein	13.9	14.2	14.6	14.9	15.1	15.4	15.6
Acid detergent fibre	17.7	15.4	14.6	12.7	11.1	9.6	8.3
Magnesium	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Potassium	1.41	1.28	1.15	1.02	0.89	0.75	0.63
Calcium	0.84	0.77	0.69	0.62	0.54	0.46	0.39
Phosphorus	0.43	0.44	0.46	0.47	0.48	0.50	0.51
NE_m (Mcal kg^{-1})[x]	1.63	1.75	1.82	1.89	1.94	1.99	2.03
NE_g (Mcal kg^{-1})[x]	1.03	1.12	1.18	1.23	1.28	1.33	1.37

[z]Concentrate level refers to wheat (dry-rolled to a density of 612 ± 6 g L^{-1}) plus the wheat-based supplement, which was provided at 10% of dietary intake (as-fed). Three supplements were prepared, containing approximately 75% wheat, minerals and vitamins as required, and (except for control) sufficient ionophore to provide either 26 ppm monensin (M) or 13 ppm salinomycin (S) in the diets (DM basis).

[y]Contained Ca (2.25%), P (0.4%), Na (0.4%), Zn (400 ppm), Mn (300 ppm), Cu (81 ppm), Se (2 ppm), I (1 ppm), vitamin A (15 000 IU kg^{-1}), vitamin D (1200 IU kg^{-1}), and vitamin E (15 IU kg^{-1}).

[x]NE_m = net energy for maintenance; NE_g = net energy for gain.

Table 2. Composition of diet (DM) fed to 72 yearling steers in Trial 2

	Percentage of concentrate in diet[z]				
	55	65	75	85	92
Ingredients (%)					
Barley grain, steam-rolled	50.0	60.0	70.0	80.0	87.0
Barley silage	45.0	35.0	25.0	15.0	8.0
Supplement[y]	5.0	5.0	5.0	5.0	5.0
Chemical analyses (%)					
Dry matter	52.4	57.6	63.9	71.8	78.6
Crude protein	12.5	12.5	12.5	12.4	12.4
Acid detergent fibre	17.2	14.9	12.6	10.3	8.7
Magnesium	0.19	0.18	0.17	0.16	0.15
Potassium	1.04	0.95	0.87	0.78	0.78
Calcium	0.81	0.77	0.74	0.71	0.68
Phosphorus	0.32	0.34	0.35	0.37	0.38
NE_m (Mcal kg^{-1})[x]	1.79	1.84	1.89	1.94	1.98
NE_g (Mcal kg^{-1})[x]	1.17	1.22	1.26	1.30	1.33

[z]Concentrate level refers to barley plus barley-based supplement. Two supplements were prepared, containing approximately 65% barley, minerals and vitamins as required, and sufficient ionophore to provide either 25 ppm monensin (M) or 13 ppm salinomycin (S) in the diets.
[y]Contained Ca (10%), Na (2.5%), Mg (0.5%), Zn (900 ppm), Mn (525 ppm), Cu (225 ppm), I (11 ppm), Se (6.5 ppm), Co (3 ppm), vitamin A (52 000 IU kg^{-1}), vitamin D (5000 IU kg^{-1}), vitamin E (520 IU kg^{-1}) and 500 ppm monensin or 260 ppm salinomycin.
[x]NE_m = net energy for maintenance; NE_g = net energy for gain.

of bunk attendance by individual animals within the pen as the antenna detects unique passive transponders in the ear tags (Schwartzkopf-Genswein et al. 1999).

Diets for the steers consisted of steam-rolled barley grain and barley silage, and included 5% supplement (Table 2). The barley-based supplement contained vitamins and minerals as recommended by the National Research Council (1996), and sufficient ionophore to yield either 25 ppm monensin or 13 ppm salinomycin (DM basis). Each diet (monensin, M or salinomycin, S) was fed in two pens, and the pens allowed 25.4 cm of linear bunk space and 12.6 m^2 of pen space for each steer. This trial was conducted from June through September.

An initial 12-d period was devoted to validation of the system, during which time the diets (M or S) comprised 55% concentrate. During the validation period, accurate detection of the transponders (electronic ID tags) was confirmed by comparing the steers' bunk attendance recorded by the GrowSafe system with that monitored visually, and by confirming that individual transponders placed manually were detectable along the full length of the bunk.

Following the validation period, the steers were adapted to a 92% concentrate finishing diet using four transition diets (55, 65, 75 and 85% concentrate) over a 14-d period. Feeding behaviors of the steers were monitored for the 3 or 4 d that each transition diet was fed, as well as for the first 4 d on the finishing ration.

Ad libitum intake was monitored for the first 8 d that the steers received the 92% concentrate diet. Feed delivery was then modified in three sequential periods to determine if differences in bunk attendance due to ionophore were influenced by feeding strategy. For 11 d, the steers were fed 95% of their ad libitum intake, in meals delivered at 0900 and 1500 h (limit feeding twice daily, LF2/d). For the next 13 d, limit feeding continued, but feed was delivered only once daily, at 0900 h (LF1/d). Finally, the amount fed (continuing at 0900 h daily) was increased to meet ad libitum intake (AL1/d) and feeding behavior was monitored for 21 d.

Throughout the transition and finishing periods, frequency of visits, daily duration at the bunk, and day-to-day variation in time spent at the bunk were monitored. A visit was defined as a return to the feedbunk after an absence of at least 5 min (intermeal period). Time at the bunk consisted only of those periods during which an animal was detected by GrowSafe (i.e., when its head was in the bunk in the down position, presumably eating). Similar to intake variation in trial 1, variation in bunk visit duration was calculated as the daily deviation from the mean duration measured over a period (i.e., concentrate level, in the transition period, or feeding protocol, in the finishing phase).

Statistical Analyses

For trial 1, intake and performance were analyzed using the GLM procedure of the SAS Institute, Inc. (1990) using animal (treatment) as the error term for testing treatment effects. Interactions were included in the model but were removed when not significant ($P > 0.10$). Orthogonal contrasts were used to make specific comparisons between treatments. Interactions were analyzed using the residual error.

For trial 2, individual feeding periods within the trial were compared and analyzed as a split plot design and included effects due to treatment, period, period × treatment, and animal × pen × treatment. Animal × pen × treatment was used as the error term for testing treatment effects and calculating treatment least square means for parameters of bunk attendance. The residual error was used as the error term to test for differences between each feeding period and treatment ×

Table 3. Daily intake and variation in intake of wheat-based diets containing no ionophore (C), 26 ppm monensin (M) or 13 ppm salinomycin (S) by 36 (n = 12) crossbred steers during the 28-d transition period in Trial 1

% Conc. in diet[y]	Days fed	Dry Matter intake (kg d^{-1})			Day to day variation[z] in DMI (%)			
		C	M	S	C	M	S	Pooled across treatments
51.8	1 to 4	8.2*aD*	6.3*cD*	7.3*bE*	8.8*BC*	8.6*ABC*	7.3*B*	8.2*B*
61.9	5 to 8	9.8*aABC*	7.3*bC*	7.8*bE*	3.8*C*	4.9*C*	7.2*B*	5.3*B*
70.8	9 to 12	10.5*aA*	7.4*bC*	9.2*cCD*	4.7*C*	5.6*BC*	5.8*B*	5.4*B*
78.6	13 to 16	10.4*aAB*	7.4*bBC*	10.1*aAB*	5.4*C*	7.7*ABC*	7.4*B*	6.8*B*
85.5	17 to 20	9.7*bBC*	8.4*cA*	10.9*aA*	7.7*C*	7.1*ABC*	7.9*B*	7.6*B*
91.7	21 to 24	9.5*aC*	8.5*bA*	10.0*aBC*	13.1*B*	10.8*AB*	13.8*A*	12.6*A*
97.4	25 to 28	9.1*aC*	8.2*bAB*	8.9*abD*	14.2*A*	11.4*A*	14.8*A*	13.5*A*
SEM		0.27	0.27	0.27	1.90	1.90	1.90	1.10
Pooled		9.6*a*	7.6*b*	9.2*a*	8.3	8.0	9.2	8.5

[z]Calculated as average daily deviation from mean intake calculated for each diet.
[y]See Table 1.
a–c Within a row and variable (i.e., ionophore effect), means bearing different letters differ ($P < 0.05$).
A–E Within a column (i.e., effect of concentrate level), means bearing different letters differ ($P < 0.05$).

period interactions. Variables that were not significant ($P > 0.10$) were removed from the statistical model. Least square means were separated using the PDIFF option of the SAS Institute, Inc. (1990).

RESULTS AND DISCUSSION

Trial 1

Over the first 28 d, steers receiving M consumed less feed ($P < 0.001$) than did those receiving S or C (Table 3). In addition, a significant treatment × diet interaction was observed (Fig. 1; $P < 0.001$). As the level of concentrate in the diets increased, intake of all treatments (C, M and S) increased initially, then declined (quadratic response, $P < 0.001$), but the patterns of these increases and decreases differed with treatment (Fig. 1).

When no ionophore was fed, the increase in DMI was rapid; intake peaked with the 70.8% concentrate diet, and dropped by 1.4 kg d^{-1} ($P < 0.05$) as concentrate level reached 97.4% (Table 3). Steers fed S had lower ($P < 0.05$) intake for the first three diets, relative to the controls, then their intake increased until at 85.5% concentrate, the S-fed steers were consuming 10.9 kg d^{-1}, the highest ($P < 0.05$) DMI observed during the transition period. This group also displayed the largest drop in intake (2 kg d^{-1}, $P < 0.05$) following the peak.

With the C diet, variability in DMI increased by over 200% (from 4.7 to 14.2%; $P < 0.001$) between the diet at which intake peaked (70.8%) and the finishing diet (97.4% concentrate). Salinomycin apparently moderated intake of the lower concentrate diets relative to control, which extended the period of increasing DMI. This moderating effect disappeared at higher concentrate levels, however; intake of S dropped substantially on the 92.0 and 97.4% concentrate diets, such that intake of the S finishing ration was similar to intake of C. Variation in intake of M diets increased by 60.6% (from 7.1 to 11.4%; $P < 0.01$) during the post-peak decline. The relatively larger increase in intake variation observed with C diet than with S or M arose at least partially because variability at peak intake of C (i.e., at 70.8 and 78.6% concentrate) was low, relative to the other diets.

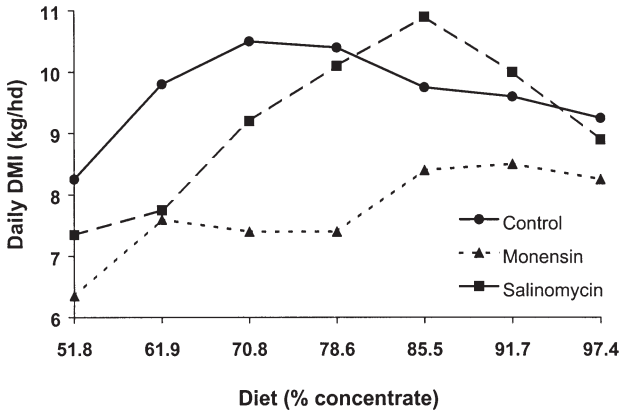

Fig. 1. Mean DMI of wheat-based transition diets containing no ionophore (control), 26 ppm monensin (M) or 13 ppm salinomycin (S) by individually fed yearling steers (n = 12). Each diet was fed for 3 or 4 d.

The pattern of intake exhibited during the transition period by cattle fed C diet was characteristic of a response to increasing energy density. The gradual decline following peak intake reached on the 70.8% concentrate diet may be attributed to energy density-associated increases in VFA production, reduced pH and increased osmolarity, all of which are known to reduce intake (Bergen 1972; Baile and Forbes 1974; Fulton et al. 1979b). In cattle fed M, these effects may not have been observed because intake was lower.

Fulton et al. (1979a) proposed that abruptly reduced intake following a peak (such as that observed in cattle fed S) is a manifestation of subacute acidosis. Although salinomycin is known to suppress acid production (Nagaraja et al.

Table 4. Dry matter intake (DMI, kg steer^{-1} d^{-1}), average daily gain (ADG, kg), and efficiency of feed conversion (FE, feed gain^{-1}) by 36 crossbred steers fed wheat-based diets containing no ionophore (C), 26 ppm monensin (M) or 13 ppm salinomycin (S) in Trial 1

	Days 0 to 28			Days 29 to 56			Day 57 to finish[z]			Overall		
	C	M	S	C	M	S	C	M	S	C	M	S
DMI	9.5*a*	7.6*b*	9.2*a*	8.7*a*	7.7*b*	8.7*a*	9.6*a*	8.7*b*	9.4*a*	9.3*a*	8.2*b*	9.3*a*
ADG	1.71*a*	1.18*b*	1.54*a*	1.38*ab*	1.12*b*	1.58*a*	1.66	1.63	1.65	1.60	1.37	1.59
FE[y]	5.6*a*	6.4*b*	6.0*a*	6.3*ab*	6.9*a*	5.5*b*	5.7	5.3	5.7	5.8	6.0	5.8

[z]Steers were shipped for slaughter on either day 87 or on day 112, toward a targeted finish of 5 mm backfat thickness between the 12th and 13th rib.
[y]Feed efficiency data were analyzed as inverse values (i.e., gain feed^{-1}).
a, b Within a row and period, means followed by different letters differ ($P < 0.05$).

1985), this suppression effect may have been overwhelmed by the higher DM intake by cattle fed the S diet. Relatively smaller reductions in intake subsequent to peak with the M diet are consistent with less acid production.

During the 28-d transition period, intake appeared to vary less from diet to diet with M than with S or C (Fig. 1). However, comparison of average 4-d mean variations in intake for each treatment (12 steers × 7 diets; Table 3) revealed that treatment did not affect deviation from mean intake ($P = 0.58$), and no diet × treatment interaction was observed ($P = 0.95$). Overall, average variation across diets and treatments was 8.5%, but pooled across treatments, intake variation was greater ($P < 0.05$) when the two highest energy diets were fed. Fulton et al. (1979a) observed that intake varied more for cattle fed wheat than for those fed corn, and proposed this to be due to greater ruminal acid production resulting from increased fermentation of the rapidly digestible starch in wheat. It is feasible that the more rapid fermentation of, and greater acid production from, diets containing more than 90% concentrate contributed to the increased variability observed in the present study.

Intake by steers fed M remained lower ($P < 0.05$) than DMI by those fed C or S throughout the remainder of the trial (Table 4). Salinomycin had no effect ($P > 0.50$) on intake, relative to diet C, during any feeding period. Merchen and Berger (1985) observed reduced DMI of corn-based finishing diet supplemented with salinomycin, but other research with similar feeds suggests that this ionophore has little effect on DMI (McClure et al. 1980; Owens et al. 1982; Turgeon et al. 1982). Reviews of research on monensin indicate that including monensin in high-energy finishing diets reduces DMI by an average of 5% (Schelling 1984) to 7.5% (Goodrich et al. 1984). In the current trial, steers fed M consumed 12% less than those fed C and S, which helps explain the trend ($P < 0.12$) of reduced ADG by cattle fed M. In the one other trial in which monensin and salinomycin were compared, neither ionophore affected DMI (Merchen and Berger 1985).

Effects of treatment on ADG and FE were observed only at day 28 and day 56 (Table 4). During both periods, steers fed S had higher ($P < 0.05$) ADG than those fed M, but their ADG did not differ from the control group. Steers fed M exhibited lower ($P < 0.001$) ADG than those fed C, at day 28 only. Lower ($P = 0.03$) feed intake by steers fed C during the second period than during the first reduced their gain ($P < 0.05$), which resulted in lack of difference ($P = 0.13$) in ADG between C and M on day 56.

Table 5. Carcass characteristics of 36 crossbred steers fed wheat-based diets containing no ionophore (C), 26 ppm monensin (M) or 13 ppm salinomycin (S) in Trial 1

	Treatment			
	C	M	S	SEM
Days on feed	105.8*a*	105.8*a*	93.3*b*	3.4
Slaughter weight (kg)	440.5*a*	414.3*b*	419.0*ab*	9.2
Carcass weight (kg)	245.8*a*	231.2*b*	228.2*ab*	5.4
Dressing percentage (%)	55.8	55.8	54.4	0.5
Ribeye area (cm^2)	74.8	75.5	71.3	1.8
Grade fat (mm)	7	5.8	5.3	0.4
Marbling score[z]	9	8.9	8.9	0.1
Canadian quality grade (number of carcasses attaining grade)[y]				
A	9	10	10	
AA	0	1	1	
B1	3	1	1	

[z]Assessed on a 9-point scale, where 1 = abundant fat and 9 = devoid of fat.
[y]A = youthful animal, bright red meat, trace marbling; AA = youthful animal, bright red meat, slight marbling; B1 = youthful animal with no marbling.
a, b Within a row, means followed by different letters differ ($P < 0.05$).

The observation that ionophores did not improve performance (ADG, FE) in this study is surprising and inconsistent with previous research. In a 228-trial summary, Goodrich et al. (1984) concluded that on average, cattle fed monensin had ADG 1.6% higher and feed/gain 7.5% better than those receiving no ionophore. Similarly, reports are consistent that salinomycin improves ADG of cattle (McClure et al. 1980; Owens et al. 1982; Turgeon et al. 1982; Merchen and Berger 1985). Although rates of gain were similar between steers fed C and S in the present study, those fed S required fewer days (93.3 vs. 105.8; $P < 0.05$) to reach 5 mm backfat (Table 5). Differences in slaughter and carcass weights between C and S treatments were not significant ($P > 0.05$), but slaughter and carcass weights of steers fed M were lower ($P < 0.05$) than those of the controls. Treatment did not affect any of the other carcass characteristics that were assessed (Table 5).

Monensin and salinomycin have been previously reported to improve FE, by averages of 7.5% (Goodrich et al. 1984) and 9% (McClure et al. 1980; Owens et al. 1982; Turgeon et al. 1982; Merchen and Berger 1985), although improvements by monensin may be lower if only high-energy finishing rations are considered (Stock et al. 1995a). However, neither ionophore affected overall FE in this study

Table 6. Patterns of feedbunk attendance by 72 yearling steers receiving barley-based diets containing 25 ppm monensin (M) or 13 ppm salinomycin (S) over an 18-d transition period[z] in Trial 2

	Percentage of concentrate in diets (see Table 2)										
	55		65		75		85		92		
	M	S	M	S	M	S	M	S	M	S	SEM
Visits per day	13.9*a*	11.8*b*	12.4*a*	11.5*b*	11.3*a*	10.3*b*	12.3*a*	10.7*b*	11.4*a*	10.0*b*	0.27
TDA[y] (min)	64.5*a*	56.7*b*	46.5	48.7	51.2	49.6	49.2	47.8	39.7*a*	35.2*b*	1.61
Variation[x] in TDA (%)	32.4	28.0	37.4	32.4	22.4	22.9	20.0	20.3	28.6*b*	37.0*a*	2.20

[z]Each diet was fed for 3 or 4 d.
[y]TDA: Total daily attendance.
[x]Average daily deviation from mean TDA calculated for each concentrate level.
a, b Within a row and concentrate level, means followed by different letters differ ($P < 0.05$).

($P > 0.05$). The only effects of treatment on FE were poorer FE ($P < 0.05$) with M than with C or S during transition, and poorer FE with M than with S at d 56 (Table 4).

It is possible that the high levels of wheat fed may have contributed to the lack of performance response to ionophores. As ruminal starch digestion increases, as occurs with high-wheat diets, relative to barley or corn (McAllister et al. 1990), microbial profiles and biochemical pathways shift to direct carbon and hydrogen away from methanogenesis and toward propionate production (Schelling 1984). Reducing methane production is also one of the primary means by which ionophores improve energetic efficiency (Bergen and Bates 1984), thus the potential for M and S to improve ruminal fermentation would decline as ruminal starch digestion increases (Spires et al. 1990). On the other hand, the moderating effect of M and S on ruminal pH (Nagaraja et al. 1985), and, therefore, on acidosis, may be most beneficial on a rapidly fermented diet. Stock et al. (1990) observed roughage level × monensin interactions when feeding dry-rolled wheat diets to cattle. In that study, monensin (27.5 ppm) positively affected FE at 0% roughage, but not at 7.5% roughage; improved ADG to a larger extent with 0 than with 7.5% roughage; and did not affect DMI. Reasons for the disparity between that study and the present one are unknown, but findings could have been influenced by several factors (e.g., cattle type, diet/feeding protocol) as outlined below.

In the present study, supplement (through which ionophore was delivered) accounted for 10.9 to 15.5% of dietary DM, which is higher than in most other studies [e.g., Stock et al. (1990) included supplement at 5.75% of DM]. Higher supplement levels may have resulted in greater dispersion of M throughout the rations, possibly suppressing intake relative to other studies. Feed intake by group-fed cattle is known to be higher than that by those fed individually (Coppock et al. 1972; Phipps et al. 1983). It is possible that the intake-suppressing effects of monensin would be amplified by the more passive eating patterns of individually fed cattle.

Trial 2

Type of ionophore did not affect DMI, ADG or FE in Trial 2. Averaged across treatments, intake, gain, and feed/gain were 11.4 kg d^{-1}, 1.61 kg d^{-1}, and 7.07, respectively.

During the transition period, steers fed M visited the bunk more frequently ($P < 0.05$) with each of the diets fed, and their total daily attendance (TDA) was higher ($P < 0.05$) when the 55 and 92% concentrate diets were fed, as compared with steers fed S (Table 6). Reduced intake by steers fed M in Trial 1 suggests that increased TDA for steers fed M versus S in the 55 and 92% concentrate diets more likely reflected slower eating rates than increased DMI.

A treatment × diet interaction ($P = 0.02$) was observed for variation in TDA, arising from higher variation ($P < 0.05$) with S (37.0%) than with M (28.6%) on the 92% concentrate diet (Table 6). The high energy content of the 92% concentrate diet may have resulted in acidosis-induced variation that may have been reduced by the moderating effects of monensin on intake (Chirase et al. 1992; Laudert 1995). Pooled across diets (i.e., concentrate levels), variation in TDA throughout the transition period did not differ between treatments ($P = 0.37$).

There was a linear decrease ($P < 0.001$) in TDA as steers progressed through the step-up rations. Decreasing TDA coincident with increasing energy concentration in the diet is consistent with the observations made in Trial 1. Increasing energy concentration beyond approximately 1.6 Mcal NE_m kg^{-1} typically results in reductions in DMI (NRC 1996). As well, increased eating rate associated with declining forage level would also contribute to reduced time at the bunk. Reduced fibrousness, including reduced forage content (Putnam et al. 1964; Gill and Kaushal 1987) or replacement of hay with silage (Suzuki et al. 1969) can increase eating rates.

While limit fed (LF1/d and LF2/d), steers given M visited the bunk more frequently ($P < 0.05$) than those given S (Table 7), and during LF1/d, TDA was higher ($P < 0.05$) and less variable ($P < 0.05$) with M than with S. Cattle fed monensin typically eat smaller, more frequent meals (Chirase et al. 1992; Laudert 1995; Fanning et al. 1999) and exhibit less intake variation (Stock et al. 1995b) than cattle fed no ionophore. Salinomycin apparently has little effect on DMI (Owens et al. 1982; Turgeon et al. 1982), but monensin tends to suppress it (Goodrich et al. 1984; Schelling 1984; Laudert 1995). Thus, feeding frequency may be higher and eating rates slower with M, which results in more stable intakes.

Elevated, less-variable bunk attendance and more frequent feeding (LF1/d), together with lower DMI and more

Table 7. Effects of frequency of feeding (once or twice daily) and level of feeding (95 or 100% of ad libitum intake) on patterns of feedbunk attendance by 72 yearling steers given a barley-based finishing diet containing 25 ppm monensin (M) or 13 ppm salinomycin (S) in Trial 2

	Frequency of feeding (to 95% of ad libitum intake)[z]						Level of feeding (once daily)[y]					
	Twice daily		Once daily			Effect of feeding frequency	95%		100%			Effect of feeding level
	M	S	M	S	SEM	(*P* value)	M	S	M	S	SEM	(*P* value)
Visits per day	10.1*a*	9.2*b*	9.7*a*	9.0*b*	0.20	0.47	9.7*b*	9.0*c*	11.0*a*	10.9*a*	0.20	0.0001
TDA[x] (min)	35.4*b*	34.3*b*	34.3*b*	28.7*a*	0.95	0.17	34.3*a*	28.7*b*	23.9*c*	20.9*d*	0.95	0.0002
Variation[w] in TDA (%)	23.5*a*	22.2*a*	20.7*b*	24.1*a*	1.06	0.62	20.7*c*	24.1*b*	27.6*a*	28.9*a*	1.06	0.0001

[z]Feed was delivered at 0900 h (once daily) or at 0900 and 1500 h (twice daily).
[y]Feed was delivered to meet 95 or 100% of ad libitum intake.
[x]TDA, total daily attendance.
[w]Average daily deviation from mean TDA calculated for each period (i.e., limit-fed twice daily; limit-fed once daily; full-fed once daily).
a–d Within a row and variable, means followed by different letters differ ($P < 0.05$).

consistent intake among diets (Trial 1) with M than with S indicate that M moderates feeding intensity, compared with S. The differences in TDA and TDA variability between treatments were only evident while feeding once daily. It appears that differences in feeding behavior between cattle fed S or M can be at least partially compensated for by increased frequency of feed delivery. Cattle were offered the same amount of feed throughout LF1/d and LF2/d. The trend toward greater TDA ($P = 0.17$) in LF2/d suggests a slower eating rate during that period. The increased eating intensity that accompanies once-daily feed delivery may amplify the moderating effect of M on feeding behavior relative to S. Slower eating rates with twice-daily feed delivery may lessen the pH insult associated with meal eating in limit-fed animals (Fanning et al. 1999) and reduce potential effects of ionophore-induced intake regulation.

During AL1/d, cattle fed M spent more time at the bunk ($P = 0.03$) than cattle fed S, but there were no differences between treatments in frequency of visits ($P = 0.96$) or variation in TDA ($P = 0.36$). This lack of treatment effect on feeding frequency again suggests that the effects of ionophore on eating behavior are influenced by eating intensity.

The higher frequency of bunk visits by cattle fed M than those fed S during the transition period, LF2/d and LF1/d, suggests that there may be a maximum tolerable level of M cattle will consume at one feeding bout. Given the passive eating patterns of cattle given ad libitum access to a high-energy ration (as in AL1/d), it is feasible that VFA production (Baile and Forbes 1974), osmolarity (Bergen 1972), or some other factor involved in intake regulation may arrest feeding activity before intake of monensin interrupts feeding. These regulatory factors would affect cattle given S or M, and, thus could explain the lack of difference in feeding frequency between ionophores during AL1/d. Passive eating patterns may also contribute to equalizing TDA variability between treatments.

Up to 50% of ingested monensin is absorbed by ruminants (Donoho et al. 1984); thus, extra-ruminal effects of this ionophore may account for some of the observed responses. Cattle infused intravenously with 40 mg of monensin stopped eating for at least 4 h, but daily feed intake was unaffected (Armstrong and Spears 1988). Infusion of 18 mg of monensin did not affect eating patterns, nor did 40 mg of lasalocid, which suggests that systemic effects are not consistent among ionophores. Limit feeding is associated with larger meals, compared with ad libitum feeding (Prawl et al. 1997; Fanning et al. 1999). This may have allowed sufficient M to be consumed and absorbed to temporarily suppress feeding during LF1/d and LF2/d, resulting in greater feeding frequency as compared with AL1/d. Infusion of 40 mg monensin also altered glucose and insulin levels (Armstrong and Spears 1988), but these factors likely have little effect on intake patterns in ruminants (Baile and Forbes 1974).

With once-daily feed delivery, limit feeding (LF1/d) resulted in less-frequent visits to the bunk (9.4 vs. 10.9 d^{-1}; $P = 0.0001$), more time spent at the bunk (31.5 vs. 22.4 min d^{-1}; $P = 0.0002$) and less variation in TDA (22.9 vs. 28.2%; $P = 0.0001$), compared with ad libitum feeding (AL1/d). This is congruent with the fewer, larger meals associated with limit feeding (Prawl et al. 1999). Empty feed bunks for up to 15 h d^{-1} were observed frequently during LF1/d, which would also have led to fewer visits. Less-variable TDA during LF1/d than AF1/d supports the theory commonly held by feedlot operators and nutritionists that the consistent feed deliveries carried out during limit feeding and/or clean bunk management protocols equates to increased consistency in intakes by individuals in the pen.

Gibb et al. (1998) reported that TDA variability with once daily feed delivery was higher during limit feeding than when cattle had ad libitum access to feed. In that study, however, variation was calculated as the average variation from day to day, as opposed to the average daily deviation from the mean duration, which was used to calculate variation in the present report. When calculated as day-to-day variation, extreme variations are greatly amplified. Calculating variation in duration as a deviation from the mean improves the normality of distribution of the data set and minimizes the impact of extreme values. This method has been used to calculate variability in intakes (Stock et al. 1995b).

Time spent at the bunk by the steers in this study declined steadily as they progressed through the transition diets to the

finishing ration, then through LF2/d, LF1/d and AL1/d. The shift to limit feeding would be expected to reduce TDA, as intakes would obviously be lower and because eating rates of limit-fed cattle are higher (Prawl et al. 1997; Fanning et al. 1999). It was also expected that TDA would decline further when feed deliveries were reduced to once per day. During LF1/d, cattle no longer had an afternoon feeding peak and bunks were frequently observed empty by 1730 h. It is more difficult, however, to explain why TDA declined further when feed delivered was increased to meet ad libitum intake (AL1/d). Research suggests both close correlation (Chase et al. 1976) and poor correlation (Metz 1974) between time spent feeding and intake of feed. It seems unlikely, however, that the steers would have spent less time consuming feed when they had ad libitum access to it than when it was restricted. Jones et al. (1966) speculated that recorded eating rates were lower when smaller quantities of feed were offered because cattle required more time to gather the more dispersed, thin layers of feed into their mouths. Similarly, eating rates likely decline for feedlot cattle as feed nears depletion. The last remaining quantity of feed consumed makes up a higher percentage of the total feed for limit-fed cattle than for those fed to ad libitum intake, thus TDA for limit-fed cattle may seem disproportionately high. This effect would be amplified with twice daily feed deliveries compared with once daily, which may have contributed to higher TDA in LF2/d than in LF1/d. As well, limit-fed cattle likely spend some time with their head in the trough looking for food.

Different eating behaviors of limit-fed and ad libitum-fed cattle may also have influenced TDA as detected by the GrowSafe system. The system requires that EID tags are parallel to and within 50.4 cm of the mat in the bunk for detection of transponders. Thus, if less aggressive eating was associated with more frequent withdrawal of the head from the bunk, detection of steers on ad libitum intake would be reduced, relative to the more aggressive (i.e., head-in) feeding of limit-fed steers. Less feed in the bunk may also have required the steers to extend their heads further into the bunk and reduced their head movement, which would ensure detection.

Continual decline of TDA as feeding periods progressed (through transition, LF2/d, LF1/d, and AL1/d) suggests that days on feed may have confounded treatment effects on TDA. To assess the effects on TDA of days on feed, Pearson correlation coefficients of TDA regressed against days on feed within a period were analyzed. Correlations (R^2) between days on feed and TDA within each period were 0.03, 0.005, and 0.009, for LF2/d, LF1/d, and AL1/d, respectively. As well, correlations were no higher between consecutive than between non-consecutive periods. For example, duration was more highly correlated between LF2/d and AL1/d than between LF1/d and AL1/d. These lack of correlations suggest minimal confounding of TDA with time.

CONCLUSION

Performance responses observed in these trials indicate little advantage to including salinomycin or monensin in a finishing diet containing high levels of wheat. This study suggests that monensin supplementation of a wheat-based finishing diet can suppress intake enough to reduce ADG. Daily intakes by cattle fed monensin were less variable than those by cattle fed salinomycin or no ionophore. Relative to salinomycin, monensin moderates eating intensity by increasing frequency and duration of bunk visits. This effect is amplified when eating behaviors are aggressive, such as when cattle are limit-fed once daily. Increased incidence of bloat commonly reported when cattle are switched from monensin to salinomycin may be a result of differences in feeding behavior. Ionophore-induced alterations in feeding behavior may contribute to their efficacy.

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