Asian-Aust. J. Anim. Sci.
Vol. 24, No. 12 : 1690 - 1698
December 2011

www.ajas.info
http://dx.doi.org/10.5713/ajas.2011.10437

Effects of Moisture and a Saponin-based Surfactant during Barley Processing on Growth Performance and Carcass Quality of Feedlot Steers and on *In vitro* Ruminal Fermentation

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ABSTRACT : Feedlot and *in vitro* ruminal experiments were conducted to assess the effects of saponin-containing surfactant applied during tempering of barley grain on cattle growth performance and on ruminal fermentation. In the feedlot experiment, treatments with three barley grain/barley silage based diets were prepared using barley grain at 7.7% moisture (dry, D), after tempering to 18% moisture (M), or after tempering with a saponin-based surfactant included at 60 ml/t (MS). Each treatment was rolled at settings determined previously to yield optimally processed barley. A total of 180 newly weaned British×Charolais steers were fed three diets in 18 pens for a 63-d backgrounding period and 91-d finishing period to determine feed intake, growth rate and feed efficiency. Cattle were slaughtered at the end of the experiment to measure the carcass characteristics. Tempering reduced ($p<0.001$) volume weight and processing index, but processing characteristics were similar between MS and M. Tempering increased ($p<0.05$) growth during backgrounding only, compared with D, but did not affect feed intake in either phase. During backgrounding, feed efficiency was improved with tempering, but during finishing and overall this response was only observed with the surfactant. Tempering did not affect carcass weight, fat content or meat yield. Surfactant doubled the proportion of carcasses grading AAA. In the *in vitro* experiment, barley (500 mg; ground to <1.0 mm or steam-rolled) was incubated in buffered ruminal fluid (40 ml) without or with surfactant up to 20 μl/g DM substrate for 24 h. Surfactant increased ($p<0.05$) apparent DM disappearance and starch digestibility but reduced productions of gas and the volatile fatty acid and acetate:propionate ratio, irrespective of barley particle size. Compared with feeding diets prepared with non-tempered barley, tempering with surfactant increased the feed efficiency of feedlot steers. This may have arisen from alteration in processing characteristics of barley grain by surfactant rather than its direct effect on rumen microbial fermentation. (**Key Words :** Barley, Feedlots, Processing, Rumen Digestion, Surfactants)

INTRODUCTION

In feedlot beef production, feed efficiency is typically improved and cost per unit of gain is decreased with increasing dietary energy levels. Due to their highly digestible starch content, grains are typically the cheapest source of energy in ruminant diets and therefore are usually included at levels greater than 85% in finishing diets in North America. Barley grain is the major grain source for feedlot cattle in western Canada. It must be processed prior to feeding so that endosperm encased within the indigestible pericarp and hull can be utilized (Wang and McAllister, 2000), with rolling being the most common form of processing for this purpose. However, the variation in kernel size of barley grain can dramatically influence the efficacy of rolling as a processing method. Therefore, tempering grain prior to rolling has been used to standardize this inherent variation and to reduce mechanical wear on processing equipment (Mathison et al., 1997). However, the effects of tempering on animal performance have been inconsistent (Hinman and Combs, 1983; Combs and Hinman, 1989; Mathison et al., 1997). Some of these discrepancies may have arisen from variations in the rate and extent of moisture uptake by the kernels during tempering. Surfactants have been used to enhance hydration in a variety of applications (Cairns, 1972; Aksenova et al.,

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Received November 30, 2010; Accepted March 17, 2011

1993; Coret and Chamel, 1993). However, there is little information on the effects of these compounds on the processing and utilization of barley grain. Wang et al. (2003), using cattle individually fed barley grain and barley silage, showed that inclusion of saponin-based surfactant at 60 ppm during tempering increased average daily gain and feed efficiency by 7 and 6%, respectively. This growth promotion effect of the surfactant appeared to be mediated by the feed particle size, but the mechanism was not clear. Their subsequent study (Wang et al., 2005) revealed that although this surfactant increased water absorption of barley grain up to 2 h of tempering it did not affect the particle size distribution after rolling. It is not known if the surfactant would produce a similar response under conditions that are more indicative of a commercial feedlot.

The objectives of this study were to assess the effects of the same surfactant (as used in our earlier study by Wang et al., 2003) applied during tempering on the growth performance of group-fed feedlot cattle and to evaluate the influence of supplementation of the surfactant on the ruminal fermentation of barley grain processed to two distinct particle sizes.

MATERIALS AND METHODS

Feedlot experiment

Grain processing: The barley grain (7.7% moisture) used in this study was from commercial sources, and consisted of a mixture of varieties. After cleaning, barley was either i) dry-rolled (D), ii) tempered for 4 h at 18% moisture and then rolled (M) or iii) tempered for 4 h at 18% moisture with 60 ppm surfactant and then rolled (MS). Barley grain was rolled to a visually optimal particle size with specific roller settings for each treatment. The surfactant (Grain Prep; AgriChem Inc., Ham Lake, MN) was applied at 60 ml/t. Moisture content of the grain was determined automatically prior to tempering by an Auto Delivery System (AgriChem Inc., Ham Lake, MN) that applied cold tap water to each batch of grain as required to attain a moisture content of 18%. After rolling, the grain was air dried at room temperature and stored in separate steel bins. Several lots of each barley treatment (D, M and MS) were prepared over the duration of the experiment, but the same processing parameters were applied each time. Sub-samples were taken from each batch of each treatment for direct measurement of the processing index (PI) and distribution of particle size.

Animals, diets and measurements: One hundred and eighty newly weaned British×Charolais (250-300 kg body weight) steers were purchased from a local auction market. Cattle were processed upon arrival at the Lethbridge Research Centre which included ear tagging, branding, deworming (Dectomax (doramectin, 0.5%), Pfizer Animal Health, Exton, PA) and vaccinating against IBR, PI_3 and *Haemophilus somnus* (Resvac 2/Somubac, Pfizer Animal Health) as well as *Clostridium* spp. (Tasvax 8, Schering-Plough Animal Health, Upper Hutt, NZ). Steers were implanted with Syn Choice® upon arrival at the feedlot and re-implanted at approximately 105 d into the experiment. The steers were randomly assigned to three treatments (60 per treatment), fed in 18 pens (10 steers per pen; 6 pens for each treatment), and were adapted to a barley silage-based diet for 4 wk prior to commencing the study. The experiment comprised of a 63-d backgrounding (growing) period and a 91-d finishing period, with a 21-d transition period during which the proportion of barley grain in the diet was increased at 7-d intervals. Steers were fed total mixed rations (TMR) and all diets were formulated to meet nutrient requirements of beef cattle as described by NRC (1996). Diets were delivered once daily for *ad libitum* intake and cattle had free access to water throughout the experiment. Monensin was included in all diets at a concentration of 33 ppm. Orts were collected, weighed and dried on a weekly basis to determine dry matter intake (DMI). The steers were weighed individually (unshrunk) using a single confinement livestock scale (Stathmas type 513417) on two consecutive days at the beginning, of the end of each feeding period and at 28-d intervals to calculate the average daily gain (ADG). All steers were slaughtered commercially at the end of the finishing period. Carcass

Table 1. Composition (g/kg DM) of total mixed rations fed to steers in the feedlot experiment

Item	Backgrounding diet	Finishing diet	SEM
Diet composition			
Barley silage	550	90	
Barley grain[1]	400	860	
Supplement[2]	50	50	
Chemical composition			
Dry matter	962.2	958.4	0.53
Organic matter	935.6	965.0	2.04
Total N	22.0	22.8	0.31
Neutral detergent fibre	286.0	149.4	6.29
Starch	260.2	568.7	5.43

[1] Barley grain was rolled dry (D), after tempering to 18% moisture (M), or after tempering to 18% moisture together with saponin-based surfactant (GrainPrep, AgriChem, Inc., Anoka, MN) applied at 60 ml/t (MS). The dry-rolled barley contained 7.7% moisture.

[2] Supplement contained (per 1,000 kg): 653 kg ground barley, 237 kg limestone, 50 kg salt, 40 kg Dynamate (Pitman-Moore Inc., Oakville, ON), 10 kg urea, and 10 kg trace mineral mix containing (per kg): sodium chloride (926 g), zinc sulfate (11 g), Dynamate (50 g), manganese sulfate (9.4 g), copper sulfate (3.2 g), cobalt sulfate (0.005 g), canola oil (as carrier of $CoSO_4$; 0.04 g), sodium selenite (0.044 g), and ethylenediaminediiodic acid (80%; 0.012 g). Dynamate contains 22% S; 18% K; 11% Mg; 0.1% Fe; 0.0005 Pb (max.).

measurements were conducted after carcasses cooled at 1°C for 24 h.

***In vitro* experiment**

Barley grain used in this experiment was from the same lot as that used in the feedlot experiment. Barley grain was ground to pass through a 1.0 mm screen (P1) or steam rolled with the standard procedure used in the feedlot (P2). The barley grain was steam-rolled in stead of dry-rolled or temper-rolled in the feedlot experiment to minimize the impact of the particle variation on the *in vitro* fermentation which utilized only a small amount (500 mg) of substrate.

Processed barley grain was pre-loaded into serum vials (500 mg/vial). Mineral buffer (1.0 ml) containing surfactant at quantities of 0, 2.5, 5.0 or 10 μl (corresponding to 0, 5, 10 and 20 μl/g DM of substrate) was added to the barley grain 16 h prior to the addition of inoculum. Mixed microbial inoculum was prepared using ruminal fluid from two fistulated cows fed an early lactation diet (40:60 barley silage:concentrate) as described by Wang et al. (2008). Inoculation and *in vitro* incubation were conducted as described by Wang et al. (2008). The incubation was conducted for 24 h, with gas production measured at 4, 12 and 24 h with a water displacement device. Prior to measurement of gas production at each time point, a sample of headspace gas was removed using a 25.0-ml gas-tight syringe and transferred into an evacuated 6.8-ml container (Labco Ltd., High Wycombe, Bucks, UK) for later estimation of methane concentration. At the end of 4, 12 and 24-h incubation, triplicate vials of each treatment as well as duplicate vials containing inoculum only were withdrawn from the incubator and processed for determinations of apparent DM disappearance (ADMD), starch disappearance (SD) and production of volatile fatty acids (VFA) using the same procedure as described by Wang et al. (2008). Three replicates incubations per treatment were conducted.

Animals used in this study were cared for according to the guidelines set by the Canadian Council on Animal Care (CCAC, 1993).

Laboratory analyses

Processing characteristics: All measurements were made on processed grain after oven drying at 70°C for 48 h. Volume weight was measured on 500-ml samples of whole or processed barley. Particle size distribution of the processed barley was determined by dry sieving with an oscillating sieve shaker (W. S. Tyler, Inc., Mentor, OH) equipped with four sieves, arranged in descending mesh size (4.75, 3.35, 2.36, and 1.70 mm), and a collection pan (for particles <1.70 mm).

Feed, orts, incubation residue and fermentation product: Substrates and incubation residues were analyzed for DM by oven drying (105°C for 48 h), organic matter by ashing, neutral detergent fibre (NDF) as described by Van Soest et al. (1991), total N by mass spectrometry (NA 1500, Carlo Erba Instruments, Rodano, MI, Italy) and for starch by the method of Herrera-Saldana et al. (1990). Methane concentrations in headspace gas were determined by gas chromatography (Chaves et al., 2006). Incubation culture supernatants were assayed for VFA by gas chromatography (Wang et al., 1998).

Calculations and statistical analyses

All calculations related to composition of the feed and characteristics of the grain were calculated on a DM basis. *In vitro* ruminal fermentation products were calculated on a per g ADMD basis. Volume weights of the processed grain were expressed as g/L of grain or processed grain. Processing index (PI) was calculated as: PI = (volume weight after rolling/volume weight before rolling) H 100%.

In the feedlot experiment, ADG, DMI and feed efficiency (FE, ADG/DMI) were calculated using pen as the experimental unit and carcass characteristics were calculated using individual cattle as the experimental unit. Data were analyzed as a complete randomized design by analysis of variance using mixed procedure of SAS (SAS, 2007), with the exception for quality grade of the carcass and liver abscesses which were analyzed by Chi-square analysis. Differences between treatments were determined using Least Square Means with the PDIFF procedure of SAS.

Data from the *in vitro* experiment were analyzed as a 2×4 factorial design with feed particle size and concentration of the surfactant as main effects. The model used for analysis of time-course data (repeated measures) included time and time×treatment interaction. When these effects (time or time×treatment interaction) were determined to be significant, the means of the treatments were compared at each time point. Orthogonal polynomial contrasts were used to compare linear or quadratic responses to surfactant concentrations.

RESULTS

Feedlot experiment

Characterization of the processed grain: Pre-rolling condition affected all characteristics of the processed barley grain measured in this study (Table 2). Compared to dry rolling (D), tempered barley (M and MS) had lower ($p<0.001$) volume weights and PI. However, tempering the barley with (MS) and without surfactant (M) resulted in similar volume weight or PI. Higher ($p<0.001$) proportions of particles were retained on the 4.75- and 3.35-mm, but fewer ($p<0.001$) particles were retained on 2.36- and 1.70-mm sieves with M or MS barley, as compared to D.

Table 2. Effect of barley condition (dry, tempered, or tempered with surfactant) on processing characteristics of barley grain[1]

	D	M	MS	SEM[2]	p
Volume weight (g/L)	560.2[a]	427.6[b]	445.0[b]	10.74	<0.001
Processing index[3]	77.6[a]	59.2[b]	61.6[b]	1.41	<0.001
Particle distribution %					
4.75 mm	0.07[b]	9.83[a]	10.61[a]	1.838	<0.001
3.35 mm	26.29[b]	60.14[a]	57.44[a]	3.917	<0.001
2.36 mm	36.82[a]	18.07[b]	17.79[b]	1.974	<0.001
1.70 mm	26.36[a]	5.88[b]	6.14[b]	1.559	<0.001
<1.70 mm	10.42	6.00	7.98	1.823	0.233

[1] Barley grain was rolled dry (D), after tempering to 18% moisture (M), or after tempering to 18% moisture together with saponin-based surfactant (GrainPrep, AgriChem, Inc., Anoka, MN) applied at 60 ml/t (MS). The dry-rolled barley contained 7.7% moisture.
[2] SEM = Standard error of the mean (n = 19, 32, 32 for D, M and MS, respectively).
[3] Processing index (PI) was calculated as volume weight after rolling/volume weight before rolling ×100%.
[a, b] Within a row, means without a common superscript letter differ (p<0.05).

Including surfactant during tempering (i.e., MS vs. M) did not affect any of the measured processing characteristics of rolled barley.

Animal performance: Feed intake was similar among D, M and MS steers in periods of backgrounding, finishing and during the overall feeding period (Table 3). However, steers fed M and MS grew faster (p<0.05) than those fed D in backgrounding, but there was no difference among treatment during the finishing or overall feeding period. Compared to D, tempering barley to 18% moisture prior to rolling improved (p<0.05) FE during backgrounding, but not during finishing or overall. Steers fed MS grain had higher (p<0.05) FE during backgrounding and tended (p = 0.09) to have higher FE during the finishing period, which resulted in an overall higher (p<0.05) FE as compared to steers fed D. However, no difference was observed in FE between M and MS during any period of the experiment.

All animals had similar carcass hot weight, grade fat or meat yield (Table 4). At slaughter, however, steers fed M grain had a higher dressing percentage (p<0.01) and higher longissimus muscle area (p<0.05) than steers fed D or MS. Additionally, steers fed MS grain achieved the highest carcass quality grade, which was about 105% greater than that of steers fed D or M.

In vitro experiment

No interactive effect of particle size×surfactant level on ADMD, SD or on productions of total gas, methane gas and VFA was observed during the 24-h incubation. Therefore, only the main effects of the substrate's particle size and

Table 3. Effect of barley condition (dry, tempered, or tempered with surfactant) on growth performance parameters of steers fed diets prepared with the processed barley grain[1]

	D	M	MS	SEM[2]	p
Initial weight (kg)	353.5	353.1	353.3	3.21	0.999
Final weight (kg)	638.9	643.7	649.3	5.62	0.416
DMI (kg/d)[3]					
Backgrounding	8.53	8.26	8.54	0.143	0.255
Finishing	11.74	11.42	11.37	0.147	0.190
Overall	10.56	10.28	10.36	0.125	0.294
ADG (kg/d)					
Backgrounding	1.20[b]	1.32[a]	1.34[a]	0.038	0.034
Finishing	1.88	1.85	1.90	0.039	0.593
Overall	1.64	1.66	1.70	0.029	0.290
FE					
Backgrounding	0.142[b]	0.161[a]	0.157[a]	0.0045	0.020
Finishing	0.160[b]	0.162[ab]	0.167[a]	0.0024	0.090
Overall	0.155[b]	0.162[ab]	0.164[a]	0.0023	0.029

[1] Barley grain was rolled dry (D), after tempering to 18% moisture (M), or after tempering to 18% moisture together with saponin-based surfactant (GrainPrep, AgriChem, Inc., Anoka, MN) applied at 60 ml/t (MS). The dry-rolled barley contained 7.7% moisture.
[2] SEM = Standard error of the mean (n = 6).
[3] DMI = Dry matter intake; ADG = Average daily gain; FE = Feed efficiency (ADG:DMI).
[a, b] Within a row, means without a common superscript letter differ (p<0.05). Mortality: D: 2, M: 1, MS: 0.

Table 4. Effect of barley condition (dry, tempered, or tempered with surfactant) on carcass characteristics of feedlot steers fed diets prepared using the processed barley grain[1]

	D	M	MS	SEM[2]	p
Carcass weight (kg)	368.4	376.4	376.0	3.23	0.151
Dressing percent (%)	57.8[b]	58.7[a]	57.8[b]	0.20	0.003
Grade fat (mm)[3]	9.5	10.2	9.6	0.41	0.488
Average fat cover (mm)	10.7	11.7	10.8	0.38	0.136
Longissimus muscle area (cm^2)	88.6[b]	93.5[a]	89.6[b]	1.38	0.030
Meat yield (%)	58.4	59.0	58.3	0.46	0.524
Quality grade[4]	14.0	13.8	28.3	-	0.177
Total liver abscesses (%)	35	29	37	-	0.500

[1] Barley grain was rolled dry (D), after tempering to 18% moisture (M), or after tempering to 18% moisture together with saponin-based surfactant (GrainPrep, AgriChem, Inc., Anoka, MN) applied at 60 ml/t (MS). The dry-rolled barley contained 7.7% moisture.
[2] SEM = Standard error of the mean (n = 60).
[3] Fat thickness was measured on each carcass between the 12th and 13th ribs, at the grade fat site and two locations dorsal to grade fat site, in accordance with Canadian Blue Tag protocol. Averages of triplicate measurements on each carcass were used to calculate treatment means.
[4] Quality grade in Canadian carcass grading system indicates the percentage of AAA.
[a,b] Within a row, means without a common superscript letter differ ($p<0.05$).

surfactant levels are presented (Tables 5 and 6).

Apparent DMD, SD and amount of total gas production per g of ADMD were all lower ($p<0.01$) for P2 than for P1 at 4, 12 and 24-h incubation (Table 5). In contrast, a lower ($p<0.05$) amount of methane per g ADMD for P2 than for P1 was observed only at 12 h of the incubation. Supplementation of surfactant at the levels from 5 to 20 μl/g DM linearly increased ADMD ($p<0.05$) at 4 and 12 h, and SD ($p<0.001$) at 12 and 24 h, but linearly reduced total gas production ($p<0.05$) at 4 and 12 h and reduced ($p<0.05$) methane production at 4 h of the incubation.

Production of total VFA from fermentation of P1 substrate was higher ($p<0.01$) at 4 but was lower ($p<0.01$) at 24-h incubation than that of P2 substrate (Table 6). However, surfactant linearly reduced ($p<0.01$) at 4 and tended to reduce ($p = 0.064$) total VFA production at 24-h incubation. Fermentation of P1 substrate produced VFA with slightly lower or lower (p values ranging from 0.053 to <0.001) molar proportions of acetate, branched chain VFA and acetate:propionate ratio (A:P) than fermentation of P2 substrate at 12 and 24 h of the incubation. Compared with P2 substrate, molar proportion of propionate was higher ($p<0.001$) at 4 h but was lower ($p<0.05$) at 12 and 24 h of the incubation. Supplementation of surfactant linearly

Table 5. Effects of saponin-based surfactant on the total gas and methane production during a 24-h *in vitro* incubation

Incubation	Particle size (A)			p	Surfactant (B; μl/g DM)					p		
(h)	P1[1]	P2	SEM[2]		0	5	10	20	SEM	L[3]	Q	A×B
Apparent DM disappearance (ADMD; mg/g)												
4	363.7	217.9	9.19	<0.001	244.7	296.0	288.9	343.7	13.00	<0.001	0.882	0.097
12	576.9	419.1	7.05	<0.001	467.1	505.0	512.7	506.2	9.97	0.030	0.019	0.296
24	676.1	561.6	13.16	<0.001	603.3	618.9	643.4	609.7	18.61	0.822	0.161	0.494
Starch disappearance (mg/g)												
4	480.2	208.8	6.24	<0.001	351.6	357.7	334.1	336.1	9.23	0.110	0.730	0.230
12	833.3	507.7	3.31	<0.001	635.1	682.7	692.2	671.8	4.68	<0.001	<0.001	0.114
24	976.6	815.2	2.76	<0.001	860.1	905.6	883.1	932.6	3.91	<0.001	0.948	0.107
Gas production (ml/g ADMD)												
4	225.4	168.8	6.48	<0.001	208.4	204.3	199.0	176.5	9.16	0.019	0.555	0.227
12	316.9	245.2	4.56	<0.001	291.4	292.2	268.3	272.5	6.09	0.017	0.267	0.625
24	352.7	331.5	4.43	0.003	339.7	343.4	337.7	347.6	6.26	0.497	0.608	0.914
Methane production (ml/g ADMD)												
4	59.0	58.6	3.95	0.935	62.4	65.1	58.3	49.5	5.58	0.049	0.527	0.221
12	78.4	71.0	1.32	0.022	77.3	71.6	74.2	75.7	1.97	0.847	0.092	0.717
24	89.3	87.1	1.31	0.398	89.4	88.1	86.5	88.8	2.37	0.874	0.359	0.629

[1] P1 = Barley grain ground to pass through 1.00 mm screen; P2 = Steam rolled barley grain.
[2] SEM = Standard error of the mean. [3] L = Linear effect of the surfactant; Q = Quadratic effect of the surfactant.

Table 6. Effects of saponin-based surfactant on the total volatile fatty acids (VFA) production and molar percentage of individual VFA during a 24-h *in vitro* incubation

Incubation	Particle size (A)			p	Surfactant levels (B; μl/g DM)					p		
h	P1[1]	P2	SEM[2]		0	5	10	20	SEM	L[3]	Q	A×B
Total VFA (mmol/g ADMD[4])												
4	7.75	6.37	0.258	0.002	7.69	7.64	6.86	6.05	0.365	0.003	0.459	0.095
12	8.41	8.50	0.412	0.884	9.32	8.30	8.03	8.17	0.583	0.233	0.251	0.175
24	9.73	10.85	0.224	0.003	10.65	11.13	9.25	10.13	0.317	0.064	0.109	0.225
Acetate (A, %)												
4	62.6	62.1	0.17	0.065	63.6	62.6	61.9	61.5	0.25	<0.001	0.025	0.132
12	61.9	59.5	0.15	<0.001	61.1	60.5	60.7	60.3	0.21	0.039	0.497	0.641
24	60.0	58.5	0.51	0.053	60.6	60.1	57.1	59.0	0.71	0.063	0.028	0.892
Propionate (P, %)												
4	17.6	16.7	0.13	<0.001	16.2	16.8	17.2	18.3	0.14	<0.001	0.445	0.274
12	17.1	18.0	0.16	<0.001	16.7	17.5	17.7	18.2	0.23	<0.001	0.578	0.696
24	15.9	16.7	0.23	0.019	15.4	16.1	17.8	16.8	0.30	0.005	0.021	0.408
Butyrate (%)												
4	15.0	16.8	0.08	<0.001	15.8	16.1	16.1	15.6	0.12	0.210	0.007	0.137
12	16.1	18.0	0.04	<0.001	17.5	17.4	17.2	16.9	0.05	0.001	0.669	0.220
24	18.7	19.8	0.40	0.126	18.4	18.6	20.9	19.1	0.56	0.241	0.028	0.146
Branched chain VFA (%)												
4	4.1	3.8	0.04	<0.001	3.8	3.9	4.0	3.9	0.06	0.497	0.043	0.127
12	4.1	3.7	0.03	<0.001	4.1	3.9	3.8	3.9	0.04	0.004	0.015	0.347
24	4.8	4.5	0.07	0.038	4.9	4.6	4.4	4.6	0.10	0.066	0.011	0.798
A:P												
4	3.58	3.71	0.031	0.003	3.94	3.72	3.58	3.37	0.044	<0.001	0.097	0.227
12	3.63	3.31	0.039	<0.001	3.66	3.46	3.44	3.31	0.054	<0.001	0.264	0.616
24	3.78	3.53	0.073	0.028	3.94	3.76	3.37	3.54	0.105	0.009	0.021	0.684

[1] P1 = Barley grain ground to pass through 1.00 mm screen; P2 = Steam rolled barley grain.
[2] SEM = Standard error of the mean. [3] L = Linear effect of the surfactant; Q = Quadratic effect of the surfactant.
[4] ADMD = Apparent dry matter disappearance.

reduced or tended to linearly reduce (p values ranging from 0.063 to <0.001) molar proportion of acetate but linearly increased (p<0.01) molar proportion of propionate, which resulted in a linear decrease (p<0.05) of A:P during the 24-h incubation.

DISCUSSION

Effects of tempering on animal performance

The observation of this study that growth of feedlot cattle in the backgrounding but not in the finishing period was increased by tempering differed from our previous study (Wang et al., 2003) in that tempering as compared to dry-rolling had no effect on growth of cattle in the backgrounding period but increased it during the finishing period when both forms of barley were optimally processed. The difference in animal growth of these two studies is likely due to the difference of feeding system employed and the different PI of the processed barley. The cattle used in this study were fed as a group in outside open pens whereas cattle used in Wang et al. (2003) were fed individually inside the barn. The PI of barley grain has been found to have a profound impact on animal performance and Wang et al. (2003) suggested that a PI of 75% might be optimal for feedlot cattle fed barley-based finishing diets. In our previous study (Wang et al., 2003), tempering reduced PI from 81 to 72%, a value that is close to this optimal level, whereas PI in the current study were reduced from 78 to 60% by tempering.

Animal growth is closely related to feed intake. In this study and Wang et al. (2003), the similar feed intake but improved animal growth rates suggests that tempering results in an improvement in the feed efficiency of feedlot cattle fed tempered as compared to dry-rolled barley. These results are in agreement with the consistent observation that tempering improved feed efficiency in all nine experiments in comparing effect of dry rolling and tempering rolling on growth performance of feedlot cattle (Alberta Feedlot Management Guide, 2009).This is likely due to the fact that tempering reduces the proportion of small size particles (i.e.,

fines) as illustrated in Table 2, which would decrease the initial rate of fermentation upon ingestion of large quantities of processed grain and may therefore provide more favorable conditions for rumen celllulolytic bacteria to digest the fiber proportion of the diet.

Effects of surfactant applied during tempering on animal performance

Similar growth rates between cattle fed processed grain with and without surfactant during tempering as well as their similar DMI indicate surfactant supplementation during tempering did not affect these two parameters in this study. Our previous study (Wang et al., 2003), however, showed that both DMI and ADG were increased in the backgrounding period although this was not observed in the finishing or overall periods of the experiment. In that study, we also observed that the effect of surfactant on animal growth performance was mediated by the roller setting (i.e., the extent of the barley grain being processed). The PI of M and MS barley in this study was 59 to 62 whereas it was 71 to 72 in Wang et al. (2003). This difference may have resulted in the apparent discrepancy between these two studies with regard to the impact of the surfactant on growth performance of feedlot cattle.

Feed efficiency at all stages of growth was higher for cattle fed MS than for cattle fed D grain, whereas a difference in FE between D and M was observed only during the backgrounding period but no difference was detected between M and MS. This indicated that surfactant alone did not affect FE under the experimental situation of this study. Wang et al. (2003) reported that efficacy of the surfactant in improving FE was mediated by the PI. In that study, application of surfactant improved FE in the finishing period when barley was processed to PI of 78 to 79, but not in the backgrounding period when barley grain was processed to PI of 71 to 72. The PI of M and MS in the current study were 59 to 62. The results of both studies indicate that inclusion of surfactant during tempering may improve FE to an extent that is greater than that of tempering alone. However, the efficacy of the positive effect of tempering with surfactant on animal performance may be mediated by the degree that the barley grain is processed after the tempering. However, the mechanism by which tempering barley with surfactant improves FE is not clear. Steroidal saponin, which is the effective compound of this surfactant, has been shown to improve rumen fermentation and energy efficiency (Santoso et al., 2004). However, the amount of the saponin in surfactant used (60 μl/kg DM) in tempering in this study would be considered too low to offer significant biological effects on rumen metabolism as that indicated in the *in vitro* experiment of this study and others (e.g., Wang et al., 2005). It is likely that the surfactant applied during tempering altered the processing characteristics that could not be detected by the current method (sieving) employed to characterize the processed barley grain. It is a common observation in our studies that a portion of the particles especially those retained on top screens (<3.35 mm) were actually smaller than the screen size but stuck together, preventing them from passing through the screen. Therefore, the similarity in processing characteristics of barley grain between tempering with and without surfactant determined using the method that is based on the sieving technique in this study and others (e.g., Wang et al., 2003, 2005) might not be able to reflect some of the characteristics that differ between these two treatments.

Effects of surfactant on *in vitro* rumen fermentation of barley grain

The linear increase of ADMD and SD as the concentration of the surfactant increased indicated that surfactant increased the microbial digestion of the barley grain. Productions of total gas and total VFA on per g of ADMD, however, were linearly reduced. This suggests that the energy from increased ADMD/SD by the surfactant was partitioned towards other metabolic pathways such as microbial protein synthesis rather than towards producing VFA or waste gas. This is consistent with our earlier research in that the steroidal saponins (the effective compound of this surfactant), promoted growth of ruminal bacteria that digest starch, enhanced *in vitro* digestion of barley grain, increased microbial protein synthesis and the ratio of propionic to acetic acid, decreased protozoal numbers and reduced protein degradation in the rumen (Wang et al., 1998, 2000a, b). Increased efficiency of rumen microbial protein synthesis by saponin and saponin-based surfactant was also observed in *in vitro* and *in vivo* studies (Zinn,et al., 1998; Santoso et al., 2004; Pen et al., 2006).

Anti-protozoal and anti-microbial activities of saponins are well described in the literature. The observation that methane production per unit of ADMD was only decreased by the surfactant at 4-h, but not at 12 or 24-h incubation suggests that the methane-decreasing effect of the surfactant may mainly be attributed to the anti-protozoal action of the saponin in the surfactant. The similar observation was also reported for other sources of saponins (Hu et al., 2005; Goel et al., 2008; Guo et al., 2008). However, the linear reduction of acetate molar proportion accompanied with linear increase of propionate molar proportion indicated the rumen microbial populations were altered by the saponins in the surfactant which is supported by our earlier study and others (Wang et al., 2000a; Muetzel et al., 2003; Wina et al., 2006; Goel et al., 2008).

The purpose of using barley grain processed to two distinct particle sizes (ground to 1.00 mm vs. stream rolled) in the *in vitro* experiment was to define the effect of

interaction between feed particle size and surfactant on ruminal fermentation. Our previous study (Wang et al., 2003) observed that application of surfactant during tempering increased growth rate of feedlot cattle to a greater extent when barley grain was processed with smaller roller space (barley grain was processed to a greater extent) than that of processed with larger roller space, suggesting efficacy of the surfactant in improving animal performance was mediated by the grain particle size. However, the results of this study showed a similar trend of the effect of the surfactant on rumen fermentation regardless of barley grain being processed to fine (ground) or to large (steam rolled) particles. Wang et al. (2005) also found the same trend of surfactant on the *in vitro* ruminal fermentation between barley grains rolled at two different roller settings. This suggests that particle size mediated effects of the surfactant on animal performance need to be explained by the mechanism other than that particle size of barley grain influenced the effect of surfactant on rumen fermentation, which needs to be further studied.

CONCLUSION

Compared to dry grain, tempering barley to increase moisture from 7.7 to 18% prior to rolling increased the steers' ADG and FE during backgrounding. Inclusion of 60 ppm surfactant during this tempering process increased ADG during backgrounding and improved FE at all stages of growth. Supplementation of processed barley grain with a surfactant increased ruminal ADMD and SD but reduced the amounts of total gas and VFA produced per g ADMD and reduced the A:P ratio irrespective of the processed particle size of barley grain. Mechanism of feed particle mediated effect of surfactant on animal performance needs to be further investigated.

ACKNOWLEDGEMENTS

This study was conducted with financial support from Agrichem, Inc. and the Matching Investment Initiative of Agriculture and Agri-Food Canada. The authors sincerely appreciate the assistance of Z. Xu, W. Smart, B. Baker, F. Van Herk, M. Anderson and J. Yanish. This is Lethbridge Research Centre contribution number 38710049.

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