Evaluation of ad libitum acidified milk replacer programs for dairy calves

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ABSTRACT

Due to renewed interest in feeding acidified milk replacer (MR) for ad libitum consumption within North America, two 112-d trials were conducted using Holstein calves obtained from one dairy farm at 2 to 3 d of age. In trial 1, a 27% crude protein (whey protein), 17% fat MR powder was reconstituted with water to 14% solids and fed at 0.66 kg of dry matter (DM) per day for 42 d (CON) or acidified to pH 4.2 using citric acid and offered 24 h/d for d 0 to 35, then switched to 0.66 kg of DM without acid per d for 7 d (A4). In trial 2, the same MR was fed as CON, ad libitum pH 5.2 MR offered from 0600 to 0800 h and 1600 to 1800 h for d 0 to 21 (R5), ad libitum pH 5.2 MR offered 24 h/d for d 0 to 35 (A5), and ad libitum pH 4.2 MR offered 24 h/d for d 0 to 35 (A4). After the ad libitum period, calves on R5, A5, and A4 were switched to CON until d 42. Growth measures were made until d 112 in each trial. Data from each trial were analyzed as a completely randomized design with repeated measurements over time using an autoregressive type 1 covariance structure when appropriate. In each trial, calves fed CON had lower average daily gain (ADG) from 0 to 42 d and greater ADG from 42 to 56 d than calves fed the other treatments. In both trials, ADG from 0 to 56 d and 56 to 112 d were not greater for A4 or A5 versus CON. From 56 to 112 d in trial 2, ADG was greater for R5 versus A5. Some calves completely rejected the MR at pH 4.2. Calves consumed more of the MR at pH 5.2 than 4.2. Calves fed A4 in trial 1 and treatments A5 and A4 in trial 2 consumed >95% of their MR between 0600 to 0800 h and 1600 to 1800 h. Time spent standing did not differ by treatment in trial 1 and increased from 312 to 332 min/d from d 6 to 56. Under the conditions of these trials, results to 112 d showed no advantage to feeding calves MR acidified to pH 4.2 or 5.2 ad libitum from 0 to 35 d with gradually weaning by 42 d compared with calves fed the control MR fed at 0.66 kg of DM/d. Additionally, when calves were fed MR ad libitum, they consumed >95% of the

MR between 0600 to 0800 h and 1600 to 1800 h and standing behavior was not greatly affected.

Key words: acidified milk replacer, feeding rate, calf, behavior

INTRODUCTION

Farm advisors in Canada and the United States have proposed group housing of calves fed acidified milk or milk replacer (MR) as a means to increase the ADG of calves in a healthy and humane environment while reducing labor requirements (Anderson, 2006; Conway, 2011). A challenge with feeding milk or MR for ad libitum consumption without using a computer feeder is keeping the milk available at all times while minimizing bacterial growth and contamination. This has been addressed by feeding calves ad libitum milk, but only for 4 h/d in 2 h periods in the a.m. and p.m., which supported similar milk intake, starter intake, and ADG to calves offered milk for 24 h/d (von Keyserlingk et al., 2006).

Several researchers have evaluated the effect of ad libitum MR feeding on intake and growth of calves (Thickett et al., 1983; Nocek and Braund, 1986; Fallon and Harte, 1988; Richard et al., 1988; Hepola et al., 2008). Where postweaning measurements were made (Nocek and Braund, 1986), calves fed the ad libitum plane of nutrition had greater ADG preweaning, but less ADG postweaning compared with calves fed conventionally (approximately 440 g of DM/d). This pattern of growth is true in calves fed low versus high planes of both milk (Bar-Peled et al., 1997; Jasper and Weary, 2002) and MR (Cowles et al., 2006; Hill et al., 2006) in non-ad libitum situations. The reduced ADG in postweaned calves has been overcome with gradual weaning over approximately 21 d (Khan et al., 2007; Hill et al., 2007, 2012; Sweeney et al., 2010).

It is difficult to assess intake of starter and feed efficiency in groups of calves compared with individually housed calves. However, it has been reported that calves fed large amounts of milk or MR and managed either as individuals or groups did not differ in MR intake, starter intake, or ADG (Nocek and Braund, 1986; Richard et al., 1988; De Paula Vieira et al., 2010), allowing research with calves in individual pens to be used.

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Choice of acids used to acidify MR is also in question; several studies have used formic acid to reduce MR pH (Bush and Nicholson, 1987; Hepola et al., 2008). However, acidifying MR with formic acid is not approved by the Food and Drug Administration. Bush and Nicholson (1987) reported that acidifying MR with formic acid reduced MR intake compared with propionic acid, formaldehyde, or unacidified control MR. Most commercial applications in the United States rely on citric acid as acidifying agent; however, few data are available in the literature that report the use of this acid as an acidifying agent. Final pH of the solution may also affect voluntary intake and subsequent performance. Studies have reported many different final MR pH: 5.6 (Thickett et al., 1983), 4.5 or 5.0 (Hepola et al., 2008), and 5.3 or 5.7 (Bush and Nicholson, 1987).

The aim of trial 1 was to evaluate an MR acidified to pH 4.2 and offered to calves ad libitum in nipple pails. Our hypothesis was that calves fed ad libitum would gain more BW preweaning, but less postweaning. Based on the results on trial 1, the aim of trial 2 was to re-evaluate ad libitum-fed MR acidified to a different pH (4.2 and 5.2), for different durations over a day (4 and 24 h availabilities/d), and total number of days (21 and 35 d). Our hypothesis was that calves fed a high pH MR would not reject it and would have greater intake. Also, calves with 4-h feed availability per day would perform equally to calves with 24-h feed availability. Finally, calves fed ad libitum for 21 d would gain as much BW as calves fed ad libitum for 35 d.

MATERIALS AND METHODS

Trial 1

All calves were cared for as described in the *Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching* (FASS, 2010). Holstein bull calves (2 to 5 d of age, $n = 20$) from a single dairy farm were transported 3.5 h to the Nurture Research Center in southwest Ohio and received at ~1100 h. Calves were randomly assigned to treatments on ar-

rival and offered their first MR at 1600 h. At 1100 h the day after arrival, the calves were weighed (initial BW), blood was sampled from the jugular vein, serum was harvested, and serum protein concentration was immediately measured using an optical refractometer (Atago U.S.A. Inc., Bellevue, WA).

A 27% CP (whey protein), 17% fat MR powder (DM basis; Table 1) was reconstituted with warm water to 14% solids. The final solution temperature was 45 to 46°C. Control calves (**CON**) were fed 0.68 kg (as-fed basis) of powder via this solution daily in 2 equal meals at 0600 and 1600 h. A second group of calves were fed the same MR solution acidified to pH 4.2 (**A4**). The liquid solution was cooled to 32°C and citric acid powder was stirred in slowly to reach the target pH. The acidified MR was placed in a covered container at 21°C for 24 h before being fed. It was agitated by hand with a whisk for approximately 60 s at 0800, 1200, and 1800 h immediately before feeding. To feed, the reconstituted MR was reheated to 45 to 46°C in a double water bath. All calves were fed MR via a nipple pail. Refused MR was weighed, and new MR fed was weighed at 0600, 0800, 1200, 1600, and 1800 h daily on d 0 to 35 for the ad libitum MR portion of the trial. The temperature of the MR fed and the MR unconsumed was measured. From d 36 to 42, all calves were fed the MR without acidification. Calves were completely weaned by d 42 by only feeding MR at 0600 h on d 40, 41, and 42. Calves were fed a textured starter (20% CP on DM basis; 37% whole corn, 35% supplement pellet, 25% whole oats, 3% molasses; supplement pellet contained 66% soybean meal, 22% wheat middlings, 9% minerals and vitamins, 3% molasses; Table 1). Calves were fed starter and water ad libitum. Newly fed and refused starter was weighed daily.

The MR powder was sampled daily at the a.m. feeding and composited. Every second bag (22.7 kg) of starter feed was sampled and composited. Composites of feeds were analyzed (AOAC International, 2000) for DM (oven method 930.15), fat (alkaline treatment with Röse-Gottlieb method 932.06 for MR; diethyl ether extraction method 2003.05 for starters and hay), and

Table 1. Nutrient analysis (% of DM, unless otherwise noted) of feeds used in trials 1 and 2

Nutrient	Milk replacer		Starter		Hay	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
DM, %	96.2	96.2	87.3	87.6	88.5	88.5
CP	27.3	27.3	20.7	20.6	14.9	14.7
Fat	18.1	18.0	3.9	3.7	3.9	3.7
ADF	—	—	5.9	6.1	32.5	33.9
NDF	—	—	11.9	12.3	51.3	53.4
Ca	0.85	0.84	0.81	0.84	0.71	0.69
P	0.63	0.63	0.62	0.61	0.28	0.25

Ca and P (dry ashing, acid digestion, analysis by ICP, method 985.01). Additionally, the starter (and hay in trial 1a and 2a) was analyzed for NDF with ash by the procedure of Van Soest et al. (1991) without sodium sulfite or α -amylase, and ADF with ash (Robertson and Van Soest, 1981).

Calves were weighed every 7 d until the end of the trial (d 56). Feed offered and refused were weighed daily. Fecal scores were assigned daily based on a 1 to 5 system (1 = normal, thick in consistency; 2 = normal, but less thick; 3 = abnormally thin but not watery; 4 = watery; 5 = watery with abnormal coloring; modified from Kertz and Chester-Jones, 2004). Hip widths were measured with a caliper, and BCS of calves were measured during the initial (d 0) measurement period and every 14 d thereafter. A 1 to 5 system using 0.25 unit increments, with 1 = emaciated and 5 = obese, was used for BCS (Wildman et al., 1982). Scores were based on changes around the vertical and transverse processes of the spine, as palpated by one experienced technician, and ranged from 1.5 to 3.5. The trial was conducted during the months of December through February. The average ambient temperature inside the barn during the trial was 1°C and ranged from -15 to 15°C, based on hourly measurements. The average humidity was 78% and ranged from 44 to 100%.

Standing and lying behavior was recorded via an electronic data logger (HOBO Pendant G Acceleration Data Logger, Onset Computer Corporation, Pocasset, MA) attached to the medial side of the right rear leg of 5 calves randomly selected per treatment. A plastic identification bracelet (Nasco, Fort Atkinson, WI) was attached to the leg and the logger was taped (Vet Wrap Co-Flex, Andover Coated Products Inc., Salisbury, MA) to the bracelet. Tape was then applied over the logger and bracelet. The logger was attached on d 4 and set to record data every 5 min from d 6 to 56. Data were managed with adjustments for a 5-min recording interval and categorized either as standing or lying similar to the description in Ito et al. (2009).

Calves were housed in 1.2 × 2.4 m individual pens within a curtain sidewall barn with no added heat. The pens were bedded with long straw. Calves received an intranasal tissue sensitive respiratory disease vaccine (TSV-2, Pfizer, Exton, PA) and subcutaneous injections of vitamins A, D, E (Vital E - A + D, Schering-Plough Animal Health, Union, NJ), and Se (MU-SE, Schering-Plough Animal Health) upon arrival. Calves received an intramuscular respiratory disease vaccine (Bovashield Gold 5, Pfizer) at d 7 and again at d 28. At d 14 and 49 calves received an intramuscular vaccine for types C and D *Clostridium* (Vision 7 with Spur, Intervet Inc., Millsboro, DE) and a subcutane-

ous *Clostridium perfringens* type A toxoid (Novartis, Larchwood, IA). A *Pasteurella* vaccine (Presponse HM, Fort Dodge, Fort Dodge, IA) was administered intramuscularly on d 35 and 49. Calves were castrated and dehorned at 39 d of age. Calves that scoured (fecal scores >2) were treated with oral electrolytes. Antibiotics were not used because the major historical causes of diarrhea in this unit are *rotavirus* or *Cryptosporidium parvum*. Additionally, the duration of diarrhea in this trial was short and antibiotics were not necessary. No calves were treated for other reasons or received other health-related products.

Data were analyzed using the MIXED procedure of SAS (Version 8, SAS Institute Inc., Cary, NC) as a completely randomized design. The statistical model used was

$$Y_{ijkl} = \mu + T_i + w_j + Tw_{ij} + C_k(T_i) + \varepsilon_{ijkl},$$

where Y_{ijkl} is the observed measurement; μ represents the overall population mean; T_i is the fixed effect of treatment i ; w_j is the random effect of week j ; Tw_{ij} is the interaction of treatment i and week j ; $C_k(T_i)$ is the random effect of calf k nested within treatment i that was used to test effect of treatment; and ε_{ijkl} is the residual assumed to be normally distributed with mean zero. Week was modeled as a repeated measurement using an autoregressive type 1 covariance structure.

Trial 1a

To assess the effect of 2 MR programs on subsequent growth postweaning, calves from trial 1 were moved to multi-calf pens on d 56 with calves grouped 4 per pen. An equal number of calves from each MR treatment were housed per pen; this precluded estimating DM intake by treatment. The diet was a mixture of the same starter used in trial 1 with 5% chopped grass hay. This diet and water were offered ad libitum. Feed refused and new feed offered to pens were weighed daily.

Pens provided 6.5 m² of outside space and 1.35 m² of inside space per calf. The inside space was bedded with long straw and had no added heat. No animals were sick or were treated for sicknesses or vaccinated during the 56-d trial. Calves were weighed, hip widths were measured, and body condition was scored initially and every 28 d thereafter. Feed offered and refused was weighed daily. The trial lasted 56 d and was conducted during the months of February through April. Average ambient temperature during the trial was 11°C and ranged from -8 to 31°C, based on hourly measurements. Average humidity was 67% and ranged from 20 to 96%. Calf was the experimental unit. Growth data

were analyzed using the model used in trial 1. Week was replaced with a 28-d period.

Trial 2

Holstein bull calves (2 to 5 d of age, $n = 48$) from a single dairy farm were transported 3.5 h to the Nurture Research Center in southwest OH and were received at ~1100 h. treatments were randomly assigned and fed as in trial 1. Calves were managed and housed as in trial 1. The trial lasted 56 d and was conducted during the months of February through March. Average ambient temperature inside the barn during the trial was 7°C and ranged from -11 to 31°C, based on hourly

measurements. Average humidity was 72% and ranged from 33 to 96%.

A 27% CP (whey protein), 17% fat MR powder (DM basis; Table 1) was reconstituted with warm water to 14% solids. The final solution was heated to 45 to 46°C. Calves were fed 4 different MR treatments: control-fed at 0.68 kg of as-fed powder/d, in 2 equal meals at 0600 and 1600 h (**CON**); ad libitum-fed pH 5.2 MR offered at 0600 and 0800 h and 1600 and 1800 h for d 0 to 21 (**R5**); ad libitum-fed pH 5.2 MR offered 24 h/d for d 0 to 35 (**A5**); ad libitum-fed pH 4.2 MR offered 24 h/d for d 0 to 35 (**A4**). Reconstituted MR for R5 calves was acidified immediately after reconstitution to pH 5.2 and fed within the 2-h periods in the a.m. and p.m.

Table 2. Performance of calves fed a control milk replacer at a fixed rate (CON) or a milk replacer acidified to pH 4.2 fed ad libitum (A4) in trial 1

Item	CON	A4	SEM	<i>P</i> -value
Calves, no.	10	9	—	—
Initial serum protein, mg/dL	5.2	5.5	0.17	0.32
Initial BW, kg	45.9	42.6	1.49	0.12
ADG, kg/d				
0 to 42 d	0.589	0.700	0.0309	0.02
42 to 56 d	0.754	0.680	0.0305	0.05
0 to 56 d	0.630	0.695	0.0309	0.09
Milk replacer intake ¹				
kg of DM/d, 0 to 42 d	0.632	0.915	0.1103	0.01
Total kg of DM, 0 to 42 d	26.6	38.5	4.64	0.01
Starter intake, kg of DM/d				
0 to 42 d	0.357	0.286	0.0390	0.20
42 to 56 d	1.794	1.849	0.1242	0.75
0 to 56 d	0.717	0.677	0.0564	0.62
Feed efficiency, gain/feed				
0 to 42 d	0.595	0.583	0.0529	0.75
42 to 56 d	0.420	0.368	0.0303	0.04
0 to 56 d	0.529	0.509	0.0308	0.13
Medical days, no.				
0 to 42 d	2.1	2.6	0.48	0.47
42 to 56 d	0.3	0.2	0.14	0.62
0 to 56 d	2.4	2.8	0.50	0.57
Fecal score ²				
0 to 42 d	1.9	1.9	0.03	0.26
42 to 56 d	1.7	1.9	0.07	0.01
0 to 56 d	1.8	1.9	0.03	0.02
Abnormal fecal score ² days, no.				
0 to 42 d	0.3	0.4	0.24	0.77
42 to 56 d	0.0	0.0	0.04	1.00
0 to 56 d	0.3	0.4	0.23	0.76
Initial BCS ³	2.3	2.2	0.04	0.04
Body condition change				
0 to 42 d	0.2	0.4	0.05	0.10
42 to 56 d	0.1	0.0	0.05	0.16
0 to 56 d	0.3	0.3	0.06	0.77
Initial hip width, cm	18.4	17.8	0.30	0.17
Hip width change, cm				
0 to 42 d	3.2	3.5	0.19	0.03
42 to 56 d	1.6	1.4	0.19	0.14
0 to 56 d	4.8	4.9	0.23	0.16

¹Citric acid was not accounted in this table. Average used 44 g per 1,000 g of milk replacer.

²Fecal scores were assigned daily based on a 1 to 5 system (1 = normal, thick in consistency; 2 = normal, but less thick; 3 = abnormally thin but not watery; 4 = watery; 5 = watery with abnormal coloring).

³Scores: 1 to 5 point system (1 = thin, 5 = obese).

Reconstituted MR was weighed before feeding and after the 2-h period. From d 22 to 42 these calves were fed the same MR and amount as the control. Similar to R5 calves, A5 calves were fed pH 5.2 MR, but feed was offered ad libitum for d 0 to 35; from d 36 to 42 these calves were fed as the control. treatment A4 calves were fed the same MR solution as CON, but acidified to pH 4.2. This liquid solution was cooled to 32°C and citric acid powder was stirred in slowly to reach the target pH of 4.2. The acidified MR was set in a covered container at 21°C for 24 h before being fed to allow the liquid to become homogenous before feeding (Anderson, 2006). It was agitated by hand with a whisk for approximately 60 s at 0800, 1200, and 1800 h immediately before feeding. To feed, the reconstituted acidified MR was reheated to 45 to 46°C in a double water bath. Calves fed acidified MR had unconsumed MR weighed and new MR fed weighed at 0600, 0800, 1200, 1600, and 1800 h daily on d 0 to 35 for the ad libitum MR portion of the trial. From d 36 to 42, calves were fed MR without acidification as control. Calves were completely weaned by d 42 by only feeding MR at 0600 h on d 40, 41, and 42. Calves were fed starter (same as in trial 1) and water ad libitum. Statistical analysis was as described in trial 1. The 4 treatment means were separated using 3 preplanned contrast statements (CON vs. A5 and A4; R5 vs. A5; A5 vs. A4).

Trial 2a

To assess the effect of 4 MR programs on subsequent growth post-weaning, calves from trial 2 were moved to multi-calf pens on d 56 with calves grouped 4 per pen. Calves were grouped by MR treatments. Measurements were the same as in trial 1a. The trial lasted 56 d and was conducted during the months of March through May. Average ambient temperature during the trial was 15°C and ranged from 0 to 32°C, based on hourly measurements. Average humidity was 65% and ranged from 20 to 94%. Statistical analysis was as described in trial 1a. treatment means were separated using 3

preplanned contrast statements (CON vs. A5 and A4; R5 vs. A5; A5 vs. A4).

RESULTS

In each trial, control calves consumed all MR offered. The temperature of the acidified MR on offer exceeded 21°C between 0600 and 1800 h but frequently was as low as 15°C, and occasionally as low as 10°C at 0600 h after sitting overnight. Initial measurements of calves in each trial did not differ among treatments.

Trial 1

One calf fed A4 refused to drink any MR during the first 2 meals and was removed from the trial. Intake of MR was greater ($P < 0.05$) for calves fed A4 ad libitum than the calves fed control MR (0.657 vs. 0.951 kg/d; Table 2). Whereas calves fed A4 has access to milk 24 h/day to 35 d, they consumed 97.3% of the total day's intake between 0600 to 0800 h (53.5%) and 1600 to 1800 h (43.8%; Table 3). Starter intake did not differ ($P > 0.05$) between treatments. Calves fed CON had lower ADG ($P < 0.05$) from d 0 to 42 but greater ADG ($P < 0.05$) from d 42 to 56 than calves fed A4, and tended to have a lower overall ADG ($P < 0.10$). Feed efficiency was greater ($P < 0.05$) for calves fed CON compared with calves fed A4 from d 42 to 56. Change in hip widths were greater ($P < 0.05$) and change in BCS tended ($P < 0.10$) to be greater in calves fed A4 compared with CON from d 0 to 42. Days with abnormal fecal scores and medical treatment did not differ between treatments; however, calves fed A4 had greater fecal scores (looser feces; $P < 0.05$) from d 42 to 56 than calves fed CON.

Standing behavior was monitored from d 6 to 56 (Table 4). During d 6 to 35, when the MR treatments were applied, total time spent standing did not differ between treatments ($P > 0.26$; 342 min for CON, 315 min for A4; 23% of the day), but CON cows spent approximately 30 more min standing between 1200 and

Table 3. Percentage of acidified milk replacers consumed during different time periods of the day when fed ad libitum during trials 1 and 2

Time period ¹	Length of period, h	Trial 1, pH 4.2	Trial 2, pH 5.2	Trial 2, pH 4.2
0600 to 0800 h	2	53.5	49.9	51.3
0800 to 1200 h	4	1.1	2.9	1.9
1200 to 1600 h	4	0.3	0.5	0.2
1600 to 1800 h	2	43.8	45.6	45.9
1800 to 0600 h	12	1.3	1.1	0.7
SEM	—	4.27	1.94	3.84

¹Data presented as percent of daily milk replacer consumed.

Table 4. Standing time (min) of calves fed a control milk replacer at a fixed rate (CON) or a milk replacer acidified to pH 4.2 and fed ad libitum between d 6 and 35 (A4) in trial 1

Time period	Length of period, h	CON	A4	SEM	<i>P</i> -value
0600 to 0800 h	2	63	50	8.8	0.15
0800 to 1200 h	4	73	74	9.9	0.93
1200 to 1600 h	4	104	72	11.8	0.03
1600 to 1800 h	2	26	36	5.2	0.10
1800 to 0600 h	12	75	83	11.9	0.53
Total day	24	342	315	41.7	0.54
% of total day	—	24	22	—	—

1600 h ($P < 0.03$; 104 vs. 72 min). Total standing time increased over the trial (d 6 to 56; $P < 0.03$) by only 20 min (312 to 332 min; 21.6 to 23.0% of the day).

Trial 1a

Calves previously fed CON had greater ($P < 0.05$) change in hip widths from d 56 to 112 than calves previously fed A4 (Table 5). Calf DM intake over the 56-d trial averaged 3.5 kg of DM/d, or 3.1% of BW. Otherwise no differences in calf performance were observed.

Trial 2

Two calves fed A4 refused to drink any MR during the first 2 meals and were removed from the trial. Intake of MR among the 4 treatments ranked A5 > A4 > R5 > CON (Table 6). Intake of MR by week among the 4 treatments is shown in Figure 1. The 2 pH 5.2 treatments (R5 and A5) were evaluated because of feed refusals when calves were offered MR at pH 4.2 MR

in trial 1; our data suggest that pH 4.2 is marginally palatable. Whereas calves fed A5 and A4 were offered MR ad libitum from d 0 to 35, they consumed >95% of the total day's intake between 0600 to 0800 h and 1600 to 1800 h (Table 3). Variability of MR intake was large for R5, A5, and A4 (Table 7), and appeared to decrease in wk 4 and 5 with calves fed A5 versus A4. Starter intake did not differ among the treatments. From d 0 to 42, ADG was less ($P < 0.05$) for calves fed CON versus A5 and A4, and greater ($P < 0.05$) for calves fed R5 versus A5. From d 42 to 56, ADG was less ($P < 0.05$) for calves fed A5 and A4 versus CON, and greater ($P < 0.05$) for calves fed R5 versus A5. From d 0 to 56, ADG tended ($P < 0.10$) to be less for calves fed CON versus A4 and A5, and tended ($P < 0.10$) to be greater for calves fed A5 versus A4. From d 42 to 56, feed efficiency was greater ($P < 0.05$) for calves fed CON versus A5 and A4, and tended ($P < 0.10$) to be greater for calves fed A4 versus A5. Some differences in hip width changes were noted during d 0 to 42 and d 42 to 56, however, overall (d 0 to 56) no differences were ob-

Table 5. Performance of calves previously fed a control milk replacer at a fixed rate (CON) or a milk replacer acidified to pH 4.2 and fed ad libitum (A4) in trial 1a

Item	CON	A4	SEM	<i>P</i> -value
Calves, no.	10	9		
Initial BW, kg	80.4	84.0	3.13	0.41
Final BW, kg	148.9	150.3	5.35	0.85
Initial hip width, cm	10.2	10.5	0.14	0.19
Final hip width, cm	13.0	12.9	0.14	0.74
Initial BCS	2.6	2.5	0.83	0.69
Final BCS	3.1	2.9	0.82	0.17
ADG, kg/d				
56 to 84 d	0.922	0.955	0.0900	0.79
84 to 112 d	1.525	1.411	0.0986	0.41
56 to 112 d	1.224	1.183	0.0491	0.57
Hip width, cm				
56 to 84 d change	2.5	2.0	0.28	0.17
84 to 112 d change	3.5	3.3	0.25	0.62
56 to 112 d change	6.0	5.3	0.19	0.01
BCS ¹				
56 to 84 d change	0.1	0.1	0.071	0.87
84 to 112 d change	0.4	0.3	0.076	0.38
56 to 112 d change	0.5	0.4	0.071	0.27

¹Scores: 1 to 5 point system (1 = thin, 5 = obese).

Table 6. Performance of calves fed a control milk replacer at a fixed rate (CON), a milk replacer acidified to pH 5.2 and fed ad libitum during 2-h time periods in the a.m. and p.m. (R5), a milk replacer acidified to pH 5.2 and fed ad libitum (A5), and a milk replacer acidified to pH 4.2 and fed ad libitum (A4) in trial 2

Item	CON	R5	A5	A4	SEM	Preplanned contrast <i>P</i> -value			
						CON vs. A5+A4	R5 vs. A5	A5 vs. A4	Overall <i>P</i> -value
Calves, no.	12	12	12	10	—	—	—	—	—
Initial serum protein, mg/dL	5.0	5.0	5.0	5.1	0.19	0.73	0.88	0.76	0.96
Initial BW, kg	42.3	47.4	46.6	42.9	1.64	0.12	0.70	0.10	0.04
ADG, kg/d									
0 to 42 d	0.520	0.601	0.691	0.616	0.0324	0.02	0.03	0.09	0.00
42 to 56 d	1.111	1.131	1.006	1.021	0.0335	0.02	0.04	0.89	0.05
0 to 56 d	0.668	0.734	0.770	0.718	0.0276	0.07	0.44	0.08	0.09
Milk replacer intake ¹									
kg/d, 0 to 42 d	0.632	0.790	0.968	0.863	0.0277	0.001	0.001	0.01	0.001
Total kg, 0 to 42 d	26.6	33.2	40.7	36.3	1.16	0.001	0.001	0.01	0.001
Starter intake, kg/d									
0 to 42 d	0.269	0.294	0.218	0.237	0.0360	0.93	0.09	0.71	0.34
42 to 56 d	1.803	2.012	2.024	1.834	0.1448	0.45	0.94	0.33	0.49
0 to 56 d	0.652	0.724	0.670	0.636	0.0594	0.68	0.46	0.66	0.68
Feed efficiency, gain/feed									
0 to 42 d	0.577	0.554	0.583	0.560	0.0220	0.69	0.27	0.45	0.72
42 to 56 d	0.616	0.562	0.497	0.557	0.0217	0.04	0.23	0.06	0.04
0 to 56 d	0.593	0.558	0.551	0.560	0.0200	0.26	0.94	0.61	0.53
Medical days, no.									
0 to 42 d	2.1	3.0	3.8	3.0	0.60	0.17	0.31	0.35	0.18
42 to 56 d	0.7	0.5	0.3	0.6	0.28	0.65	0.46	0.41	0.66
0 to 56 d	2.8	3.5	4.0	3.6	0.73	0.33	0.58	0.65	0.58
Fecal score ²									
0 to 42 d	1.9	2.1	2.0	2.0	0.05	0.15	0.76	0.39	0.22
42 to 56 d	1.9	2.0	2.0	1.8	0.06	0.52	0.82	0.06	0.13
0 to 56 d	1.9	2.0	2.0	1.9	0.05	0.14	0.85	0.17	0.09
Abnormal fecal score ² days, no.									
0 to 42 d	0.5	1.7	1.6	0.7	0.43	0.16	0.88	0.12	0.07
42 to 56 d	0.3	0.7	0.7	0.2	0.27	0.71	1.00	0.23	0.48
0 to 56 d	0.8	2.3	2.3	0.9	0.59	0.23	0.91	0.09	0.07
Initial BCS ³	2.2	2.3	2.2	2.2	0.04	0.34	0.02	0.77	0.10
BCS change									
0 to 42 d	0.2	0.2	0.4	0.3	0.06	0.35	0.01	0.36	0.02
42 to 56 d	0.1	0.1	0.0	0.1	0.06	0.40	0.08	0.17	0.11
0 to 56 d	0.3	0.3	0.4	0.4	0.06	0.92	0.40	0.67	0.66
Initial hip width, cm	17.3	17.9	18.1	17.7	0.31	0.17	0.58	0.34	0.23
Hip width change, cm									
0 to 42 d	2.8	2.9	3.3	3.1	0.22	0.93	0.13	0.04	0.05
42 to 56 d	2.3	2.2	2.0	2.0	0.25	0.06	0.54	0.54	0.30
0 to 56 d	5.1	5.1	5.3	5.1	0.36	0.20	0.61	0.38	0.30

¹Citric acid was not accounted in this table. Average used was 12 and 44 g per 1,000 g of milk replacer for pH 5.2 and 4.2, respectively.

²Fecal scores were assigned daily based on a 1 to 5 system (1 = normal, thick in consistency; 2 = normal, but less thick; 3 = abnormally thin but not watery; 4 = watery; 5 = watery with abnormal coloring).

³Scores: 1 to 5 point system (1 = thin, 5 = obese).

served. No differences among treatments in days with abnormal fecal scores, medical treatments, or average fecal scores were observed.

Trial 2a

From d 56 to 112, calves on CON had a greater ADG ($P < 0.05$) than calves on A5 and A4, whereas calves on R5 had a greater ADG ($P < 0.05$) than calves on A5 (Table 8). Intake did not differ ($P < 0.05$) among treatments. From d 56 to 112, calves on CON had greater

feed efficiency ($P < 0.05$) than calves on A5 and A4, whereas calves on R5 had greater feed efficiency ($P < 0.05$) than calves on A5. From d 56 to 112, calves on CON had greater change in hip width ($P < 0.05$) than calves on A5 and A4, whereas calves on R5 had greater change in hip width ($P < 0.05$) than calves on A5.

DISCUSSION

Intake of pH 4.2 MR was a concern in these trials, with 3 of 22 calves refusing to drink any MR and with

Figure 1. Intake of milk replacer by week by calves fed a control milk replacer at a fixed rate (CON), a milk replacer acidified to pH 5.2 and fed ad libitum during 2-h periods in the a.m. and p.m. (R5), a milk replacer acidified to pH 5.2 and fed ad libitum (A5), and a milk replacer acidified to pH 4.2 and fed ad libitum (A4) in trial 2. Treatments CON and R5 were fed at the same fixed rate during wk 4 and 5. During wk 6, all calves were fed the same fixed rate of milk replacer. Variation reported in Table 7. Color version available in the online PDF.

intake of pH 4.2 MR being less than intake of pH 5.2 MR in trial 2. This related to less preweaning ADG in trial 2 with calves fed A4 versus A5. Others that have acidified milk replacer generally have maintained pH at or above 5.2 (Bush and Nicholson, 1987; Fallon and Harte, 1988; Woodford et al., 1987). Digestion in calves only fed MR was unaffected with acidification to pH 5.3 (Woodford et al., 1987).

It was interesting that >95% of the MR consumed by calves fed ad libitum was consumed during the 2-h intervals during the a.m. and p.m., despite those cows having the opportunity to consume MR 24 h per day. This is somewhat consistent with results reported by von Keyserlingk et al. (2006). Whereas they did not

measure intake over different hours of the day, they measured time spent on the nipple of pails. The majority of time on the nipples was around the 2 h of milk feeding in the a.m. and p.m. for both calves fed milk during this restricted time period and calves fed ad libitum 24-h daily. Milk intake, starter intake, and ADG did not differ between their treatment groups.

The pattern in MR intake increasing over time for the different treatments (Figure 1) has been reported in experiments where milk was delivered using automated feeders. Borderas et al. (2009) and de Passillé et al. (2011) reported a substantial increase in milk intake as the calf aged, similar to what we observed. Conversely, Jensen (2006) reported little increase in milk consumption with increasing age in 3 different breeds. Jensen (2006) did cap intake, however, preventing a large increase in milk consumed. Many of their calves appeared not to consume the maximum allowed intake (7.2 to 9.6 L/d depending upon breed) even after 42 d on the nipple (calves ≥ 54 d of age).

In trial 1, where standing time was measured, only minor differences were noted between MR treatments. Minutes standing per day only increased by 20 min (312 to 332 min) from d 6 to 56, when measurements were made. Panivivat et al. (2004) reported similar standing times as we observed, however, as their calves aged from 1 to 6 wk, time standing increased by approximately 110 min/d. Camiloti et al. (2012) reported approximately 100 min/d more standing time than we observed.

As in trials 2 and 2a, where ADG was increased over CON preweaning but decreased versus CON postweaning with A5 and A4, others have reported this in calves fed milk (Bar-Peled et al., 1997; Jasper and Weary, 2002) and calves fed unacidified MR (Cowles et al.,

Table 7. Minimum and maximum intake of milk replacer and CV by week for calves fed a control milk replacer at a fixed rate (CON), a milk replacer acidified to pH 5.2 and fed ad libitum during 2-h time periods in the a.m. and p.m. (R5), a milk replacer acidified to pH 5.2 and fed ad libitum (A5), and a milk replacer acidified to pH 4.2 and fed ad libitum (A4) in trial 2

Treatment	Wk 1	Wk 2	Wk 3	Wk 4	Wk 5
Minimum, kg of DM/d					
CON	0.655	0.655	0.655	0.655	0.655
R5	0.587	0.664	0.770	0.655	0.655
A5	0.433	0.510	0.645	1.059	1.059
A4	0.414	0.626	0.770	0.742	0.684
Maximum, kg of DM/d					
CON	0.655	0.655	0.655	0.655	0.655
R5	1.165	1.271	1.290	0.655	0.655
A5	1.040	1.233	1.242	1.348	1.445
A4	1.098	0.973	1.233	1.483	1.608
CV, %					
CON	—	—	—	—	—
R5	23.2	23.5	15.4	—	—
A5	22.1	22.2	15.5	8.5	9.2
A4	34.6	24.6	16.6	19.9	27.7

Table 8. Performance of calves previously fed a control milk replacer at a fixed rate (CON), a milk replacer acidified to pH 5.2 and fed ad libitum during 2-h time periods in the a.m. and p.m. (R5), a milk replacer acidified to pH 5.2 and fed ad libitum (A5), and a milk replacer acidified to pH 4.2 and fed ad libitum (A4) in trial 2a

Item	CON	R5	A5	A4	SEM	Preplanned contrast <i>P</i> -value			Overall <i>P</i> -value
						CON vs. A5+A4	R5 vs. A5	A5 vs. A4	
Pens, no.	3	3	3	3	—	—	—	—	—
Initial BW, kg	79.7	88.5	89.7	83.1	2.72	0.05	0.71	0.07	0.02
Final BW, kg	145.8	158.7	152.3	143.9	3.32	0.16	0.05	0.04	0.05
Initial hip width, cm	22.4	22.9	23.4	22.8	0.31	0.17	0.58	0.34	0.23
Final hip width, cm	28.1	28.5	28.5	27.6	0.29	0.21	0.48	0.08	0.08
Initial BCS	2.6	2.6	2.6	2.6	0.04	0.34	0.02	0.77	0.10
Final BCS	3.1	3.1	3.0	3.0	0.04	0.19	0.68	0.22	0.23
ADG, kg/d									
56 to 84 d	0.983	1.011	0.903	0.941	0.0714	0.49	0.76	0.61	0.67
84 to 112 d	1.376	1.497	1.334	1.231	0.0672	0.09	0.06	0.14	0.07
56 to 112 d	1.179	1.254	1.119	1.086	0.0310	0.05	0.03	0.38	0.04
DMI, kg/d									
56 to 84 d	2.612	2.897	2.817	2.768	0.11852	0.28	0.62	0.76	0.48
84 to 112 d	4.132	4.752	4.456	3.955	0.21346	0.77	0.27	0.08	0.06
56 to 112 d	3.372	3.825	3.637	3.362	0.15426	0.87	0.62	0.41	0.10
DMI, % of BW									
56 to 84 d	2.89	2.82	2.72	2.91	0.164	0.86	0.61	0.35	0.85
84 to 112 d	3.39	3.44	3.26	3.14	0.099	0.16	0.19	0.41	0.18
56 to 112 d	3.09	3.09	2.96	2.99	0.092	0.47	0.21	0.81	0.60
Feed efficiency, gain/feed									
56 to 84 d	0.376	0.349	0.321	0.340	0.0111	0.49	0.32	0.16	0.13
84 to 112 d	0.333	0.315	0.299	0.311	0.01236	0.93	0.99	0.58	0.93
56 to 112 d	0.350	0.328	0.308	0.323	0.00714	0.05	0.04	0.88	0.04
Hip width, cm									
56 to 84 d change	3.0	2.2	2.3	2.3	0.063	0.02	0.76	0.66	0.05
84 to 112 d change	2.8	3.3	2.8	2.5	0.034	0.09	0.01	0.09	0.00
56 to 112 d change	5.8	5.5	5.1	4.9	0.069	0.02	0.05	0.41	0.04
BCS ¹									
56 to 84 d change	0.1	0.1	0.0	0.0	0.032	0.09	0.85	0.83	0.99
84 to 112 d change	0.5	0.5	0.4	0.4	0.025	0.33	0.59	0.44	0.52
56 to 112 d change	0.5	0.5	0.5	0.4	0.031	0.30	0.55	0.53	0.55

¹Scores: 1 to 5 point system (1 = thin, 5 = obese).

2006; Hill et al., 2006) or acidified MR (Nocek and Braund, 1986; Hepola et al., 2008). In addition, Hepola et al. (2008) reported that calves fed an acidified MR for ad libitum consumption consumed very little water, which could exacerbate limited starter intake and further delay rumen development. Two laboratories have reported 6 to 9% lower digestion postweaning in calves fed high versus low amounts of MR (Terré et al., 2006, 2007; Hill et al., 2012). The low digestion in calves fed high levels of MR was associated with less development of the rumen (Terré et al., 2006, 2007; Suarez-Mena et al., 2011). Reduced ADG in the weaning and postweaning periods from feeding large amounts of milk or MR has been overcome by gradually weaning calves over 14 to 25 d (Khan et al., 2007; Hill et al., 2007, 2012; Sweeney et al., 2010); thus providing a reason for implementing R5 in trial 2. Gradual weaning by reducing MR fed at d 21 in R5 reduced preweaning ADG compared with A5 and A4, but increased postweaning ADG, resulting in no difference in 0 to 56 d ADG. Ad-

ditionally, ADG from d 56 to 112 in trial 2a was greater in calves managed on R5 versus A5.

For trial 2, total BW gain (0 to 112 d) was 104, 111, 106, and 101 kg for CON, R5, A5, and A4, respectively. Total DM consumed was 258, 296, 289, and 268 kg for CON, R5, A5, and A4, respectively. Overall feed efficiency (gain:feed) was 0.40, 0.38, 0.37, and 0.38 for CON, R5, A5, and A4, respectively. Because the experimental unit changed from individual calf during the first 56 d to pen of 4 calves during the last 56 d, statistical analyses of these data were not performed. Only R5, pH 5.2 MR fed ad libitum for 21 d before feeding at fixed rate of 0.68 kg of MR powder until weaning at 42 d, yielded any trends for BW gain advantage over CON. Because of the lower intake of MR and its higher cost versus starter and hay, feed costs and cost per unit BW gain should be lowest in most US market situations for calves fed the control. Use of nonsaleable milk that has a low value could change this economic assumption if ADG was not reduced versus the current results.

CONCLUSIONS

Under the conditions of these trials, results to 112 d showed no advantage to feed MR acidified to pH 4.2 or 5.2 ad libitum from 0 to 35 d and then gradually wean by 42 d compared with the control MR fed at 0.66 kg of DM/d. Acidification to pH 4.2 versus 5.2 resulted in some calves refusing to drink the MR and less total MR consumption. Additionally, when calves were fed MR ad libitum, they consumed >95% of the MR between 0600 to 0800 h and 1600 to 1800 h and standing behavior was not greatly altered versus control calves.

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