Effect of milk replacer feeding rate and functional fatty acids on dairy calf performance and digestion of nutrients

T. M. Hill,¹ J. D. Quigley, F. X. Suarez-Mena, H. G. Bateman II,² and R. L. Schlotterbeck

Nutrition and Research Center, Provimi, 10 Nutrition Way, Brookville, OH 45309

ABSTRACT

Calves fed large amounts of milk replacer (MR) gain more body weight preweaning than calves fed less MR; however, postweaning growth may be reduced because of impaired digestion of nutrients. This was explored in the current research, as was the inclusion of functional fatty acids (NT) that could ameliorate some poor growth and digestion issues in calves fed large amounts of MR. Two MR rates [moderate (MOD) or aggressive (AGG)] with and without NT were compared using 48 male Holstein calves initially 3 d old (43 ± 1.5 kg of body weight) randomly assigned to treatments. The MOD rate was fed at 0.66 kg of dry matter (DM) for 49 d. The AGG rate was fed for 4 d at 0.66 kg of DM, 4 d at 0.96 kg of DM, then 34 d at 1.31 kg of DM, followed by 0.66 kg of DM for the last 7 d. Calves were completely weaned at 49 d. The MR contained 27% crude protein and 17% fat. The textured starter was 20% crude protein. Starter and water were fed free-choice for the first 56 d when calves were housed in individual pens. From 56 to 112 d, calves were grouped (4 calves/pen), maintaining the same MR rate and NT treatments, and fed starter blended with 5% chopped grass hay free-choice with free-choice water. Digestibility was estimated from fecal collections made on d 19 to 23, 40 to 44, and 52 to 56. Data were analyzed as a completely randomized design with a factorial arrangement of MR rate and NT using repeated measures with a mixed procedure. Fiber and starch digestion increased with age and was lower for AGG versus MOD. Calf average daily gain and hip width change were greater before approximately 6 wk of age for AGG versus MOD, but this was reversed from approximately 6 to 16 wk. Calves fed AGG had lower average daily gain per unit intake of DM, crude protein, and metabolizable energy from 8 to 16 wk than calves fed MOD. Preweaning starter intake was less for calves fed AGG versus MOD. Calves fed AGG had

greater body weight gain than MOD over 112 d, but hip width change did not differ. Feeding NT improved digestibility of organic matter, DM, neutral detergent fiber, and acid detergent fiber (over 50% improvement for neutral detergent fiber and acid detergent fiber), which resulted in 10.7 kg (13%) more body weight gain and 1.4 cm (16%) more hip width change over 112 d. This was a greater improvement in growth than the difference in AGG and MOD programs over 112 d.

Key words: calf, milk replacer, digestion

INTRODUCTION

As milk more milk or milk replacer (MR) has been fed to calves, preweaning ADG has increased and preweaning starter intake has decreased (Jasper and Weary, 2002; Cowles et al., 2006; Hill et al., 2013). However, when the DM fed from liquid has exceeded approximately 0.7 kg of DM and weaning has taken place over approximately a week or less, postweaning ADG was less than when less liquid was fed (Cowles et al., 2006; Hill et al., 2007c, 2013). The lower postweaning ADG appears to largely be the result of lower digestion of OM and NDF by calves fed greater amounts of MR (Terre et al., 2007a,b; Hill et al., 2010) and less a function of postweaning DMI. The low digestibility in calves fed high levels of MR has been associated with less development of the rumen (Terre et al., 2007a,b; Suarez-Mena et al., 2011). Preweaning MR intake has not influenced DMI after 56 d when expressed as grams per day; however, intake has been less after 56 d when expressed as DM per kilograms of BW when the MR program delivered more than approximately 0.7 kg of DM daily (Hill et al., 2010, 2013; Osorio et al., 2012). Postweaning feed efficiency has been poor in calves fed high versus low amounts of MR, beyond the immediate few days postweaning (Hill et al., 2007c, 2010). This suggests that digestion is compromised for at least a few weeks postweaning.

Starter intake and the fermentation of starch in the rumen develops the rumen (Hibbs et al., 1956; Warner et al., 1956), drives ADG in the first 2 mo of a calf's life (Heinrichs and Heinrichs, 2011; Bateman et al., 2012),

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¹Corresponding author: mhill@provimi-na.com

²Deceased.

and has been associated with more milk, fat, and protein production in first lactation and throughout life (Heinrichs and Heinrichs, 2011). Thus, feeding more milk or MR can reduce starter intake and slow rumen development, often reducing growth of calves in the late preweaning and early postweaning period (Terre et al., 2007a,b; Hill et al., 2010).

There is more to providing nutrients to calves than simply amount of MR, energy, or CP. A balance of AA (Hill et al., 2007b, 2008) and fatty acids (Hill et al., 2011; Kato et al., 2011; Esselburn et al., 2013) have been reported to optimize growth and health of calves, and many MR in the United States lack specific fatty acids (i.e., butyric and linolenic acids) for optimum growth and health of calves. Butyric and linolenic acid are functional in the immune and digestive systems (Hill et al., 2011; Esselburn et al., 2013). Butyric acid stimulates the maturation of pancreatic enzymes (Guiloteau et al., 2009; Górka et al., 2011; Kato et al., 2011) and rumen papillae, both digestive components that may be delayed in calves fed large amounts of milk or MR.

More information is needed to understand how MR rate alters digestion with age in calves. For that reason, we evaluated 2 MR feeding rates on calf performance, as well as pre- and postweaning digestion of several nutrients. Additionally, functional fatty acids that are missing in typical MR and that influence the digestive development of the calf were evaluated. Our hypothesis was that pre- and early postweaning digestion of nutrients would be less in calves fed more MR and that specific functional nutrients could increase digestive maturation.

MATERIALS AND METHODS

All animals were cared for as described in the *Guide for the Care and Use of Agricultural Animals in Research and Teaching* (FASS, 2010). This trial began with a 56-d nursery phase where calves were housed in individually pens. Two MR rates [moderate (**MOD**) or aggressive (**AGG**)] with and without functional nutrients of NeoTec5g (**NT**; Provimi, Brookville, OH) were compared using 48 calves (12/treatment; 43 ± 1.5 kg of BW) randomly assigned to treatments. NeoTec5g contains a specific blend of functional fatty acids that are primarily butyric, lauric, myristic, and linolenic acid. These fatty acids have been shown to have function in the immune and digestive systems and for growth in calves, and are typically in low concentrations of the diets fed to calves (Hill et al., 2009a, 2011; Kato et al., 2011). The MOD rate of MR was fed at 0.66 kg of DM for 49 d. The AGG rate of MR was fed for 4 d at

0.66 kg of DM, 4 d at 0.96 kg of DM, then 34 d at 1.31 kg of DM, followed by 0.66 kg of DM for the last 7 d. The MR feedings were divided into 2 equal morning and evening meals. The MOD rate was reconstituted to 13% solids. The AGG rate was reconstituted to 15% solids for the first 42 d, then 13% solids for the last 7 d. All calves were fed the same the last 7 d (0.66 kg of DM from MR in a 13% solution, divided into 2 equal meals daily d 41 to 49 and no MR was fed on d 50 and after) to minimize any effect that liquid feeding method would have on calves postweaning to better evaluate the amount of MR fed. The MR powder had 27% CP and 17% fat from whey, whey protein concentrate, lard, minerals, and vitamins. Calves were fed a 20% CP textured starter, composed of 37% whole corn, 35% supplement pellet (soybean meal, wheat middlings, minerals, and vitamins), 25% whole oats, and 3% liquid molasses. A premix with the fatty acids for NT was included in the designed MR and starters. Calves were fed the starter and water ad libitum for the 56-d trial. During the first 49 d, the starter fed to all calves did not contain NT. For last 7 d of the nursery phase, a second similar starter with NT was fed to calves previously receiving NT via the MR whereas other calves continued on the starter without NT. The MR were formulated to contain 0.25% chromic oxide (as-fed basis). The basis was to achieve an intake of approximately 2 g or more of chromic oxide per calf daily, exceeding the minimum suggested 1 g/calf daily for digestibility estimates (Bouchard et al., 1973).

From 56 to 112 d, a grower phase was conducted with the same calves grouped (4 per pen) based on the 4 nursery phase treatments. The same starters with and without NT were fed blended with 5% chopped grass hay. This allowed the continuation of the factorial arrangement of 2 MR rate (previously fed) and 2 starters (with and without NT). The analyses of MR, starters, and hay are reported in Table 1.

Calves were 2 to 4 d of age at the beginning of the trial and came from a single dairy farm. According to the farm's protocol, these calves were fed 3 L of maternal colostrum at birth and again approximately 12 h after birth. Calves were received at midday after a 3.5-h transit and at the evening feeding calves were randomly assigned to experimental programs. The day after arrival, at approximately noon, the calves were weighed (d 0, initial BW), and blood was collected from the jugular vein. Serum was separated by centrifugation at $3,000 \times g$ at 20°C for 15 min (VWR, Batavia, IL) and serum protein concentration was estimated using an optical refractometer (ATAGO U.S.A. Inc., Bellevue, WA). Fecal grab samples were taken from the same 5 calves randomly selected per treatment on d 19 to 23,

40 to 44, and 52 to 56, frozen daily, combined on an equal wet weight basis, and subsampled for analysis. Twelve fecal grab samples per calf were taken via rectal palpation by hand to account for 2-h intervals (0200, 0400, 0600 h, and so on) of the 24-h day by rotating sampling times over the 5-d collection period.

In the first 56-d nursery phase, calves were weighed initially and every 7 d. Hip widths of the calves were measured with a caliper and BCS was estimated initially and every 14 d. Calf BCS was based on a 1-to-5 system using 0.25-unit increments, with 1 being emaciated and 5 being obese (Wildman et al., 1982). Scores were based on changes around the vertical and transverse processes of the spine as palpated by an experienced technician. Starter intake offered and refused was measured daily. Feces were scored daily in the first 56 d (1-to-5 scale modified from Kertz and Chester-Jones, 2004). In the grower phase from 56 to 112 d, calves were weighed, measured for hip width, and scored for BCS on d 84 and 112. Feed and water were offered free-choice and were available at all times; refused feed was measured daily.

In the nursery phase (first 56 d) calves were housed individually in 1.2- by 2.4-m pens bedded with straw in a curtain-sided, naturally ventilated barn with no added heat. From d 56 to 112, calves were housed in

group pens (4 calves/pen) with 6.5 m² of outside pen space and 1.35 m² of inside pen space per calf. Calves were grouped by previous MR treatment, randomly assigned before the previous 56-d period, at time of initial randomization. The inside pen space was bedded with straw and there was no added heat. The trial was conducted July through October. The average temperature in the nursery was 21°C with a range from 5 to 35°C. The average relative humidity was 77% with a range from 32 to 98%.

Composites of feed and fecal samples were analyzed (AOAC International, 2000) for DM (oven method 930.15), CP (Kjeldahl method 988.05), fat (alkaline treatment with Roese-Gottlieb method 932.06 for MR; diethyl ether extraction method 2003.05 for starters and hay), fatty acids (feed only, GC; method 963.22), starch (α -amylase method; Hall, 2009), and sugar (Dubois et al., 1956). The starter and feces were 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). The MR and feces from the 2 preweaning collection times were analyzed for Cr (AOAC International, 2000; method 993.14). Feeds and fecal samples during the postweaning period were analyzed for acid-insoluble ash (Van Keulen and Young, 1977). Measured concentrations of

Table 1. Analyzed nutrients in feeds

Nutrient	Phase 1, 0 to 56 d				Phase 2, 56 to 112 d		
	MR + NT ¹	MR – NT	Starter + NT	Starter – NT	Starter + NT	Starter – NT	Hay
DM, %	92.1	92.2	88.4	88.3	88.1	88.2	87.8
CP, % of DM	27.6	27.7	21.2	21.4	21.3	21.4	13.5
Fat, % of DM	18.3	17.9	3.9	3.8	3.8	3.9	2.8
ADF, % of DM	—	—	5.9	5.8	5.9	5.7	37.5
NDF, % of DM	—	—	12.9	12.7	13.1	12.8	59.6
Sugar, % of DM	—	—	6.7	6.9	6.5	6.8	7.6
Starch, % of DM	—	—	43.0	43.2	43.1	42.9	1.3
Ash, % of DM	4.6	4.7	7.3	7.3	7.2	7.3	9.6
ME, ² Mcal/kg of DM	4.7	4.7	2.7	2.7	2.7	2.7	2.3
Fatty acid, % of DM							
Butyric	0.46	0.04	0.22	0.02	0.24	0.03	<0.01
Caproic	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Caprylic	0.01	<0.01	0.01	<0.01	0.01	0.01	<0.01
Capric	0.07	<0.01	0.02	<0.01	0.03	<0.01	<0.01
Lauric	0.51	0.03	0.31	0.02	0.33	0.02	<0.01
Myristic	0.19	0.02	0.19	0.01	0.18	0.01	<0.01
Palmitic	3.76	4.08	0.42	0.36	0.43	0.32	0.22
Palmitoleic	0.46	0.48	0.12	0.15	0.11	0.17	0.15
Stearic	1.97	2.22	0.22	0.19	0.23	0.17	0.13
Oleic	7.29	7.89	0.76	1.11	0.79	1.16	0.79
Linoleic	1.42	1.54	1.34	1.78	1.21	1.84	1.21
Linolenic	0.18	0.06	0.19	0.07	0.21	0.05	0.06
Other longer acids	0.05	0.02	0.02	0.02	0.03	0.02	0.03

¹Milk replacer (MR) and functional fatty acids (NT).

²Calculated using NRC (2001).

Cr or acid-insoluble ash and other nutrients in the feed, feed intake, and Cr or acid-insoluble ash and other nutrient concentrations in the feces were used to estimate fecal output and apparent digestibility.

Statistical analyses were conducted for the first 56-d period when calves were penned individually and again separately for the d 56 to 112 when calves were grouped in pens of 4 calves. Data for the first 56 d were summarized by week for all data, except hip widths and BCS that were summarized by 14 d. Data for d 56 to 112 were summarized by 28 d. Data were analyzed as a completely randomized design, using repeated measures over time by Proc Mixed in SAS (version 8, SAS Institute, Inc., Cary, NC) in a 2 by 2 factorial arrangement of MR rate (MOD and AGG) by NT (with and without NT). Significance was declared when $P < 0.05$. Pen was the experimental unit. Initial BW differed in the analysis, so initial BW was added to the model as a covariate. The covariate analysis did not change the differences among treatments or improve the model; thus, the model without covariate analyses was used.

RESULTS

Initial serum protein was lower ($P = 0.04$) for calves fed NT versus not fed NT (Table 2). We found no interactions of the main effects. Week interacted with MR rate for ADG, hip width change (HWC), and

starter intake ($P < 0.01$; Figure 1). For all performance measurements, week was significant ($P < 0.05$). Calves fed AGG had greater ($P < 0.05$) ADG, BCS change, and average fecal score compared with calves fed MOD. Calves fed NT had greater ($P < 0.03$) ADG and HWC compared with calves not fed NT.

Total intake in units per day of DM, CP, fat, and ME were greater ($P < 0.02$) for calves fed AGG versus MOD (Table 3). Intake per unit BW of CP, fat, and ME were greater ($P < 0.05$) for calves fed AGG versus MOD. Intake of nutrients did not differ by NT. Efficiency of CP and ME use (grams of ADG per grams of CP intake or megacalories of ME intake) was not different among treatments.

The interaction of NT by MR rate by period was significant ($P < 0.03$) for most nutrients measured (Table 4). We noted no interaction of NT by MR rate; however, rate by period did interact ($P < 0.05$). Digestibility of DM, OM, NDF, and ADF was greater ($P < 0.05$) for calves fed NT versus not fed NT for each digestibility measurement period (Tables 5, 6, and 7) and overall (Table 4).

From d 19 to 23, digestibility of CP, DM, and OM was greater ($P < 0.003$) in calves fed AGG versus MOD (Table 4). From d 40 to 44, digestibility of fat, DM, and OM was greater ($P < 0.05$) in calves fed AGG versus MOD. From d 52 to 56, digestibility of fat, DM, and OM was less ($P < 0.05$) in calves fed AGG versus

Table 2. Performance of calves fed 2 milk replacer (MR) rates¹ with and without functional fatty acids (NT) during the 0- to 56-d nursery phase

Item	With NT		Without NT		SEM	P-value		
	MOD	AGG	MOD	AGG		NT	Rate	NT × rate
Calves, no.	12	12	12	12	—	—	—	—
Initial serum protein, mg/dL	5.1	5.3	5.4	5.6	0.14	0.04	0.21	0.81
Initial BW, kg	41.6	46.5	38.6	43.8	1.50	0.07	0.001	0.93
Final BW, kg	74.3	89.6	67.5	83.9	2.06	0.001	0.001	0.79
Initial hip width, cm	17.5	18.6	17.3	18.1	0.31	0.24	0.003	0.76
Final hip width, cm	22.8	24.2	21.6	22.8	0.28	0.001	0.001	0.83
Initial BCS	2.2	2.2	2.2	2.2	0.03	1.00	1.00	0.54
Final BCS	2.5	2.6	2.5	2.6	0.03	0.11	0.001	0.86
MR intake, kg/d	0.578	1.044	0.578	1.044	—	—	—	—
Starter intake, kg/d	0.628	0.413	0.496	0.410	0.0501	0.19	0.004	0.21
ADG, kg/d	0.584	0.770	0.515	0.716	0.0282	0.03	0.001	0.79
Feed efficiency ²	0.487	0.532	0.473	0.479	0.0216	0.13	0.24	0.37
Hip width change, cm	5.3	5.6	4.3	4.7	0.25	0.001	0.14	0.90
BCS change ³	0.3	0.4	0.3	0.4	0.07	0.12	0.001	0.81
Fecal score ⁴	2.1	2.2	2.1	2.2	0.05	0.58	0.05	0.91
Abnormal fecal days ⁵	0.8	1.1	0.5	0.9	0.29	0.47	0.19	0.88
Medical days	1.8	2.9	2.8	2.5	0.40	0.53	0.30	0.10

¹Moderate (MOD): 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 49 d; aggressive (AGG): 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 4 d, then 0.96 kg of DM for 4 d, then 1.31 kg of DM fed for 34 d, then 0.66 kg of DM for 7 d.

²Feed efficiency was calculated as gain divided by the sum of MR and starter intake.

³1- to 5-point system, with 1 being thin and 5 being obese.

⁴Feces were scored daily using a 1- to 5-scale, with 1 being normal and 5 being watery.

⁵Days with fecal scores of 3 or greater.

Table 3. Dry matter and nutrient intake of calves fed 2 milk replacer (MR) rates¹ with and without functional nutrients (NT) during the 0 to 56-d nursery phase

Item	With NT		Without NT		SEM	<i>P</i> -value		
	MOD	AGG	MOD	AGG		NT	Rate	NT × rate
DMI, kg/d	1.21	1.46	1.07	1.45	0.121	0.26	0.03	0.37
CP intake, kg/d	0.29	0.38	0.27	0.38	0.031	0.25	0.02	0.21
Fat intake, kg/d	0.13	0.20	0.12	0.20	0.016	0.35	0.01	0.28
ME intake, ² Mcal/d	4.41	6.02	4.06	6.01	0.052	0.31	0.01	0.34
g of ADG/g of CP intake	1.99	2.04	1.94	1.90	0.098	0.32	0.24	0.31
g of ADG/Mcal of ME intake	132	128	127	119	6.3	0.11	0.35	0.25
DMI, g/kg of BW	20.8	21.4	20.2	22.8	1.11	0.25	0.37	0.36
CP intake, g/kg of BW	5.1	5.5	5.0	5.9	0.25	0.19	0.05	0.26
Fat intake, g/kg of BW	2.2	3.0	2.3	3.2	0.12	0.34	0.02	0.39
ME intake, ² kcal/kg of BW	76.1	88.5	76.5	94.2	4.17	0.18	0.01	0.32

¹Moderate (MOD): 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 49 d; aggressive (AGG): 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 4 d, then 0.96 kg of DM for 4 d, then 1.31 kg of DM fed for 34 d, then 0.66 kg of DM for 7 d.

²Calculated using NRC (2001).

MOD. Preweaning (d 19 to 23, 40 to 44) digestibility of starch was less ($P < 0.001$) in calves fed AGG versus MOD. For each digestibility measurement period and overall, digestibility of ADF and NDF were less ($P < 0.04$) in calves fed AGG versus MOD.

From 56 to 84 d, calves fed NT had greater ($P < 0.02$) ADG and HWC than calves not fed NT (Table 8). Additionally, calves fed NT had a greater ($P = 0.04$) DMI as kilograms per day than calves not fed NT; however, DMI did not change when expressed per unit BW. Calves previously fed AGG had a lower ($P < 0.02$) feed efficiency, HWC, and BCS change than calves fed MOD. Calves previously fed AGG tended ($P < 0.08$) to have a lower ADG than calves fed MOD.

Total BW gain from 0 to 112 d was 97.1, 105.8, 86.5, and 95.0 kg for calves fed NT-MOD, NT-AGG, MOD, and AGG, respectively. Total HWC from 0 to 112 d was 11.3, 10.5, 9.4, and 9.3 cm for calves fed NT-MOD, NT-AGG, MOD, and AGG, respectively. Statistics were not performed on these means because the experimental unit changed between the nursery and grower phases.

DISCUSSION

Postweaning digestibility measurements in our trial were consistent with measurements previously reported (Terre et al., 2007a,b; Hill et al., 2010) where digestibility was less with higher versus lower MR feeding

Figure 1. Average daily gain, starter intake (SI), and hip width change (HWC) for calves fed moderate (MOD) and aggressive (AGG) milk replacer (MR) programs over 8 wk of the nursery phase. The main effect of functional nutrient is averaged into MR programs; ADG differed for wk 2 through 5 ($P < 0.01$), SI differed for wk 4 through 7 ($P < 0.01$), HWC differed for wk 2, 4, and 8 ($P < 0.01$.) MOD = 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 49 d; AGG = 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 4 d, then 0.96 kg of DM for 4 d, then 1.31 kg of DM fed for 34 d, then 0.66 kg of DM for 7 d.

Table 4. Apparent digestibility of nutrients and intake of feeds during 3 fecal collections periods¹ for feeding 2 milk replacer (MR) rates² with and without functional nutrients (NT) to 5 calves per treatment during the 0- to 56-d nursery phase

Item	With NT			Without NT			Main effect P-value			Period			P-value	
	MOD	AGG		MOD	AGG		NT × MR	MR	NT	1	2	3	SEM	NT × MR × Period
CP digestibility, %	73.0	77.9	74.5	71.5	74.5	1.86	0.21	0.04	0.61	80.3	71.3	71.1	1.41	0.16
DM digestibility, %	82.3	83.7	80.2	80.0	80.2	0.98	0.01	0.42	0.51	84.9	84.6	75.2	0.77	0.001
Fat digestibility, %	89.1	91.3	89.8	89.9	89.8	1.26	0.81	0.41	0.37	96.0	92.4	81.7	0.91	0.03
OM digestibility, %	83.5	84.6	81.6	81.3	81.6	0.93	0.01	0.44	0.63	85.9	85.9	76.4	0.72	0.001
Starch digestibility, %	80.4	70.7	69.5	77.9	69.5	1.45	0.22	0.001	0.70	53.1	73.3	97.6	1.10	0.003
ADF digestibility, %	17.0	7.6	12.3	12.3	4.2	1.09	0.002	0.001	0.55	4.8	10.0	16.0	1.05	0.005
NDF digestibility, %	26.5	13.3	7.3	20.0	7.3	1.65	0.002	0.001	0.90	10.5	17.3	22.5	1.25	0.001
Starter DMI, kg/d	1.039	0.716	0.790	0.983	0.790	0.1083	0.93	0.03	0.56	0.15	0.58	1.91	0.066	0.51
MR DMI, kg/d	0.419	0.837	0.841	0.421	0.841	—	—	—	—	0.941	0.947	—	—	—
Total DMI, kg/d	1.457	1.553	1.632	1.403	1.632	0.1083	0.91	0.16	0.55	1.09	1.53	1.91	0.066	0.001

¹Period 1 was d 19 to 23, period 2 was d 40 to 44, and period 3 was d 52 to 56.²Moderate (MOD): 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 49 d; aggressive (AGG): 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 4 d, then 0.96 kg of DM for 4 d, then 1.31 kg of DM fed for 34 d, then 0.66 kg of DM for 7 d.

rates. Additionally, the difference in NDF digestibility during the postweaning period between MR rates was large, as previously reported (Terre et al., 2007a,b; Hill et al., 2010). These OM and NDF digestibility values obtained in postweaned calves of approximately 2 mo of age are lower than that reported in lactating cows fed typical mixed corn and forage diets (Bernard et al., 1991) and feedlot steers fed high-corn, low-forage diets (Sayer et al., 2013).

Prewaning digestibility of NDF and ADF was much lower than postweaning digestibility in the current trial and previously reported (Terre et al., 2007a,b; Hill et al., 2010), indicating that the rumen was developing. Additionally, NDF and ADF digestibility was lower in calves fed AGG versus MOD, indicating that rumen development was less in AGG versus MOD calves. Starch digestion was lower in calves fed AGG versus MOD preweaning, plus digestibility of starch increased with age, further evidence for rumen development increasing with age. Starch is fermented by microbes in both the rumen and large intestine and digested by mammalian enzymes in the small intestine of calves and should be easier to digest than NDF and ADF (NRC, 2001), as indicated by greater digestibility coefficients of starch versus NDF and ADF. The starch digestion results reflect AGG slowing rumen and pancreatic development of calves compared with MOD.

Whereas calves fed AGG had greater ADG and HWC in the first 4 to 5 wk of age (Figure 1), this was not true thereafter. During d 52 to 56, digestion of many nutrients were less for AGG versus MOD. With lower efficiency of nutrient use for ADG from d 56 to 112, it could be assumed that digestion of nutrients were also lower for calves fed AGG versus MOD. A lower feed efficiency and digestion of nutrients combined with more ADG, and less HWC and BCS change could reflect more gut fill and gut mass gain in calves fed AGG versus MOD, yet gut fill would not influence HWC.

Others have reported similar BW gain from birth until 3 or 4 mo of age between calves fed AGG and MOD (Hill et al., 2007c, 2010, 2013), whereas here the BW gain of AGG calves was greater than MOD calves at 112 d. A difference between the findings could be the weaning programs implemented. In the current trial, calves fed both MOD and AGG were fed the same amount of MR during wk 7 (final week of the preweaning phase) and weaned on d 49, which was intentional in the design to bring consistency to weaning programs. Other trials have either fed different amounts of MR the last week or weaned calves on a different week for MOD and AGG programs. Another difference was less total MR fed in some of the previous versus the current AGG program. Nonetheless, total HWC were similar at the end of the grower phase for all of these trials.

Table 5. Apparent digestibility of nutrients and intake of feeds for d 19 to 23 pre-weaning for feeding 2 milk replacer (MR) rates¹ with and without functional nutrients (NT) to 5 calves per treatment during the 0 to 56-d nursery phase

Item	With NT		Without NT		SEM	P-value		
	MOD	AGG	MOD	AGG		NT	MR rate	NT × MR rate
Digestibility, %								
CP	75.0	86.5	77.0	82.9	2.82	0.78	0.003	0.33
DM	82.2	89.5	80.8	86.9	1.54	0.02	0.001	0.71
Fat	93.6	97.4	95.5	97.6	1.83	0.56	0.11	0.65
OM	83.4	90.3	82.1	87.9	1.44	0.02	0.001	0.72
Starch	61.4	47.9	57.7	45.1	2.19	0.15	0.001	0.85
ADF	5.8	4.6	5.5	3.4	2.09	0.03	0.04	0.83
NDF	15.2	6.5	12.9	7.4	2.51	0.04	0.01	0.53
DMI, kg/d								
Starter	0.18	0.08	0.25	0.09	0.133	0.78	0.33	0.84
MR	0.63	1.25	0.63	1.25	—	—	—	—
Total	0.81	1.33	0.87	1.34	0.133	0.78	0.001	0.84

¹Moderate (MOD): 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 49 d; aggressive (AGG): 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 4 d, then 0.96 kg of DM for 4 d, then 1.31 kg of DM fed for 34 d, then 0.66 kg of DM for 7 d.

Table 6. Apparent digestibility of nutrients and intake of feeds for d 40 to 44 pre-weaning for feeding 2 milk replacer (MR) rates¹ with and without functional nutrients (NT) to 5 calves per treatment during the 0 to 56-d nursery phase

Item	With NT		Without NT		SEM	P-value		
	MOD	AGG	MOD	AGG		NT	MR rate	NT × MR rate
Digestibility, %								
CP	70.9	76.6	66.7	70.9	2.82	0.08	0.08	0.77
DM	85.5	87.6	82.6	82.8	1.54	0.02	0.05	0.52
Fat	89.1	95.9	91.6	92.8	1.83	0.88	0.03	0.14
OM	86.8	88.4	84.1	84.3	1.44	0.02	0.05	0.64
Starch	81.3	67.2	78.6	65.9	2.19	0.37	0.001	0.75
ADF	18.2	4.4	13.4	4.0	2.09	0.02	0.001	0.30
NDF	27.0	14.6	17.7	9.9	2.51	0.01	0.001	0.36
DMI, kg/d								
Starter	0.83	0.38	0.70	0.43	0.133	0.80	0.01	0.52
MR	0.63	1.26	0.63	1.26	—	—	—	—
Total	1.46	1.64	1.34	1.69	0.133	0.85	0.05	0.50

¹Moderate (MOD): 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 49 d; aggressive (AGG): 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 4 d, then 0.96 kg of DM for 4 d, then 1.31 kg of DM fed for 34 d, then 0.66 kg of DM for 7 d.

Table 7. Apparent digestibility of nutrients and intake of feeds for d 52 to 56 preweaning for feeding 2 milk replacer (MR) rates¹ with and without functional nutrients (NT) to 5 calves per treatment during the 0 to 56-d nursery phase

Item	With NT		Without NT		SEM	P-value		
	MOD	AGG	MOD	AGG		NT	MR rate	NT × MR rate
Digestibility, %								
CP	73.0	70.6	70.9	69.8	2.82	0.61	0.53	0.82
DM	79.1	74.1	76.6	70.8	1.54	0.05	0.001	0.79
Fat	84.5	80.6	82.6	79.0	1.83	0.35	0.05	0.95
OM	80.2	75.2	77.7	72.4	1.44	0.05	0.001	0.92
Starch	98.4	97.1	97.5	97.4	2.19	0.89	0.76	0.79
ADF	26.9	13.7	18.0	5.3	2.09	0.002	0.001	0.90
NDF	37.2	18.9	29.4	4.6	2.51	0.001	0.001	0.20
DMI, kg/d	2.11	1.69	2.00	1.85	0.133	0.85	0.04	0.31

¹Moderate (MOD): 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 49 d; aggressive (AGG): 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 4 d, then 0.96 kg of DM for 4 d, then 1.31 kg of DM fed for 34 d, then 0.66 kg of DM for 7 d.

In the current trial, calves fed the AGG program had their MR reduced approximately in half for the last 7 d to 0.66 kg of DM daily before full weaning. A possible way to avoid less postweaning growth in calves fed AGG versus MOD programs is to reduce the MR rate to approximately 0.7 kg of DM for 3 wk before weaning (Hill et al., 2007c, 2012). Weaning by gradually reducing MR fed for approximately 3 wk before weaning (Khan et al., 2007a,b; Sweeney et al., 2010) has also been reported to maintain preweaning ADG from feeding high amounts of MR. This has allowed for more intake of dry feed during that 3-wk period and maintained growth during the first 3 wk of age when MR feeding rates were greater than 0.7 kg of DM; this should aid in rumen development and improve postweaning digestion.

Another possible way to avoid less postweaning growth in calves fed AGG versus MOD programs is to feed a MR with a balanced CP-to-ME or CP-to-fat ratio (Hill et al., 2009a,b). The ratio of CP to ME influences both preweaning growth and intake of dry feed. A near optimal ratio in MR was reported to be 25% to 27% CP with AA balance and approximately 17% fat (Hill et al., 2009a,b).

Whereas feeding an AGG program reduced digestion compared with feeding a MOD program, feeding NT increased the digestibility of many nutrients. Improved digestibility from feeding NT translated into a 13% improvement in ADG (10.7 kg more) and 16% improve-

ment in HWC (1.4 cm more) over the 112-d trial. This was 10.7 kg more BW gain and 1.4 cm more HWC over 112 d. The difference in feeding AGG versus MOD programs was 8.6 kg more BW gain and 0.4 cm less HWC over 112 d. Calves fed MOD with NT gained 97.1 kg BW and 11.3 cm of HWC, whereas calves fed AGG without NT gained 95 kg of BW and 9.3 cm of HWC over 112 d. Butyric acid, a component of NT, has been shown to increase digestion in calves (Guilloteau et al., 2009; Górka et al., 2011; Kato et al., 2011). Linolenic acid, another component of NT, has been shown to increase frame growth in calves (Hill et al., 2007a,b, 2009a). Additionally, butyrate has been reported to improve insulin sensitivity (Kato et al., 2011). Insulin insensitivity was an issue in calves fed large amounts of MR in 2 meals daily (Bach et al., 2013), as with AGG, and might also explain why growth slows after 5 wk of age, as observed in the current trial.

CONCLUSIONS

Digestibility of nutrients increased with age, but digestibility of NDF and ADF was still lower than mature cows at d 56. Digestibility was less in calves fed AGG versus MOD. These increasing digestibility measurements with age reflect that rumen development was increasing with age, it was not completely developed by d 56, and was less in calves fed AGG versus MOD. Calves fed AGG had greater ADG and HWC before 8

Table 8. Performance of calves previously fed 2 milk replacer (MR) rates¹ with and without functional nutrients (NT) during the 56 to 112-d grower phase

Item	With NT		Without NT		SEM	P-value		
	MOD	AGG	MOD	AGG		NT	MR rate	NT × MR
Pens (4 calves/pen), n	3	3	3	3	—	—	—	—
Initial BW, kg	74.3	89.6	67.5	83.9	3.02	0.02	0.001	0.93
Final BW, kg	138.7	152.4	125.1	138.8	4.24	0.002	0.003	0.92
Initial hip width, cm	22.4	23.7	21.5	22.7	0.53	0.06	0.006	0.77
Final hip width, cm	28.4	28.6	26.6	27.3	0.49	0.002	0.34	0.39
Initial BCS	2.4	2.5	2.3	2.5	0.07	0.99	0.03	0.52
Final BCS	2.9	2.9	2.9	2.9	0.03	0.99	0.19	0.99
ADG, kg/d	1.15	1.12	1.03	0.98	0.036	0.001	0.08	0.89
DMI, kg/d	3.23	3.45	2.89	3.19	0.201	0.04	0.16	0.59
DMI, % BW	2.89	2.85	2.98	2.88	0.166	0.71	0.18	0.58
CP intake, kg/d	0.69	0.73	0.62	0.68	0.029	0.04	0.11	0.30
Fat intake, kg/d	0.12	0.13	0.11	0.12	0.004	0.04	0.12	0.41
ME intake, Mcal/d	8.72	9.32	7.80	8.61	0.453	0.04	0.11	0.34
Feed efficiency, gain/feed	0.359	0.324	0.357	0.308	0.0189	0.54	0.02	0.55
g of ADG/g of CP intake	1.67	1.52	1.67	1.44	0.065	0.19	0.02	0.29
g of ADG/Mcal of ME intake	132	120	132	114	4.9	0.22	0.03	0.23
Hip width change, cm	6	4.9	5.1	4.6	0.39	0.02	0.006	0.15
BCS change ²	0.4	0.4	0.6	0.4	0.09	0.85	0.02	0.77

¹Moderate (MOD): 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 49 d; aggressive (AGG): 0.66 kg of DM of a 27% CP, 17% fat MR powder fed for 4 d, then 0.96 kg of DM for 4 d, then 1.31 kg of DM fed for 34 d, then 0.66 kg of DM for 7 d.

²1- to 5-point system, with 1 being thin and 5 being obese.

wk of age, but lesser ADG and HWC after 6 wk of age compared with calves fed MOD. The lower feed efficiency (ADG per unit intake of DM, CP, and ME) from 8 to 16 wk of age in calves fed AGG is likely reflective of poor digestion of nutrients in calves fed AGG versus MOD. Calves fed NT had greater digestibility of OM, DM, NDF, and ADF compared with calves not fed NT. Calves fed NT had 10.7 kg (13%) more BW gain and 1.4 cm (16%) more HWC over 112 d compared with calves not fed NT. This was a greater improvement in growth than the difference in AGG and MOD programs over 112 d.

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