Effect of milk replacer program on digestion of nutrients in dairy calves

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ABSTRACT

There are concerns with feeding young dairy calves amounts of milk solids approaching 0.9 kg of dry matter (DM) or more because of slumps in average daily gain (ADG) at weaning and low starter intakes. Additionally, programs feeding more than 0.6 kg of DM have not been thoroughly tested for success at different weaning ages. Four milk replacer (MR) programs were compared in trial 1. Program A was 0.44 kg of DM of a 21% crude protein (CP), 21% fat MR powder fed daily for 42 d. Program B was 0.66 kg of DM of a 27% CP, 17% fat MR powder fed daily for 42 d. Program C was 0.66 kg of DM of a 27% CP, 17% fat MR powder daily fed for 28 d. Program D was up to 1.09 kg of DM of a 29% CP, 21% fat MR daily fed for 49 d. Digestibility estimates were made and blood was sampled for serum constituents on d 53 to 56, and performance was measured for 84 d. Three programs feeding a 27% CP, 17% fat MR powder were compared in trial 2 over 56 d. Calves on program A were fed 0.66 kg of DM powder daily and weaned at 28 d. Calves on program B were fed 0.66 kg of DM powder daily and weaned at 42 d. Calves on program C were fed up to 1.09 kg of DM powder daily and weaned at 42 d. Digestibility estimates were made and blood was sampled for serum constituents d 21 to 24, d 36 to 39, and d 53 to 56. In trial 1, calves fed program A had the least overall ADG. Calves fed program D had the greatest ADG from 0 to 56 d, the least ADG from d 56 to 84, the least digestibility estimates, and the least concentrations of serum amylase. At 84 d, there were no differences in body weights of calves fed programs B, C, and D. In trial 2, calves fed program A had the greatest starter intake and greatest concentrations of serum amylase. Calves fed program C had the least estimates of digestibility from d 53 to 56 and the least serum concentrations of amylase. Calves fed up to 1.09 kg/d of 27 to 29% MR powders and weaned at 42 or 49 d had lower starter intakes, concentrations of serum amylase, and digestion of starter postweaning compared with calves fed conventional 21% CP, 21%

fat MR powders fed at 0.44 kg/d. Calves fed 0.66 kg/d of a 27% CP, 17% fat MR powder and weaned at 28 or 42 d of age had no reductions in intake or digestion compared with calves fed conventional MR and gained as much total body weight from 0 to 84 d as calves stepped up to 1.09 kg of MR.

Key words: calf, milk replacer, digestion

INTRODUCTION

Interest in feeding dairy calves more than the conventional 3.8 L of liquid milk or milk replacer (MR) daily has increased since Diaz et al. (2001) reported rapid and efficient BW gains in calves fed large amounts of MR without feeding any dry starter. However, the success of some high MR feeding rate programs when starter is fed has been plagued by a weaning and postweaning slump in ADG (Bar-Peled et al., 1997; Jasper and Weary, 2002; Cowles et al., 2006). This reduced ADG has been because of reduced starter intake and feed efficiency (Strzetelski et al., 2001; Hill et al., 2006a,b), reduced rumen development and function (Terre et al., 2006), or reduced digestion of the starter (Terre et al., 2007). A 27% CP, 17% fat MR powder fed at 0.66 kg of DM/d has been successful at improving ADG and not reducing starter intake compared with a 21% CP, 21% fat MR fed at 0.44 kg of DM/d (Hill et al., 2006b); however, this program does not maximize ADG during the first month of life, but does maximize ADG during the second and third months of life (Hill et al., 2007b).

Starter intake, and specifically that of starters high in starch concentration, serves to develop the rumen epithelium from the yield of volatile fatty acids from fermentation (Warner et al., 1956). Additionally, pancreatic amylase secretion increases with age and the amount of starch consumed (Guilloteau et al., 1985). Thus, feeding more milk or MR to enhance calf growth is counterproductive to development of the calf's rumen and pancreatic enzyme system needed to digest starter and other dry feeds postweaning.

One way to overcome the slump in ADG and starter intake at weaning time could be to implement a gradual weaning program as tested by Khan et al. (2007a, b). They slowly increased the milk offered until 23 d of age and slowly removed milk until 49 d of age. However,

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this gradual increase and decrease in milk or MR is not practical to implement on many farms.

Early weaning has been shown to not reduce ADG in calves when conventional milk and MR programs are employed (Owen and Larson, 1982; Kehoe et al., 2007). Early weaning does not appear to have been tested in calves fed more than 0.6 kg DM of milk or MR. Intuitively, early weaning may not work with high rates of MR fed because of the time needed to increase the rate of MR fed and then decrease it to wean without having the slump in ADG and starter intake. However, early weaning is a way to reduce the cost of a MR program through the reduction in the amount of expensive MR fed and reduction in the labor costs to manage the calf fed MR.

From the existing research, our first hypothesis was that if the amount of MR fed was too high, starter intake, digestion, and ADG would be reduced in young calves postweaning. Our second hypothesis was that early weaning would reduce ADG in calves fed at moderate amount of MR (27% CP, 17% fat MR powder fed at 0.66 kg of DM/d). Our objectives were to evaluate these hypotheses using 2 digestion trials to test the feeding rate of MR and weaning age of calves.

MATERIALS AND METHODS

General

Holstein bull calves that were 2 to 4 d of age from a single dairy farm were received at midday after a 3.5-h transit. For each trial, all calves arrived at one time. At the p.m. feeding, calves were randomly assigned to experimental programs. The day after arrival at approximately noon, the calves were weighed (d 0, initial BW). At this time, blood was sampled intravenously, serum was separated by centrifugation at $3,000 \times g$ (VWR, Batavia, IL), and serum protein concentration was estimated using an optical refractometer (Atago U.S.A. Inc., Bellevue, WA). General calf management, health protocols, and measurements of BW, starter intake, fecal scoring, body condition scoring, and nutrient analysis of feeds (all methods for feed analysis were from AOAC, 2000) were conducted as described in Hill et al. (2007a, 2008a). Chromium (AOAC, 2000; method 993.14) concentrations were determined in the feed and feces of calves and used to estimate digestibility of DM consumed. Serum was analyzed for albumin, alkaline phosphatase, amylase, creatinine, glucose, total protein, and urea-N. These serum constituents could be markers for protein status (albumin, total protein, urea-N), bone growth (alkaline phosphatase), enzyme development and digestion (amylase), muscle growth (creatinine), and energy status (glucose).

During both trials, calves were initially housed in a curtain-sided, naturally ventilated nursery with no added heat in 1.2- $\times$ 2.4-m pens bedded with straw for the first 56 d. For the next 28 d in trial 1, calves were housed in group pens (6 calves per pen, 2 pens pretreatment) with 5.5 m² of outside pen space and 0.9 m² of inside pen space per calf. Calves were initially assigned to group pens when received, and then randomly assigned to individual pens within the nursery, using group pen assignment as a blocking factor. The inside pen space was bedded with straw and there was no added heat. Calves had access to clean, fresh water and starter at all times. All animals were cared for as described in the Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching (FASS, 1999). Calves in trial 2 were used only while individually housed.

Calves were weighed initially and every 7 d thereafter. Hip widths of the calves were measured with a caliper, and BCS was estimated initially and every 14 d thereafter. 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 one experienced technician. Starter intake offered and refused was measured daily. Feces were scored daily in the first 56 d (1 to 5 scale; 1 = firm, normal, 2 = less firm, normal, 3 = thick, batter-like, 4 = thin, batter-like, 5 = watery). Empty BW ADG was estimated by first estimating gut fill (fill as a percentage of BW = $10.4 - 0.39 \text{ diet CP } \% + 0.41 \text{ diet ADF } \%$) and correcting BW as described by Jahn and Chandler (1976).

To estimate the number of calves needed for the trials, power analyses for different measurements were conducted using the residual error mean squares and means from previous trials in our research unit. Using 20 similar trials, an 11% difference in ADG means could be separated at $P < 0.05$ with 12 calves per treatment. Using 3 digestion trials, a 5% difference in DM digestibility could be separated at $P < 0.05$ with 4 calves per treatment. Serum data from 10 trials predicted a 10% difference in serum urea nitrogen or amylase means could be separated at $P < 0.05$ with 4 calves per treatment.

Trial 1

Four MR programs were compared using 12 calves/program (46 ± 1.2 kg of BW). Program A was 0.44 kg DM of a 21% CP, 21% fat MR powder (Akey, Lewisburg, OH) fed daily for 42 d. Program B was 0.66 kg DM of a 27% CP, 17% fat MR powder (Akey) fed daily

Table 1. Analyzed nutrient composition of milk replacers, starters, growers, and hay used in the grower in trial 1

Item	Milk replacer program				Starter ABC	Grower ABC ¹	Starter D	Starter CR	Hay
	A	B	C	D					
DM, %	95.38	96.52	96.64	97.32	87.34	87.43	87.21	87.39	89.23
DM basis, %									
CP	21.1	27.0	26.9	28.7	20.6	20.4	25.3	20.9	15.5
Fat	21.3	17.7	17.7	21.4	4.2	4.1	4.5	4.1	2.4
ADF	—	—	—	—	6.8	7.4	17.4	6.7	18.7
NDF	—	—	—	—	16.3	18.5	27.9	16.1	58.7
Ash	7.22	6.54	6.45	9.18	6.89	6.91	9.05	9.54	7.23
Calcium	0.86	0.80	0.77	0.95	0.82	0.81	1.00	0.85	0.55
Phosphorus	0.67	0.59	0.60	1.01	0.63	0.62	0.75	0.62	0.37
Lys	1.92	2.40	2.43	2.50	—	—	—	—	—
Met	0.61	0.77	0.76	0.63	—	—	—	—	—
Cys	0.28	0.59	0.57	0.63	—	—	—	—	—
Thr	1.10	1.89	1.87	1.98	—	—	—	—	—
Arg	0.61	0.66	0.68	0.76	—	—	—	—	—
Glu	3.66	4.55	4.50	4.92	—	—	—	—	—
His	0.50	0.55	0.53	0.57	—	—	—	—	—
Ile	1.25	1.61	1.57	1.71	—	—	—	—	—
Leu	2.04	2.62	2.67	2.78	—	—	—	—	—
Phe	0.92	0.86	0.88	0.94	—	—	—	—	—
Trp	0.37	0.45	0.43	0.45	—	—	—	—	—
Tyr	0.57	0.70	0.71	0.81	—	—	—	—	—
Val	1.23	1.62	1.62	1.73	—	—	—	—	—
ME, Mcal/kg ²	4.80	4.74	4.74	4.85	3.22	3.20	3.10	3.14	2.41
g of CP/Mcal of ME	44.0	57.0	56.8	59.2	64.1	63.6	81.7	66.5	64.4

¹Hay was 5% of grower ABC (as-fed basis).²Calculated using NRC (2001) equations.

for 42 d. Program C was 0.66 kg DM of a 27% CP, 17% fat MR powder (Akey) fed daily for 28 d. Program D was up to 1.09 kg DM of a 29% CP, 21% fat MR powder (Land O'Lakes Inc., Shoreview, MN) fed daily for 49 d. All MR were reconstituted at the rate of 134 g of as-fed powder into a volume of 1 L with warm water (45°C). To facilitate weaning of calves on programs A, B, and C, the MR were only fed at the a.m. feeding of the last 3 d of the assigned MR feeding period. Calves on program D were fed 0.78 kg of DM/d for d 0 to 7, 1.09 kg of DM/d for d 8 to 42, and 0.54 kg of DM/d for d 43 to 49. In each program, all calves consumed all of the MR offered. Calves on programs A, B, and C were fed a 20% CP textured starter (starter ABC, Akey) from d 1 to 56 and a 20% CP grower (grower ABC, which contained 5% chopped hay; Akey) from d 56 to 84. The hay was leafy grass hay (mostly timothy). Calves on program D were fed a 25% CP textured starter (Land O'Lakes) from d 0 to 84. From d 42 to 56, 43 g of DM/calf daily of a 20% CP pelleted feed (starter CR; Akey) containing chromic oxide (2.5%) was fed in addition to free-choice starter. Consumption was assured by first blending the 43 g with a portion of the assigned starter and allowing the calves to consume all of this feed allotment. Then, additional amounts of the assigned starter were offered ad libitum. The basis was to achieve an intake of chromic oxide per calf daily exceeding the

minimum suggested 1 g/calf daily for digestibility estimates (Bouchard et al., 1973). Fecal grab samples were taken from 4 calves randomly selected per program d 52 to 56, frozen daily, combined on an equal wet weight basis, and subsampled for analysis. Fecal samples were systematically collected such that a total of 12 fecal samples were collected over the 4 d to represent every 2 h in a 24-h period. Measured concentrations of Cr and other nutrients in the feed, feed intake, and in the feces were used to estimate fecal output and apparent digestibility. Blood was sampled on d 56 from the same 4 calves per program that were used for feces collection, and serum obtained via centrifugation was analyzed as described previously. Analyzed nutrient content of the diets is shown in Table 1. The trial was conducted July through September; the average temperature was 23°C, and ranged from 11 to 36°C.

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). Treatment means were separated using Tukey's honestly significant difference comparisons if the overall *F* test for the measurement was significant ($P < 0.05$). Because of differences in handling of calves, data were analyzed separately for d 0 to 56 and d 56 to 84. During d 0 to 56, the experimental unit was calf. During d 56 to 84, the experimental unit was pen.

Table 2. Analyzed nutrient composition of feeds in trial 2

Item	Milk replacer	Starter
DM, %	96.2	87.3
DM basis, %		
CP	26.9	21.1
Fat	18.0	4.0
ADF	—	6.9
NDF	—	16.7
Ash	6.78	7.10
Calcium	0.84	0.88
Phosphorus	0.63	0.58
ME, Mcal/kg ¹	4.74	3.22
g of CP/Mcal of ME	56.8	65.5

¹Calculated using NRC (2001) equations.

Trial 2

Three MR programs were compared using 5 calves/program (43 ± 1.5 kg of BW). All calves were fed a 27% CP, 17% fat MR powder (Akey) and a 20% CP textured starter (Akey). Calves on program A were fed 0.66 kg DM daily and weaned at 28 d. Calves on program B were fed 0.66 kg DM daily and weaned at 42 d. Calves on program B were fed up to 1.09 kg DM daily and weaned at 42 d. The MR were reconstituted at the rate of 134 g of as-fed powder into a volume of 1 L with warm water (45°C). To facilitate weaning of calves on programs A and B, the MR were fed only at the a.m. feeding of the last 3 d of the assigned MR feeding period. Calves on program C were fed 0.78 kg of DM/d for d 0 to 7, 1.09 kg of DM/d for d 8 to 35, and 0.54 kg of DM/d for d 36 to 42. In each program, all calves consumed all of the MR offered. Both the MR and starter contained 0.25% chromic oxide as a digestibility marker. Fecal grab samples were collected during 3 periods of 4 d each (d 21 to 24, d 36 to 39, and d 53 to 56) using the system described previously such that every 2 h of a 24-h period were represented. Samples were handled and calculations were made as described in trial 1. Blood was sampled on d 21, 35, and 56 to correspond with the digestion measurements, and serum was analyzed as described previously. Analyzed nutrients of the diets are shown in Table 2. The trial was conducted from February through April. The average temperature was 4°C and ranged from -16 to 27°C.

Growth data were analyzed as a completely randomized design using repeated measures over time by Proc Mixed in SAS. Intake, digestion, and serum metabolite data were analyzed by measurement period as a completely randomized design using a mixed model. When the overall *F* test for the measurement was significant ($P < 0.05$), contrast statements of program A versus B and program B versus C were used to separate the means. The experimental unit was calf.

RESULTS

There were no differences in the initial measurements of serum protein concentrations, BW, and hip widths in either of the trials. Target nutrient concentrations of the various MR powders were achieved (Tables 1 and 2). All MR offered was consumed. No calves died or were removed from the trials.

Trial 1

Calves fed program D had the greatest ($P < 0.05$) ADG from 0 to 56 d and had the greatest ($P < 0.05$) BW at d 56, whereas calves fed program A had the least ($P < 0.05$) ADG from 0 to 56 d and the least ($P < 0.05$) BW at d 56 (Table 3). Empty BW ADG was the least ($P < 0.05$) for calves fed program A and not different among calves fed programs B, C, or D from 0 to 56 d. Calves fed program C had the greatest ($P < 0.05$) ADG and empty BW ADG from 56 to 84 d. Calves fed programs A and D had the least ($P < 0.05$) ADG from 56 to 84 d. Calf BW at d 84 was the least ($P < 0.05$) for calves fed program A and not different among calves fed programs B, C, or D. Starter intake was greatest ($P < 0.05$) for calves fed program C and least ($P < 0.05$) for calves fed program D from 0 to 56 d. Total intake (MR plus starter) was greatest ($P < 0.05$) for calves fed program D and least ($P < 0.05$) for calves fed program A from 0 to 56 d. Starter intake was greatest ($P < 0.05$) for calves fed program C from d 56 to 84. Feed efficiency and changes in BCS and hip widths were not different among programs. Average fecal score and abnormal fecal score days were greatest ($P < 0.05$) in calves fed program D.

The fractional digestibility of DM and OM was less ($P < 0.05$) in calves fed program D (Table 4). Calves fed program D also had the least ($P < 0.05$) amount of OM digested. Calves fed program D digested less ($P < 0.05$) DM than calves fed program B and C, whereas digestion of OM in calves fed program A was intermediate ($P < 0.05$) and not different from the other programs.

Serum amylase concentrations were the least ($P < 0.05$), whereas serum urea N concentrations were the greatest ($P < 0.05$) for calves fed program D (Table 5). Serum concentrations of albumin, alkaline phosphatase, amylase, and total protein did not differ among groups.

Trial 2

In trial 2, performance measurements did not differ among calves fed the 3 MR programs (Table 6); however, this is not surprising considering there were

only 5 calves per program. Trial 2 was not designed to evaluate differences in growth of calves fed the different programs. Rather, it was designed to evaluate differences in digestibility of diets and selected plasma metabolites of calves fed different MR programs. In the first measurement period, there were no differences between calves fed programs A and B (Table 7). Intakes were greater ($P < 0.05$) in calves fed program C versus program B. The digestibility of Ca in calves fed program C was less ($P < 0.05$) than that in calves fed program B. The amount of DM, OM, CP, fat, and P digested in calves fed program C was greater ($P < 0.05$) than that in calves fed program B.

In the second measurement period, intake of starter DM, total DM and OM, and P was greatest in calves fed program A, least in calves fed program C, and intermediate in calves fed program B ($P < 0.05$; Table 8). Intake of fat differed and ranked greatest in calves fed program B, intermediate in calves fed program C, and least in calves fed program A ($P < 0.05$). Intake of CP was greater ($P < 0.05$) in calves fed program B versus program C. Intake of Ca was greater ($P < 0.05$) in calves fed program A versus program B. Digestibility fraction of DM, OM, fat, Ca, and P were different and ranked greatest in calves fed program B, intermediate in calves fed program A, and least in calves fed

Table 3. Performance of calves fed different milk replacer (MR) and starter programs in trial 1

Item	Milk replacer program				SEM	$P > F$
	A	B	C	D		
MR CP, %	21.1	27.0	26.9	28.7		
MR fat, %	21.3	17.7	17.7	21.4		
Days fed MR, n	42	42	28	49		
Maximum MR fed daily, kg	0.44	0.66	0.66	1.09		
Total MR intake, kg/calf	17.5	26.6	17.4	48.1		
Initial BW, kg	45.4	45.3	46.3	45.7	1.19	0.18
56-d BW, kg	72.1 ^a	79.1 ^b	78.6 ^b	82.2 ^c	1.62	0.04
Final 84-d BW, kg	100.1 ^a	108.8 ^b	112.2 ^b	108.7 ^b	2.85	0.04
Initial serum protein, mg/dL	5.6	5.3	5.2	5.5	0.23	0.60
ADG, kg/d						
0–56 d	0.48 ^a	0.60 ^{bc}	0.58 ^b	0.65 ^c	0.039	0.02
56–84 d	1.00 ^a	1.06 ^b	1.20 ^c	0.95 ^a	0.031	0.02
0–84 d	0.65	0.76	0.78	0.75	—	—
Empty BW ADG, ¹ kg/d						
0–56 d	0.43 ^a	0.55 ^b	0.52 ^b	0.56 ^b	0.036	0.02
56–84 d	0.94 ^{ab}	1.00 ^b	1.13 ^c	0.87 ^a	0.029	0.02
0–84 d	0.60	0.70	0.72	0.66	—	—
Starter intake, kg/d						
0–56 d	0.724 ^a	0.728 ^a	0.908 ^b	0.667 ^c	0.0466	0.01
56–84 d	2.583 ^a	2.716 ^a	3.173 ^b	2.828 ^a	0.1864	0.03
Total intake, kg/d						
0–56 d	1.037 ^a	1.204 ^b	1.220 ^b	1.525 ^c	0.0819	0.02
56–84 d	2.583 ^a	2.716 ^a	3.173 ^b	2.828 ^a	0.1923	0.03
Feed efficiency ²						
0–56 d	0.460	0.501	0.472	0.428	0.0252	0.36
56–84 d	0.387	0.391	0.379	0.334	0.0193	0.08
Average fecal score ³						
0–56 d	1.8 ^a	1.8 ^a	1.9 ^a	2.1 ^b	0.17	0.03
Abnormal fecal score days ³						
0–56 d	0.3 ^a	0.4 ^a	0.5 ^a	0.9 ^b	0.07	0.01
BCS ⁴						
Initial	2.3	2.3	2.3	2.3	0.04	0.67
0–56 d change	0.3	0.4	0.3	0.4	0.06	0.53
56–84 d change	0.2	0.1	0.2	0.1	0.01	0.09
Hip width, cm						
Initial	17.7	18.1	18.2	18.4	0.25	0.25
0–56 d change	2.8	3.1	3.0	3.4	0.26	0.36
56–84 d change	3.2	3.3	3.1	3.0	0.31	0.62

^{a–c}Within a row, means with different superscripts differ ($P < 0.05$).

¹Empty BW ADG was estimated by first estimating gut fill (fill as a percentage of BW = $10.4 - 0.39$ diet CP % + 0.41 diet ADF %) and correcting BW as described by Jahn and Chandler (1976).

²BW gain divided by milk replacer plus starter intake.

³1 to 5 system: 1 = firm, normal, 2 = less firm, normal, 3 = thick, batter-like, 4 = thin, batter-like, 5 = watery; abnormal > 2.

⁴1 to 5 system: 1 = thin, 5 = fat.

Table 4. Postweaning digestibility of starter from calves fed different milk replacer (MR) and starter programs (measured during d 53 to 56) in trial 1

Item	Milk replacer program				SEM	<i>P</i> > <i>F</i>
	A	B	C	D		
MR CP, %	21.1	27.0	26.9	28.7		
MR fat, %	21.3	17.7	17.7	21.4		
Days fed MR, n	42	42	28	49		
Maximum MR fed daily, kg	0.44	0.66	0.66	1.09		
Intake, g/d						
As-fed	2,206	2,349	2,539	1,903	221.8	0.08
DM	1,926	2,052	2,218	1,659	194.3	0.08
OM	1,811	1,928	2,084	1,528	182.0	0.06
CP	351	374	404	366	36.4	0.54
Fat	71	75	81	65	6.7	0.18
Digestibility, g/g of intake						
DM	0.756 ^a	0.783 ^a	0.787 ^a	0.673 ^b	0.0219	0.01
OM	0.774 ^a	0.783 ^a	0.787 ^a	0.680 ^b	0.0220	0.01
CP	0.724	0.723	0.741	0.718	0.0258	0.83
Fat	0.703	0.754	0.763	0.754	0.0337	0.33
Digested, g/d						
DM	1,452 ^{ab}	1,573 ^a	1,707 ^a	1,119 ^b	154.1	0.02
OM	1,398 ^a	1,511 ^a	1,641 ^a	1,041 ^b	146.2	0.01
CP	251	271	299	264	24.6	0.30
Fat	49	57	62	49	5.7	0.14

^{a,b}Within a row, means with different superscripts differ ($P < 0.05$).

program C ($P < 0.05$). The amount of DM and OM digested differed and ranked greatest in calves fed program A, intermediate in calves fed program B, and least in calves fed program C ($P < 0.05$). The amount of fat digested differed and ranked greatest in calves fed program B, intermediate in calves fed program C, and least in calves fed program A ($P < 0.05$). The amounts of CP, Ca, and P digested were greater ($P < 0.05$) in calves fed program A versus B.

During the third measurement period, intakes of all nutrients differed and were greatest in calves fed program A, intermediate in calves fed program B, and least in calves fed program C ($P < 0.05$; Table 9). Calves fed program C had lower ($P < 0.05$) digestibility of DM,

OM, Ca, and P than calves fed program B. The amount of DM, OM, CP, and fat digested differed and ranked greatest in calves fed program A, intermediate in calves fed program B, and least in calves fed program C ($P < 0.05$).

Serum amylase concentrations were lower ($P < 0.05$) for calves fed program C than program B on d 21, 35, and 56 (Table 10). On d 56, serum amylase concentration was lower ($P < 0.05$) for calves fed program B than for calves fed program A. Serum urea N concentrations were greater ($P < 0.05$) in calves fed program C compared with B on d 21. Serum concentrations of albumin, alkaline phosphatase, and total protein did not differ.

Table 5. Postweaning serum constituents from calves fed different milk replacer (MR) and starter programs (measured d 56) in trial 1

Item	Milk replacer program				SEM	<i>P</i> > <i>F</i>
	A	B	C	D		
MR CP, %	21.1	27.0	26.9	28.7		
MR fat, %	21.3	17.7	17.7	21.4		
Days fed MR, n	42	42	28	49		
Maximum MR fed daily, kg	0.44	0.66	0.66	1.09		
Alkaline phosphatase, units/L	159	185	187	162	14.5	0.12
Amylase, units/L	46.0 ^a	48.8 ^a	50.9 ^a	35.9 ^b	3.15	0.02
Total protein, g/L	59.2	60.1	59.5	59.8	3.34	0.34
Albumin, g/L	18.6	18.4	18.8	18.5	0.77	0.45
Urea nitrogen, mmol/L	3.6 ^a	3.5 ^a	3.5 ^a	4.6 ^b	0.47	0.04
Creatinine, μ mol/L	76.8	90.6	84	75.4	6.83	0.12
Glucose, mmol/L	5.34	5.40	5.21	5.41	0.288	0.89

^{a,b}Within a row, means with different superscripts differ ($P < 0.05$).

Table 6. Performance of 15 calves fed 27% CP, 17% fat milk replacer (MR) at different rates and weaned on different days (DM basis) in trial 2

Item	Program A: 28-d wean, 0.66 kg/d	Program B: 42-d wean, 0.66 kg/d	Program C: 42-d wean, 1.09 kg/d	SEM
Total MR fed, kg	17.4	26.5	39.9	—
Initial serum protein, mg/dL	5.2	5.1	5.4	0.73
Initial BW, kg	42.4	43.0	43.1	1.54
56-d BW, kg	72.4	74.2	79.2	4.09
ADG, kg/d	0.54	0.56	0.64	0.062
Empty BW ADG, ¹ kg/d	0.49	0.51	0.59	0.058
Starter DM intake, kg/d	0.829	0.705	0.603	0.0760
Total DM intake, kg/d	1.139	1.179	1.316	0.1287
Feed efficiency ²	0.471	0.472	0.489	0.0488
Average fecal score ³	2.1	2.1	2.1	0.24
Abnormal fecal score days ³	0.6	0.6	0.8	0.08
BCS ⁴				
Initial	2.3	2.3	2.4	0.22
0 to 56 d change	0.3	0.3	0.4	0.04
Hip width, cm				
Initial	17.4	17.5	17.4	1.70
0 to 56 d change	2.9	3.0	3.1	0.28

¹Empty BW ADG was estimated by first estimating gut fill (fill as a percentage of BW = 10.4 – 0.39 diet CP % + 0.41 diet ADF %) and correcting BW as described by Jahn and Chandler (1976).

²BW gain divided by MR plus starter intake.

³1 to 5 system: 1 = firm, normal, 2 = less firm, normal, 3 = thick, batter-like, 4 = thin, batter-like, 5 = watery; abnormal >2.

⁴1 to 5 system: 1 = thin, 5 = fat.

DISCUSSION

The overall low growth rates in calves fed program A in trial 1 were expected because calves fed the other programs were provided with a greater amount of nutrients from MR during the early periods of their life.

Although calves fed program D were the heaviest and had the greatest ADG from 0 to 56 d, their empty BW ADG from 0 to 56 d was not different from that of calves fed programs B and C. This lack of difference in empty BW ADG can be attributed to the greater fiber content of the starter fed with program D (Jahn

Table 7. Intake and apparent total-tract digestibility of nutrients in calves fed 27% CP, 17% fat milk replacers (MR) at different rates and weaned on different days as determined on d 21 to 24 (DM basis) in trial 2

Item	Program A: 28-d wean, 0.66 kg/d	Program B: 42-d wean, 0.66 kg/d	Program C: 42-d wean, 1.09 kg/d	SEM
Intake, g/d				
Starter DM ¹	286	270	146	28.4
MR DM	659	659	1,099	—
Total DM ¹	945	929	1,245	28.3
OM ¹	878	864	1,160	25.1
CP ¹	222	219	304	18.6
Fat ¹	115	115	179	10.8
Calcium ¹	6.7	6.5	8.3	0.62
Phosphorus ¹	4.8	4.7	6.3	0.56
Digestibility, g/g of intake				
DM	0.866	0.855	0.859	0.0379
OM	0.874	0.869	0.876	0.0374
CP	0.770	0.767	0.758	0.0382
Fat	0.907	0.890	0.908	0.0411
Calcium ¹	0.701	0.699	0.571	0.0428
Phosphorus	0.815	0.786	0.758	0.0383
Digested, g/d				
DM ¹	818	794	1,069	60.4
OM ¹	767	750	1,017	58.6
CP ¹	171	168	231	28.9
Fat ¹	105	102	163	25.0
Calcium	4.7	4.6	4.7	0.42
Phosphorus ¹	3.9	3.7	4.7	0.40

¹Programs B vs. C were different ($P < 0.05$) based on contrast statement.

Table 8. Intake and apparent total-tract digestibility of nutrients in calves fed 27% CP, 17% fat milk replacers (MR) at different rates and weaned on different days as determined on d 36 to 39 (DM basis) in trial 2

Item	Program A: 28-d wean, 0.66 kg/d	Program B: 42-d wean, 0.66 kg/d	Program C: 42-d wean, 1.09 kg/d	SEM
Intake, g/d				
Starter DM ^{1,2}	1,372	470	351	54.3
MR DM	—	659	549	—
Total DM ^{1,2}	1,372	1,129	901	54.9
OM ^{1,2}	1,261	1,047	836	50.1
CP ²	276	259	208	10.3
Fat ^{1,2}	53	122	100	8.8
Calcium ¹	11.9	8.3	6.5	0.61
Phosphorus ^{1,2}	7.4	5.8	4.6	0.53
Digestibility, g/g of intake				
DM ^{1,2}	0.801	0.866	0.758	0.0288
OM ^{1,2}	0.808	0.879	0.777	0.0289
CP	0.782	0.806	0.763	0.0344
Fat ^{1,2}	0.868	0.943	0.790	0.0351
Calcium ^{1,2}	0.549	0.671	0.514	0.0508
Phosphorus ^{1,2}	0.691	0.822	0.565	0.0601
Digested, g/d				
DM ^{1,2}	1,097	979	683	48.3
OM ^{1,2}	1,016	921	649	46.7
CP ²	215	209	159	15.8
Fat ^{1,2}	46	115	79	11.9
Calcium ²	6.5	5.5	3.4	0.56
Phosphorus ²	5.1	4.8	2.6	0.55

¹Programs A vs. B were different ($P < 0.05$) based on contrast statement.

²Programs B vs. C were different ($P < 0.05$) based on contrast statement.

and Chandler, 1976). The ADG of calves fed program D from d 56 to 84 was low because of reduced starter intake and reduced diet digestibility. The pattern of ADG of calves fed program D is consistent with that in previously cited research (Bar-Peled et al., 1997; Jasper and Weary, 2002; Cowles et al., 2006). The low starter intake of calves fed program D is also consistent with previously cited research (Strzetelski et al., 2001; Hill et al., 2006a, 2007b), as is the low dietary digestibility that may result in reduced rumen development and microbial function (Terre et al., 2006, 2007). High MR intakes appear to be substituting for starter at early ages, probably reducing rumen development and reducing pancreatic amylase to contribute to the slumps in ADG at and after weaning observed in the current and previous trials. The high MR feeding rate programs in each trial (D in trial 1 and C in trial 2) reduced the digestion of starter postweaning, similar to reports by Terre et al. (2007). Weaning early in trial 2 (program A) resulted in reduced digestion at d 36 to 39 when the diet changed from a highly digestible milk-based diet to a grain-based diet. This disadvantage of weaning was overcome, as shown by greater ADG from 56 to 84 d in calves fed the early-wean program C in trial 1.

The digestibility measurements during the last period of d 53 to 56 in trials 1 and 2 and those measured by Terre et al. (2007) were of similar magnitude. Terre et al. (2007) reported an OM digestibility of 78.7% in calves fed their low amount of MR and 71.8% in

calves fed their high amount of MR. We observed a 6- to 9-percentage-unit reduction in postweaning OM digestibility as feeding rate of MR increased. Terre et al. (2006) used purine excretion to assess microbial and rumen development; purine excretion in calves fed high amounts of MR was 60% that of calves fed the low amount of MR presumably associated with reduced digestibility. We did not estimate rumen development in these trials, but we did note reductions in serum enzymes typically associated with digestion of dry feeds when the feeding rate of MR increased.

Several commercial programs that promote high feeding rates of high protein MR instruct feeders to wean calves slowly over a 7-d period by feeding half of the MR in a morning-only feeding regimen as implemented in program D in trial 1 and program C in trial 2, rather than using a more abrupt weaning program of 3 d as in the other programs in trials 1 and 2. Khan et al. (2007a, b) tested a much longer duration of reduced milk feeding in an effort to overcome the slump in performance noted by so many researchers. Their results were promising to overcome the slump in growth but are complicated to practically implement on-farm. The weaning regimen used with calves fed the high rate of high-protein MR in the present trials did not appear to be long enough to prevent postweaning slumps in growth.

Several serum constituents are sometimes used as markers of lean body mass (creatinine, albumin),

Table 9. Intake and apparent total-tract digestibility of nutrients in calves fed 27% CP, 17% fat milk replacers (MR) at different rates and weaned on different days as determined on d 53 to 56 (DM basis) in trial 2

Item	Program A: 28-d wean, 0.66 kg/d	Program B: 42-d wean, 0.66 kg/d	Program C: 42-d wean, 1.09 kg/d	SEM
Intake, g/d				
Starter DM ^{1,2}	2,321	2,053	1,804	86.0
MR DM	—	—	—	—
Total DM ^{1,2}	2,321	2,053	1,804	86.0
OM ^{1,2}	2,133	1,887	1,658	82.4
CP ^{1,2}	466	413	363	19.2
Fat ^{1,2}	89	79	69	12.3
Calcium ^{1,2}	20.1	17.8	15.6	0.77
Phosphorus ^{1,2}	12.5	11.1	9.7	0.56
Digestibility, g/g of intake				
DM ²	0.823	0.820	0.767	0.0208
OM ²	0.829	0.829	0.778	0.0204
CP	0.789	0.760	0.743	0.0456
Fat	0.883	0.900	0.860	0.0404
Calcium ²	0.556	0.546	0.422	0.0428
Phosphorus ²	0.670	0.675	0.484	0.0437
Digested, g/d				
DM ^{1,2}	1,910	1,684	1,385	85.4
OM ^{1,2}	1,769	1,564	1,291	81.2
CP ^{1,2}	368	314	269	19.0
Fat ^{1,2}	79	71	60	3.9
Calcium	11.2	9.7	8.5	1.08
Phosphorus	8.4	7.5	6.3	0.92

¹Programs A vs. B were different ($P < 0.05$) based on contrast statement.

²Programs B vs. C were different ($P < 0.05$) based on contrast statement.

bone growth (alkaline phosphatase), or dietary protein and energy balance (total protein, urea-N, glucose). No differences among treatments in either trial were detected in creatinine, albumin, alkaline phosphatase, total protein, and glucose. Urea-N was greater in calves fed program D during d 53 to 56 in trial 1 when all calves were weaned. This can likely be attributed to the higher CP starter (25.3 vs. 20.9% CP) fed to calves on program D compared with the other programs. Urea-N was greater in calves fed program C on d 21 (preweaning) compared with calves fed less MR (1.09 vs. 0.66 kg of DM/d) on programs A and B and could be the result of greater CP intake.

Sabb et al. (1986) reported that pancreatic lipase activity in rats declined approximately 40% when dietary fat concentration was reduced from 23 to 17% of the diet (replaced by corn starch), and this decline was greater if the fat was saturated versus unsaturated. In rats, amylase activity was directly related to carbohydrate intake (Thornburg et al., 1987; Sankaran et al., 1992) and declined with the intake of fat (Forman and Schneeman, 1980). In calves, amylase was least in the milk-fed calf and increased as starter consumption increased during weaning and postweaning (Guilloteau et al., 1985). As dietary fat concentration increased, intake decreased in rats, but rats fed diets with butter consumed approximately 15% more feed at an equal fat concentration compared with rats fed diets with other sources of fat (Sabb et al., 1986). Therefore, in calves fed

a somewhat constant amount of MR high in saturated fat with increasing consumption of starter with age, their total dietary concentration of fat declines with age. The digestive enzyme system of the neonatal calf does not appear to be as well defined as that of the rat but if the systems of the 2 species are somewhat similar, the change from a high saturated fat to a low fat diet and from a low starch to a high starch diet could lend itself to inefficiencies of digestion. Recently, it was reported that ADG was less in calves fed high fat MR (20, 23, and 27% fat in the MR powder) than in calves fed MR with 17% fat, and differences in starter intake did not explain the difference in ADG (Hill et al., 2009a,b). Digestion of OM, DM, fat, Ca, and P decreasing as fat concentration increased from 13 to 23% of a 27% CP MR powder fed at 0.66 kg of DM/d explained much of the differences in ADG (Hill et al., 2009b). Calves weaned on d 28 in trial 2 (program A) had greater d-56 serum amylase concentrations, and calves fed the large amounts of MR in both trials 1 (program D) and 2 (program C) had lower serum amylase concentrations. Thus, early weaned calves would have less time spent on diets intermediate in fat and starch and may more quickly develop their amylase enzyme system.

CONCLUSIONS

Calves fed increasing amounts of a 27 to 29% MR (up to 1.09 kg DM/d) and weaned at 42 or 49 d in

Table 10. Serum constituents in calves fed 27% CP, 17% fat milk replacer at different rates and weaned on different days in trial 2

Item	Program A: 28-d wean, 0.66 kg/d	Program B: 42-d wean, 0.66 kg/d	Program C: 42-d wean, 1.09 kg/d	SEM
Alkaline phosphatase, units/L				
d 21	129	136	149	14.7
d 35	135	145	155	14.1
d 56	159	154	143	12.8
Amylase, units/L				
d 21 ²	58	56	39	5.7
d 35 ²	76	69	57	5.4
d 56 ^{1,2}	93	81	68	5.2
Total protein, g/L				
d 21	59.3	59.6	60.2	3.65
d 35	59.8	59.4	59.1	3.53
d 56	59.8	59.1	59.7	3.37
Albumin, g/L				
d 21	18.3	18.7	18.6	1.41
d 35	18.6	18.9	18.3	1.29
d 56	18.1	18.2	18.8	0.87
Urea nitrogen, mmol/L				
d 21 ²	3.6	3.5	4.2	0.26
d 35	3.4	3.5	3.7	0.29
d 56	3.2	3.3	3.0	0.24
Creatinine, umol/L				
d 21	65	69	84	7.8
d 35	67	65	71	7.4
d 56	76	74	73	7.3
Glucose, mmol/L				
d 21	5.4	5.4	5.8	0.21
d 35	5.3	5.3	5.3	0.19
d 56	5.3	5.3	5.2	0.18

¹Programs A vs. B were different ($P < 0.05$) based on contrast statement.

²Programs B vs. C were different ($P < 0.05$) based on contrast statement.

2 trials had low starter intakes, low concentrations of serum amylase, and low digestion of starter postweaning compared with calves fed a 21% CP, 21% fat MR powder fed at 0.44 kg DM/d. Although calves fed 1.09 kg of DM/d had the greatest ADG for 0 to 56 d, their lower starter intake and reduced digestion postweaning reduced their postweaning ADG. Calves fed 0.66 kg of DM/d of a 27% CP, 17% fat MR powder and weaned at 28 or 42 d had no reduction in starter intake or digestion compared with calves fed the conventional MR, and gained as much or more total BW from 0 to 84 d as calves fed 1.09 kg of DM/d. Calves fed 0.66 kg of DM/d of a 27% CP, 17% fat MR and weaned at 28 d had the greatest intake of starter and greatest concentrations of serum amylase. Calves fed a 21% CP, 21% fat MR powder at 0.44 kg of DM/d had the least ADG.

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