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Growth performance of newborn dairy calves fed a milk replacer with 2 protein concentrations at 2 feeding rates

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ABSTRACT

Objective: The objective was to evaluate the growth performance by calves fed a conventional milk replacer (MR) or modified accelerated MR (24% CP) to prevent the slump in postweaning calf starter intake and feed efficiency.

Materials and Methods: A total of 104 (1 to 5 d old) Holstein heifer calves (39.3 ± 0.66 kg) were assigned randomly to 1 of 4 MR treatments to evaluate preweaning (1 to 42 d) and postweaning (43 to 56 d) performance in a 2 × 2 factorial arrangement of CP concentrations [20% CP or 24% CP high protein (HP) with feeding rates (FR) of 0.57 or 0.68 kg/d]. Treatments were MR fed at 15% solids (as fed): (1) control (CP1): a 20% CP:20% fat MR fed at 0.284 kg 2×/d for 35 d; (2) CP2: the 20:20 MR fed at 0.34 kg 2×/d for 35 d; (3) HP1: a 24:20 MR fed at CP1 rate; and (4) HP2: the 24:20 MR fed at CP2 rate.

Results and Discussion: No interactions of CP by FR were detected for growth parameters. During 1 to 14 d, calves fed higher MR FR (CP2 and HP2) had greater ($P < 0.01$) ADG (0.37, 0.44, 0.36, and 0.45 kg/d for CP1, CP2, HP1, and HP2, respectively) compared with calves fed lower MR FR (CP1 and HP1). Preweaning ADG (1 to 42 d) were similar ($P > 0.10$). Intakes of calf starter from 1 to 56 d were similar ($P > 0.10$) for calves fed MR with different CP concentrations (0.77 and 0.78 kg/d), whereas calf starter intake (0.81 and 0.74 kg/d) was reduced ($P < 0.05$) for calves fed higher MR FR. Feed conversions from 1 to 56 d were similar ($P > 0.01$) for calves fed different CP concentrations (0.54 and 0.55 kg/kg) but were improved when fed higher MR FR (0.53 and 0.56 kg/kg). However, a trend ($P < 0.10$) of CP by FR interaction from 43 to 56 d suggested that calves fed CP2 had greater feed conversions (0.46, 0.53, 0.46, and 0.49 kg/kg for CP1, CP2, HP1, and HP2, respectively). This suggests a carryover effect on postweaning performance for calves fed CP2.

Implications and Applications: Feeding calves a conventional MR (20%CP:20% fat) at different FR with different CP concentrations resulted in similar performance. Feeding a higher CP MR (24% CP:20% fat) at higher FR did not affect preweaning gain of dairy calves.

Key words: milk replacer, protein concentration, feeding rate, calf starter, performance

INTRODUCTION

For several decades, the amount of milk or milk replacer (**MR**) offered to calves has been restricted to maintain low rearing and labor costs (Kehoe et al., 2007) but also to promote feed DMI and rumen development (Davis and Drackley, 1998). Calves will drink large milk amounts when provided (Jasper and Weary, 2002; Vieira et al., 2008; Borderas et al., 2009), which is used to justify higher CP MR and feeding rates (**FR**). However, the success of some high MR FR programs when feeding calf starter (**CS**) has been plagued by a weaning and postweaning ADG slump (Bar-Peled et al., 1997; Jasper and Weary, 2002; Hill et al., 2006a). The postweaning ADG slump has been reported to be due to lower CS intake and feed efficiency (Strzetelski et al., 2001; Hill et al., 2006a,b), reduced rumen development and function (Terre et al., 2006), and reduced CS digestion (Terre et al., 2007). A 27% CP, 17% fat MR fed at 0.66 kg of DM/d was successful at improving ADG while maintaining CS intake (Hill et al., 2006b). However, this MR feeding program did not maximize ADG during the first month of life compared

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with the second and third months of life (Hill et al., 2007). Intakes of CS, specifically high-starch CS, serve to develop the rumen epithelium via VFA produced during ruminal fermentation (Roth et al., 2009). Thus, feeding more milk or MR to enhance calf growth may be counterproductive to ruminal development and pancreatic enzymes needed to digest CS after weaning (Terre et al., 2007).

One impractical method, unless using an auto-feeder, to overcome the weaning ADG and CS slump may be to implement a gradual weaning program by increasing milk amounts until 23 d of age and then slowly reducing them until 49 d (Khan et al., 2007). Early weaning (3 to 6 wk) has been shown to maintain ADG (Kehoe et al., 2007) but has not been tested when feeding more than 0.6 kg of DM of milk or MR. Intuitively, this program may not work due to the time needed to increase and decrease milk amounts without having the postweaning ADG and CS intake slumps.

Thus, developing a modified accelerated MR would minimize the cost with the added benefit of more CP supplied for lean tissue growth using a standard 6-wk weaning program. The study hypothesis was that feeding more MR with the same CP concentration would not increase growth as much as feeding a MR having a higher CP concentration to avoid the slump in postweaning CS intake. The study objective was to evaluate the pre- and postweaning performance and health of calves fed a conventional MR feeding program and a modified accelerated MR feeding program to prevent the slump in postweaning CS intake and feed efficiency.

MATERIALS AND METHODS

Animals, Housing, and Diets

While housed at the Southern Research and Outreach Center (**SROC**) Calf and Heifer Research Facility, calves were housed and cared for according to the University of Minnesota Institutional Animal Care and Usage Committee recommendations (Animal Subjects Code 1203B11621). The study used 104 Holstein heifer calves sourced from 3 commercial dairy farms in Minnesota. Upon arrival at the SROC Calf and Heifer Research Facility, calves were weighed and randomly assigned, within calf source (farm), to 1 of 4 MR treatments. During the preweaning and early-weaning period, calves were housed in individual pens (2.3 × 1.2 m) bedded with sawdust throughout the study in 2 curtain side-wall, naturally ventilated, 61 × 9.1 m barns. Each barn was divided into 2 rooms with approximately 40 calves in individual pens per room. Calves weighing less than 34.0 kg or greater than 50.0 kg of BW were excluded from this trial. Calves arrived at SROC after receiving a minimum of 3 feedings of colostrum at the source farm. Calves started the trial upon arrival at SROC. Trial d 1 was arrival day at SROC. The start of the trial day coincided with the afternoon feeding, and each trial day concluded after the morning feeding.

Holstein heifer calves (received at 2 to 5 d old; 39.3 ± 0.66 kg of BW) were randomly assigned to 1 of 4 MR to evaluate preweaning (d 1 to 42) and postweaning (d 43 to 56) performance using a randomized complete block design having a 2 × 2 factorial arrangement of CP concentrations [20% CP or 24% CP (high protein, **HP**; Table 1) with FR of 0.57 (**1**) or 0.68 (**2**) kg/d]. Treatments were MR fed at 15% solids: (1) control (**CP1**): a 20% CP:20 % fat MR fed at 0.284 kg 2×/d for 35 d; (2) **CP2**: the 20:20 MR fed at 0.34 kg 2×/d for 35 d; (3) **HP1**: a 24:20 MR fed at CP1 rate; and (4) **HP2**: the 24:20 MR fed at CP2 rate. All MR were fed only 1×/d (1/2 FR) from 36 d through weaning after 42 d. Water and 18% CP texturized CS with decoquinate (41.6 mg/kg; Decoxx; Zoetis Inc., Kalamazoo, MI) were offered free choice from 1 through 56 d. All CS were manufactured by Hubbard Feeds Inc. (Mankato, MN), and all MR were manufactured by Milk Products (Chilton, WI) as proprietary formulas. The study was conducted from April 23, 2012, to August 20, 2012. The environmental temperatures (maximum, minimum, and average, respectively) were 15.1, 2.4, and 8.7°C for April; 23.2, 10.9, and 17.1°C for May; 27.1, 14.9, and 21.0°C for June; and 30.8, 19.9, and 24.9°C for July.

Table 1. Nutrient composition (% of DM unless otherwise indicated) of milk replacer (MR) containing different concentrations of CP (20 or 24%) and calf starter (CS)

Item[1]	MR 20[2]	MR 24[3]	CS[4]
DM, %	95.98	96.13	89.87
CP	21.37	24.72	20.64
ADF	—	—	11.34
NDF	—	—	22.48
Fat	20.41	19.56	3.87
Ash	10.87	10.95	7.78
Ca	1.03	1.14	1.06
P	0.79	0.91	0.57
Mg	0.16	0.17	0.26
K	2.55	2.52	1.22
TDN[5]	—	—	72.28
ME,[5] Mcal/kg	4.78	4.72	2.65

[1]Nutrient analysis was conducted according to AOAC International (2016) procedures by Dairyland Laboratories Inc. (Arcadia, WI).

[2]The proprietary MR consisted of 40.1% fat base; 58.2% milk proteins; 1.0% minerals and vitamins; 0.02% synthetic AA; and 0.2% flavors, emulsifiers, and so on.

[3]The proprietary MR consisted of 37.8% fat base; 60.3% milk proteins; 0.9% minerals and vitamins; 0.3% synthetic AA; and 0.2% flavors, emulsifiers, and so on.

[4]The proprietary texturized CS consisted of 40% pellets (proteins, minerals, and vitamins) and 60% grains (corn, oats, and molasses).

[5]The TDN and ME were calculated using equations from the NRC (2001).

Feed Analyses

Milk replacer and CS samples were taken from each bag and composited by treatment for nutrient analysis. Samples were stored frozen (−20°C) until being composited for nutrient analyses according to the AOAC International (2016) methods: DM (935.29); CP (976.06); ether extract (989.05 for MR and 920.39 for CS); ash (942.05); and Ca, P, K, and Mg (985.01). Nutrient analyses were conducted by a commercial laboratory (Dairyland Laboratories Inc., Arcadia, WI). Samples of MR and CS were analyzed in duplicate.

Body Growth and Health Monitoring

On d 1, a blood sample was taken via jugular venipuncture using a 10-mL Vacutainer (Beckton Dickinson Vacutainer Systems, Rutherford, NJ) serum separation tube. Samples were allowed to clot and centrifuged at 3,000 × g for 20 min at room temperature. Serum was separated and immediately analyzed for total serum protein concentrations using a hand-held refractometer (Spartan Refractometer, Model A 300 CL, Spartan, Tokyo, Japan). Intakes of MR and CS on an as-fed basis were recorded daily using a digital scale (Rice Lake Weighing Systems, Cardinal Model 205, Rice Lake, WI). Body weights were taken in the afternoon before the evening feeding on d 1, 14, 28, 42, and 56 (Rice Lake Weighing Systems, Cardinal Model 205). Hip heights were taken on d 1 and 56 at the same time as BW using a Nasco Dairy and Beef Measuring Stick (Ft. Atkinson, WI). Fecal consistency was evaluated during the morning feeding and scored daily on a scale from 1 to 4 (1 = normal; 2 = loose, pudding; 3 = very loose, no watery separation; and 4 = very watery) according to Larson et al. (1977). All health incidents, treatments, and medical treatment costs were recorded through 56 d.

Statistical Analysis

All data were subjected to least squares ANOVA using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC, version 9.4) for a randomized complete block design with a factorial arrangement of treatments. Main factors evaluated were 2 concentrations of CP (20 and 24% CP) with 2 FR (0.57 and 0.68 kg/d) and their interaction. Heifer calves were blocked by farm source and week of arrival at the SROC heifer raising facility to account for any seasonal effects. The statistical model used was as follows:

$$Y_{ijk} = \mu + \mathrm{Farm}(B_j) + \mathrm{MR}_i + \mathrm{FR}_k + (\mathrm{MR}_i \times \mathrm{FR}_k) + e_{ijk},$$

where Y_{ijk} = dependent variable, μ = overall mean, Farm(B_j) = farm nested within the block effect, MR_i = main effect of MR, FR_k = main effect of FR, $\mathrm{MR}_i \times \mathrm{FR}_k$ = interaction of MR by FR, and e_{ijk} = random error. Whenever significant differences due to the CP × FR interaction were detected, the Fischer's LSD test was used to separate treatment means (Steele and Torrie, 1980). Farm (block), CP, FR, and the interaction of CP × FR were all considered to be fixed effects. Significant differences were declared at $P < 0.05$ and trends at $0.05 < P < 0.10$. Data were analyzed as individual weeks and time frames of 1 to 42 d (preweaning), 43 to 56 d (postweaning), and 1 to 56 d (overall study).

RESULTS AND DISCUSSION

Feed Analyses

The nutrient composition of the 20:20 MR fed to calves receiving the CP1 and CP2 treatments met or exceeded CP formulation specifications but was slightly below specifications for fat concentration. The 24:20 MR fed to calves receiving HP1 and HP2 contained less CP and fat concentrations than the formulation specifications (Table 1). Why the MR did not meet CP and fat specifications is not known but could be due to variations in ingredients, manufacturing, sampling, or laboratory methods. The CS met or exceeded formulation specifications to provide the nutrients for meeting or exceeding the NRC (2001) requirements of growing dairy calves.

Serum Protein and DMI

Total serum proteins indicated adequate passive immunity transfer (Table 2) by exceeding the 5.2 g/dL recommended by Tyler et al. (1996). No MR × FR interactions ($P > 0.10$) were detected for intake of MR and CS (Table 2). The MR main effects for MR, CS, and total DMI were similar ($P > 0.10$) for calves fed both MR, whereas calves fed MR at higher FR demonstrated greater ($P < 0.05$) MR intakes during all study time periods. However, calves fed higher MR FR had lower ($P < 0.05$) CS intake during several study time periods and total CS intake for the study (d 1 to 42 and d 1 to 56). Total DMI during selected time periods were greater ($P < 0.05$) for calves fed MR at greater FR. Calves fed the lower CP MR had greater ($P < 0.01$) CS intake d 1 to 42 compared with calves fed the HP MR. Intakes of CS during d 1 to 56 were greater ($P = 0.03$) for calves fed CP1 compared with calves fed the CP2, with calves fed HP1 and HP2 being intermediate. The total DMI (kg/d) for d 1 to 56 were similar for calves fed all treatments (Table 2).

BW, Growth, Feed Efficiency, and Hip Height Measurements

Calves entered the study at an averaging age of 3 d. The initial mean BW of all calves was 39.6 ± 0.74 kg (Table 3). There were no MR × FR interactions ($P > 0.10$) detected for all parameters measured in this study, except for 2 (G:F and g of CP/Mcal of ME), which exhibited a MR × FR interaction trend ($P \leq 0.10$), which will be discussed later. No differences ($P > 0.10$) were found for overall BW, BW gain, ADG, and hip height gain. Calves fed at the higher FR tended ($P < 0.06$) to have greater BW on d 14 and 28, but after d 28, BW were similar ($P > 0.10$) for calves fed at both FR (Table 3). The ADG (kg/d) were improved ($P < 0.06$) in specific periods by MR FR, but for the overall study, the MR × FR resulted in similar ($P > 0.10$) ADG. During this time, calves were being fed 1×/d starting on d 36 and calves fed the lower FR were eating more CS during this time period. Calves fed MR at the lower FR consumed more CS throughout the whole study, which would have improved transition during the weaning phase, having less stress, resulting in better BW gains during that time period. The ADG from 1 to 56 d were similar ($P > 0.10$) for calves fed both MR at both FR.

Hip heights were similar ($P > 0.10$) for calves fed both MR at both FR. There was a trend ($P \leq 0.10$) for an interaction of MR × FR from d 43 to 56 for feed efficiency as calves fed CP2 tended ($P < 0.10$) to have greater feed efficiency (G:F) than calves fed the other treatments. Overall, feed efficiency was greatest ($P < 0.01$) for calves fed the higher MR FR (i.e., CP2 and HP2). The lack of a MR × FR interaction for many parameters measured in this study was not expected. Reasons for this could be that calves fed the higher FR had greater energy intake from the added calories supplied by the increased amounts of MR powder, which resulted in a lower CS for calves fed a lower MR FR. Basically, MR DMI is replacing CS DMI, which has implications for slowing ruminal development. The reduction in CS intake has been observed in many studies (Terre et al., 2007; Hill et al., 2009b, 2010). Terré et al. (2007) reported that calves fed relatively large amounts of MR (up to 1,260 g of DM/d) had lower DM and NDF digestibilities compared with calves fed low amounts of MR (up to 500 g of DM/d) during the week after weaning. More recently, Hill et al. (2010) reported similar findings when comparing MR allowances of 0.66 versus 1.09 kg of MR/d. Even though calves on the higher MR FR treatments consumed less CS, they had greater overall ADG. Hill et al. (2006b) observed that a 27% CP, 17% fat MR

Table 2. Milk replacer (MR), calf starter (CS), and DMI for calves fed MR with 2 protein concentrations at 2 feeding rates (FR)

	Treatment[1]					Main effects and interaction, *P* <		
Item	**CP1**	**CP2**	**HP1**	**HP2**	**SEM**	**MR**	**FR**	**MR × FR**
No. of calves	25	26	26	27	—	—	—	—
Initial serum protein, g/dL	5.74	5.75	5.54	5.76	0.18	0.54	0.50	0.63
MR intake, kg/d DM								
1 to 14 d	0.53	0.63	0.52	0.64	0.01	0.78	0.01	0.14
15 to 28 d	0.54	0.64	0.54	0.65	0.01	0.43	0.01	0.75
29 to 42 d	0.40	0.49	0.40	0.49	0.01	1.00	0.01	1.00
Total MR intake, kg/d								
1 to 42 d	0.49	0.59	0.49	0.59	0.01	0.96	0.01	0.13
CS intake, kg/d DM								
1 to 7 d	0.02	0.02	0.02	0.01	0.01	0.34	0.66	0.83
8 to 14 d	0.05	0.04	0.06	0.03	0.01	0.94	0.21	0.41
15 to 21 d	0.17	0.11	0.15	0.11	0.03	0.54	0.04	0.48
22 to 28 d	0.38	0.24	0.33	0.26	0.05	0.69	0.03	0.39
29 to 35 d	0.62	0.38	0.58	0.47	0.06	0.68	0.01	0.27
36 to 42 d	1.19	0.91	1.13	0.96	0.08	0.68	0.01	0.42
43 to 49 d	2.02	1.80	1.94	1.94	0.09	0.71	0.13	0.11
50 to 56 d	2.31	2.32	2.33	2.41	0.08	0.41	0.51	0.56
Total CS intake, kg/d								
1 to 42 d	0.40	0.28	0.38	0.31	0.04	0.88	0.01	0.40
1 to 56 d	0.85	0.73	0.82	0.77	0.04	0.85	0.03	0.30
DMI, kg/d								
1 to 14 d	0.57	0.67	0.56	0.66	0.01	0.76	0.01	0.96
15 to 28 d	0.81	0.83	0.77	0.83	0.04	0.59	0.21	0.44
29 to 42 d	1.31	1.18	1.26	1.20	0.07	0.90	0.05	0.33
43 to 56 d	2.17	2.06	2.14	2.18	0.08	0.55	0.61	0.25
Total DMI, kg/d								
1 to 42 d	0.89	0.88	0.86	0.90	0.04	0.89	NS	0.35
1 to 56 d	1.21	1.17	1.18	1.22	0.04	0.87	NS	0.28

[1]Treatments were as follows: control (CP1) = a 20% CP:20% fat MR fed at 0.284 kg 2×/d for 35 d; CP2 = the 20:20 MR fed at 0.34 kg 2×/d for 35 d; HP1 = a 24:20 MR fed at the CP1 rate; and HP2 = the 24:20 MR fed at the CP2 rate. All MR were fed only 1×/d from 36 d to weaning at 42 d.

powder fed at 0.66 kg of DM/d has been successful at improving ADG while maintaining CS intake compared with a 21% CP, 21% fat MR fed at 0.44 kg of DM/d. However, the previous program discussed by Hill et al. (2006b) 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., 2007). This would suggest that calves fed the HP2 treatment would potentially have improved growth rates (fed at a higher rate than Hill et al., 2006a, 28:17), even though these calves consume lesser amounts of CS compared with the calves fed other treatments because these calves had the greatest ADG. This would demonstrate that calves fed HP2 did not experience the post-weaning slump that is commonly observed when feeding accelerated MR feeding programs (Bar-Peled et al., 1997; Jasper and Weary, 2002; Hill et al., 2006a).

Differences in growth rates during the 14-d periods (Table 3) do lead to speculation that ADG increases could potentially be due to gut fill, gut tissue growth, growth composition (fat vs. protein/bone), or water intake associated with differences in MR and CS intakes. Cowles et al. (2006) evaluated the effect of lactoferrin addition to MR varying in CP on DMI, growth, and days medicated. Holstein heifer calves were assigned to 4 treatments including 562 g daily of a nonmedicated conventional MR (20% CP:20% fat) feeding regimen with or without 1 g of supplemental bovine lactoferrin or a nonmedicated intensified MR feeding regimen (0.2 Mcal/kg of $BW^{0.75}$ d 2 to 9 and 0.27 Mcal/kg of $BW^{0.75}$ d 10 to 42) with or without 1 g of supplemental bovine lactoferrin (n = 8 for both treatments). Calves were fed pelleted CS beginning on d 2 and had free choice access to water. Calves remained on the study for 14 d after weaning. Calves on conventional treatments ate more CS before weaning, during weaning, and after weaning. Before weaning, intensively fed calves had higher DMI. Weights of intensively fed calves were greater at weaning. Intensified MR-fed calves had greater ADG before weaning and overall and higher G:F ratios before weaning, but conventionally fed calves had higher G:F ratios during weaning. Intensified MR-fed calves had

Table 3. Body weight, ADG, G:F, and hip height (HH) measurements for calves fed milk replacer (MR) with 2 protein concentrations at 2 feeding rates (FR)

	Treatment[1]					Main effect and interaction, $P <$		
Item	CP1	CP2	HP1	HP2	SEM	MR	FR	MR × FR
No. of calves	25	26	26	27	—	—	—	—
Initial BW, kg	39.4	39.9	39.6	39.6	0.74	0.99	0.63	0.78
BW, kg								
14 d	44.5	45.9	44.6	45.9	0.81	0.98	0.06	0.83
28 d	51.1	52.5	51.1	53.0	0.87	0.67	0.02	0.80
42 d	61.6	61.3	61.3	62.8	1.18	0.56	0.65	0.33
56 d	75.2	76.1	74.6	77.2	1.35	0.82	0.16	0.50
ADG, kg/d								
1 to 14 d	0.37	0.44	0.36	0.45	0.02	0.93	0.01	0.82
15 to 28 d	0.47	0.47	0.46	0.51	0.04	0.54	0.38	0.47
29 to 42 d	0.75	0.62	0.73	0.69	0.05	0.54	0.02	0.17
43 to 56 d	0.96	1.06	0.95	1.03	0.04	0.55	0.02	0.79
1 to 42 d	0.53	0.51	0.52	0.55	0.02	0.41	0.69	0.14
1 to 56 d	0.64	0.65	0.63	0.67	0.02	0.73	0.13	0.30
Total BW gain, kg								
1 to 42 d	22.3	21.5	21.6	23.3	0.95	0.41	0.69	0.14
1 to 56 d	35.9	36.3	35.0	37.7	1.21	0.74	0.13	0.31
G:F, kg/kg								
1 to 42 d	0.60	0.58	0.60	0.62	0.01	0.07	0.88	0.12
43 to 56 d	0.44[b]	0.52[a]	0.45[b]	0.48[b]	0.02	0.15	0.01	0.08
1 to 56	0.53	0.55	0.53	0.56	0.01	0.57	0.01	1.00
Initial HH, cm	80.8	80.3	80.3	80.0	0.46	0.61	0.43	0.63
56-d HH, cm	90.8	90.7	90.8	91.0	0.56	0.71	0.92	0.76
HH gain, cm								
1 to 56 d	10.0	10.4	10.5	11.0	0.46	0.24	0.27	0.71

[a,b]Means within a row with different superscripts differ ($P < 0.05$).

[1]Treatments were as follows: control (CP1) = a 20% CP:20% fat MR fed at 0.284 kg 2×/d for 35 d; CP2 = the 20:20 MR fed at 0.34 kg 2×/d for 35 d; HP1 = a 24:20 MR fed at the CP1 rate; and HP2 = the 24:20 MR fed at the CP2 rate. All MR were fed only 1×/d from 36 d to weaning at 42 d.

greater hip heights during weaning and after weaning and greater heart girths before weaning, during weaning, and after weaning. An intensified MR feeding regimen promotes faster growth during the preweaning period when compared with calves fed conventional treatments, but supplemental bovine lactoferrin was not beneficial under these experimental conditions.

How do different feeding regimens affect body composition? Chapman et al. (2017) developed a simple technique to determine body composition in Holstein dairy calves using deuterium dilution methods. Calves were assigned to 1 of 3 treatments: (1) 446 g of DM of a conventional MR (20% CP, 20% fat), (2) 669 g of DM of a moderately high protein MR (26% CP, 18% fat), or (3) 892 g of DM of a moderately high protein MR (26% CP, 18% fat). Free-choice water and CS were fed. After weaning, a series of blood samples was taken after injections of deuterium oxide. No differences were detected in total body water, protein, fat, or mineral content in calves fed the different MR, which provides an interesting perspective.

Gelsinger et al. (2016) conducted a meta-analysis based on several studies following previous work that proposed that increased feeding of milk or MR to neonatal calves may improve subsequent milk production. However, data from individual studies are conflicting, and the previous meta-analysis was unable to assess the influence of CS intake. The current meta-analysis was to review newly published data and evaluate the effects of preweaning diet (including CS intake) and growth rate on first-lactation milk, fat, and protein yield. The differences in preweaning ADG are small and account for less than 3% of the variation in first-lactation milk production. Genetics, health, and other farm-management practices will account for 97% of the actual milk production that was observed. Furthermore, any ADG improvement to be accomplish in preweaned calves is far more economically accomplished by increasing CS intakes in combination with a reasonable milk or MR program. These authors found a synergistic relationship between preweaning liquid and CS DMI for improving milk, fat, and protein production, and a positive relationship between first-lactation performance and preweaning ADG. These data indicated that provision of adequate nutrients from liquid and solid feeds and maintaining ADG above 0.5 kg/d can enhance first-lactation heifer performance when combined with proper postweaning practices. In the current study, calves gained at least 0.5 kg/d across treatments.

Further support was developed by Chester-Jones et al. (2017), who reported the relationships between early-life parameters (including ADG, BW, MR intake, CS intake, and birth season) and the first-lactation performance of Holstein cows. Data were collected from birth years 2004 to 2012, resulting in 2,880 Holstein heifer observations. Calves were received from 3 commercial dairy farms and enrolled in 37 different calf research trials at the University of Minnesota SROC from 3 to 195 d. Upon trial completion, calves were returned to their respective farms. Milk replacer studies evaluated varying protein levels and amounts fed, but for the majority of studies, calves were fed a MR containing 20% CP and 20% fat at 0.57 kg/d. Most calves (93%) were weaned at 6 wk. The ADG at 6 wk resulted in increased first-lactation milk and milk component yields. Intake of CS at 8 wk had a significant positive relationship with first-lactation 305-d yield of milk and milk components. Milk replacer intake, which varied very little in this data set, had no effect on first-lactation 305-d yield of milk and milk components.

Calculation Results of Protein-to-Energy Ratio

The intake data were used to calculate the CP and energy intake and the ratio of CP to ME for calves fed all treatments in relationship to ADG (Table 4). No MR by FR interactions were detected ($P > 0.10$), except for a tendency ($P < 0.10$) for a MR by FR interaction when evaluating the CP/ME ratio for the overall d 1 to 56 study, whereas other time periods were similar ($P > 0.10$). Per the experimental design, the MR CP content increased ($P < 0.05$) CP intake and CP/ME ratio for calves fed 24% CP MR compared with calves fed the 20% CP MR for the time period d 1 to 42. Calves fed the greater MR FR demonstrated greater ($P < 0.05$) ME intakes with a lower CP/ME ratio compared with calves fed the lower MR FR for 1 to 42 d. For the time period, 43 to 56 d, no differences ($P > 0.10$) were observed for calves for intake of CP, ME, and the ratio of CP/ME, which indicates no effect of the MR feeding stage on postweaning performance. The tendency ($P < 0.10$) for a MR by FR interaction for the time period d 1 to 56 for the CP/ME ratio indicated that calves fed CP2 demonstrated the lowest ($P < 0.05$) CP/ME ratio, whereas calves fed HP1 demonstrated the greatest ($P < 0.05$) ratio of CP/ME, with the remaining treatments being intermediate and different ($P < 0.05$). Adjusting the CP concentration, MR FR, or both can influence the ratio of CP/ME to potentially improved calf growth performance.

The protein:energy ratio is a fundamental concept for determining DMI, ADG, composition of gain, and body composition. The protein requirement for maintenance is relatively low, but the requirement for gain is relatively high (Vermeire, 2005). Vermeire (2005) noted that the opposite is true for energy and that the composition of protein and energy can affect calf performance. The current NRC (2001) publication illustrates this. For example, a 60-kg calf consuming 1.04 kg of DM/d and gaining 600 g requires 217 g of CP and 4.31 Mcal of ME for a CP:ME ratio of 50.4 CP:Mcal of ME. A 60-kg calf consuming 1.24 kg of DM and gaining 800 g/d requires 275 g of CP and 5.16 ME for a CP:ME ratio of 53.3. Postweaned calves of 70 kg of BW gaining 500 g/d with 1.54 kg of DMI require a CP:ME of 55.5. The same BW heifer consuming 2.03 kg of DMI and gaining 800 g/d requires a CP:ME ratio of 58.4. The efficiency of ME for maintenance is higher than the efficiency for gain (NRC, 2001). This was supported by Brown et al. (2005), who observed that increasing energy and protein intake from 2 to 8 wk and 8 to 14 wk of age increased BW, rate of growth, frame size, and G:F ratio but did not alter carcass composition.

Recent studies by Hill et al. (2009a,b) predicted the preweaning CP and energy requirements for calves fed solely MR are approximately 51 to 55 g of CP/Mcal of ME when calves are weaned at 28 d. They also emphasized the importance of maintaining Lys, Met, and Thr AA balances. The predicted CP/ME ratio requirements for MR up to weaning of 51 to 55 g of CP/Mcal of ME were met or exceeded using the treatments in this study; however, our calculations include both MR and CS. Hill et al. (2009a,b) recommended a calf CP/ME ratio before weaning of 51 to 55 g of CP/Mcal of ME. Our data preweaning (42 d) ranged from 51.4 to 59.9 g of CP:Mcal of ME (Table 5). Our data overall for the 56-d study ranged from a CP/ME of 67.4 to 71.4, with the best growth performance occurring at a ratio of 67.4 g of CP/Mcal of ME being higher than those of Hill et al. (2009b) when combining both MR and CS.

Health Performance

No differences ($P > 0.10$) were detected for the MR by FR interaction and the main effects of MR and FR for total serum protein, fecal scores, scouring days, and treatment costs (Table 5). There was a difference ($P < 0.05$) for the FR main effect in that calves fed higher MR FR compared with calves fed low MR FR had higher fecal scores, number of days scouring with a score equal to or greater than 3, and treatment costs for the overall periods of 1 to 42 d.

Fecal scores and scouring days were increased ($P < 0.01$) when calves were fed both MR at greater FR (Table 5) for the first 14 d and the d 1 to 42 and d 1 to 56 time periods. Greater fecal scores and scouring days were observed by Hill et al. (2006a,b). Hill et al. (2006a) reported that calves fed a 28% CP and 20% fat MR had an average fecal score of 1.88 compared with calves fed 20% CP and 20% fat MR, having an average fecal score of 1.57, with the average scouring days being 5.74 and 3.22, respectively. Hill et al. (2006a) observed the same responses when compar-

Table 4. Protein and energy intake by treatment for calves fed milk replacer (MR) with 2 protein concentrations at 2 feeding rates (FR)

	Treatment[1]					Main effects and interaction, $P <$		
Item	CP1	CP2	HP1	HP2	SEM	MR	FR	MR × FR
No. of calves	25	26	26	27				
d 1 to 42								
DMI,[2] kg/d	0.89	0.88	0.96	0.90	0.04	0.89	0.84	0.35
ADG, kg/d	0.53	0.51	0.52	0.55	0.02	0.41	0.69	0.14
CP intake,[3] g/d	188.3	185.2	198.3	209.9	7.31	0.01	0.53	0.22
ME intake,[4] Mcal	3.42	3.58	3.30	3.61	0.09	0.54	0.01	0.34
g of CP/Mcal of ME[5]	54.7	51.4	59.9	58.0	0.66	0.01	0.01	0.19
d 43 to 56								
DMI, kg/d	2.17	2.06	2.14	2.18	0.80	0.55	0.61	0.25
ADG, kg/d	0.96	1.06	0.95	1.03	0.04	0.55	0.02	0.79
CP intake, g/d	447.8	425.2	440.4	450.0	16.2	0.54	0.61	0.24
ME intake, Mcal	5.74	5.45	5.64	5.77	0.21	0.54	0.6	0.24
g of CP/Mcal of ME	78.1	78.1	78.1	78.1	0.00	—	—	—
d 1 to 56								
DMI, kg/d	1.21	1.17	1.18	1.22	0.04	0.89	0.4	0.35
ADG, kg/d	0.64	0.65	0.63	0.67	0.02	0.72	0.18	0.28
CP intake, g/d	636.2	610.6	639.9	660.1	22.20	0.18	0.7	0.21
ME intake, Mcal	9.16	9.04	8.94	9.38	0.28	0.80	0.55	0.25
g of CP/Mcal of ME	69.2^{c}	67.4^{d}	71.4^{a}	70.3^{b}	0.33	0.01	0.01	0.09

$^{a–d}$Means within a row with different superscripts differ ($P < 0.05$).

[1]Treatments were as follows: control (CP1) = a 20% CP:20% fat MR fed at 0.284 kg 2×/d for 35 d; CP2 = the 20:20 MR fed at 0.34 kg 2×/d for 35 d; HP1 = a 24:20 MR fed at the CP1 rate; and HP2 = the 24:20 MR fed at the CP2 rate. All MR were fed only 1×/d from 36 d to weaning at 42 d.

[2]Total of MR and calf starter DM.

[3]Percent CP × MR intake (kg) + % CP × calf starter intake (kg) (all on DM basis)/d.

[4]ME (Mcal/kg) × MR intake (kg) + ME (Mcal/kg) × CS intake (kg) (all on DM basis)/d.

[5]CP intake (g/d)/ME intake (Mcal).

Table 5. Health data for calves fed milk replacer (MR) with 2 protein concentrations at 2 feeding rates (FR)

	Treatment[1]					Main effects and interaction, *P* <		
Item	CP1	CP2	HP1	HP2	SEM	MR	FR	MR × FR
No. of calves	25	26	26	27	—	—	—	—
Fecal score[2]								
1 to 14 d	1.5	1.8	1.7	1.8	0.07	0.05	0.01	0.18
15 to 28 d	1.3	1.3	1.3	1.3	0.05	0.68	0.27	0.57
29 to 42 d	1.0	1.0	1.0	1.1	0.02	0.05	0.14	0.24
43 to 56 d	1.1	1.1	1.0	1.1	0.02	0.11	0.78	0.44
1 to 42 d	1.3	1.4	1.3	1.4	0.03	0.13	0.01	0.41
1 to 56 d	1.2	1.3	1.3	1.3	0.02	0.27	0.01	0.53
Scouring days[2]								
(d 1 to 42) ≥3	1.8	3.1	2.5	2.9	0.47	0.57	0.06	0.31
Treatment cost, $								
1 to 42 d	0.32	0.57	0.43	0.83	0.25	0.28	0.04	0.54
43 to 56 d	0.00	0.00	0.00	0.00	0.00	—	—	—
1 to 56 d	0.32	0.57	0.43	0.83	0.25	0.28	0.05	0.54

[1]Treatments were as follows: control (CP1) = a 20% CP:20% fat MR fed at 0.284 kg 2×/d for 35 d; CP2 = the 20:20 MR fed at 0.34 kg 2×/d for 35 d; HP1 = a 24:20 MR fed at the CP1 rate; and HP2 = the 24:20 MR fed at the CP2 rate. All MR were fed only 1×/d from 36 d to weaning at 42 d.

[2]Fecal score = 1 to 4; 1 = normal, ≥3 = scours.

ing 2 FR of 2 MR containing either 20% CP and 20% fat or 28% CP and 20% fat with the 20:20 MR fed at the same rate as the 28:20 MR. Average fecal scores were 1.42, 1.50, and 1.60 and average scouring days were 3.65, 4.11, and 4.23 for 20:20 MR fed at 0.45 kg/d, 20:20 MR fed at 0.68 kg/d, and 28:20 MR fed at 0.68 kg/d, respectfully. Hill et al. (2006b) reported that the scouring days varied from 2.4 to 3.3. A minimal number of calves were used (10 per treatment) in that study, but the results do support the results found in this study, that feeding MR at higher FR does increase fecal scores and scouring days.

APPLICATIONS

The objective was to develop a modified accelerated MR (higher CP) that when fed at a high FR would enhance growth rates and prevent the slump in postweaning CS intake. Under the study conditions, the MR × FR interaction had a greater influence on calf growth performance than MR CP concentration. The CP and energy intakes across all treatments were apparently adequate to meet or exceed preweaning CP and energy requirements. Further research is warranted to determine the economic optimization of an appropriate FR of a 24:20 MR to enhance calf health, growth, and performance without a postweaning slump in ADG and CS intake.

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