Effects of egg yolk inclusion, milk replacer feeding rate, and low-starch (pelleted) or high-starch (texturized) starter on Holstein calf performance through 4 months of age

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ABSTRACT

The objectives of this research were to evaluate milk replacer (MR) feeding rates, alternative protein and fat sources in MR, and calf starter starch concentration and their effects on calf performance to 4 mo of age. Male Holstein calves (42.6 ± 1.2 kg of body weight; $n = 192$) were assigned at 3 d of age to 1 of 8 treatments in a randomized complete block design with a $2 \times 2 \times 2$ factorial arrangement of treatments. Factors tested from d 0 to 56 (nursery) were low or high MR feeding rates, 0 or 10% inclusion of spray-dried egg yolks in MR, and low- or high-starch calf starter. The low MR rate was 0.66 kg of dry matter (DM) fed for 39 d followed by 0.33 kg of DM for 3 d. The high MR rate was 0.87 kg of DM fed for 5 d, 1.08 kg of DM for 37 d, and 0.43 kg of DM for 7 d. The MR contained 27.5% crude protein and 19.6% fat (DM basis) and starters were 21.2% crude protein; low starch was a complete pellet with 10.2% starch, and high starch was textured using whole corn and oats with 43.3% starch. From d 56 to 112 (grower), calves were randomly assigned to pens (4 calves/pen) maintaining MR rate and starch content while stratifying yolk treatments within pen, resulting in a 2×2 factorial arrangement. Starter was blended with 5% chopped hay during the grower trial. Fecal scores and medical treatments were recorded daily. In the nursery trial, calves were weighed initially and weekly thereafter. Hip width and body condition score (BCS) were measured initially and every 2 wk thereafter. In the grower trial, body weight, hip width, and BCS were measured on d 56, 84, and 112. Data were analyzed as repeated measures with calf (nursery) or pen (grower) as the experimental unit. Calf average daily gain, hip width, and BCS change were greater for calves fed high versus low MR, 0 versus 10% yolk, and high versus low starch in the nursery. In the grower trial, calves fed low MR and high starch had the great-

est average daily gain (1.09 vs. 0.87 kg/d) and hip width change (5.4 vs. 3.9 cm) compared with calves fed low MR and low starch with other treatments intermediate. From 0 to 112 d, calves fed high MR had 9% greater body weight gain and 4% greater hip width change than calves fed low MR, yet nutrient efficiency was similar despite 80% more MR intake than calves fed low MR. Additionally, calves fed high-starch starter achieved 18% greater body weight gain and 17% greater hip width than calves fed low starch starter overall, a more than 2-fold greater response than the effect of MR feeding rate.

Key words: calf, starch, egg, milk replacer

INTRODUCTION

Many have reported that as more milk or milk replacer (MR) is fed, preweaning ADG increases (Bar-Peled et al., 1997; Nocek and Braund, 1986). However, when the amount of milk or MR fed is more than approximately 0.7 kg of DM, postweaning ADG is typically less than when ≤ 0.7 kg of DM from milk or MR is fed (Hill et al., 2006a,b, 2007, 2010). Reduced postweaning ADG has been thought to be related to less dry feed intake before weaning, but preweaning MR intake has shown mixed effects on DMI immediately postweaning and after 56 d (Hill et al., 2007, 2010, 2013). Less postweaning ADG when feeding more milk or MR may be associated with lesser rumen development (Terré et al., 2007a,b; Suarez-Mena et al., 2011), leading to less digestion of dry feed at and after weaning (Terré et al., 2007a,b; Hill et al., 2010, 2016c; Chapman et al., 2016). Some data suggest calves fed large amounts of milk to achieve more ADG early in life may increase milk yield in the first lactation (Soberon et al., 2012). Other researchers have suggested calves fed more starter and less MR to achieve more balanced early life ADG may also increase potential for more milk in the first lactation (Bach and Ahedo, 2008; Heinrichs and Heinrichs, 2011; Bach, 2012; Gelsinger et al., 2016).

Milk proteins are expensive relative to other proteins due to increased demand for human use (Davis and

Received May 15, 2017.

Accepted July 28, 2017.

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Drackley, 1998) and the use of alternative, lower cost proteins are of interest for calf MR. Egg protein has been shown to have a comparable protein efficiency ratio to milk protein (Schaafsma, 2000), could have utility in MR, and offers a lower cost than milk proteins. However, the success of using egg protein in MR for calves has been mixed. Quigley (2002) reported a linear reduction in ADG for calves fed 10 and 20% spray-dried whole egg (SDWE) as a partial replacement for whey protein and animal fat, particularly from d 0 to 28 when no starter was fed. However, Touchette et al. (2003) found 5% SDWE inclusion in MR supported similar or improved ADG compared with all-milk protein, but 15% SDWE inclusion reduced ADG approximately 18% compared with lower inclusions of SDWE. It is unclear why SDWE reduces performance when partially replacing milk proteins, though it may be due to anti-nutritional factors present in egg protein (Quigley, 2002). Some of these factors may be avoided by using spray-dried egg yolk, a co-product of egg white separation for human consumption. Egg yolk is composed primarily of lipids, which make up approximately 61% of the total DM of the yolk and include palmitic acid, oleic acid, linoleic acid, and phosphatidylcholine (Quigley, 2002; USDA, 2015). Protein makes up approximately 35% of the yolk DM and includes lipoproteins and phosphoproteins (Byrne et al., 1989). Use of alternative proteins for MR fed to calves less than 3 wk of age is advised against by NRC (2001) due to difficulties in protein digestion. However, most of the research in neonatal calves where alternative proteins were fed in MR have been with low to moderate (0.44 to 0.73 kg of DM/d) MR feeding rates and formulas with less than 24% CP on a DM basis.

The use of low-starch co-products is prevalent in the US dairy calf feed market (Hill et al., 2012). Quality carbohydrates are required by the young calf because the rumen and other digestive systems are underdeveloped (NRC, 2001). Inclusion of low-starch ingredients in the diet of calves less than 4 mo of age has resulted in reductions in ADG and structural growth (Hill et al., 2008, 2012, 2016a; Suarez-Mena et al., 2011; Terré et al., 2013) likely stemming from low digestibility (Hill et al., 2016a) compared with high-starch feeds. However, these data were collected when feeding calves low to moderate MR feeding rates. Kosiorowska et al. (2011) did not observe interactions of whole milk feeding rate (3.2 vs. 6.4 kg/d) with calf starter starch content (35 vs. 11% starch on a DM basis) on the performance of male Holstein calves, but ADG was improved when milk allowance or starch content were high. It is unclear if the response would be similar when alternative proteins are used in MR.

Most studies evaluating preweaning nutrition in calves do not report performance beyond 1 to 2 wk postweaning. Additionally, even fewer studies have evaluated potential interactions between preweaning and postweaning nutrition on growth in dairy calves. Therefore, the objectives of this research were to evaluate spray-dried egg yolk as an alternative fat and protein source in MR, MR feeding rate, and starch concentration in the starter and their potential interactions on calf performance pre- and postweaning until 4 mo of age.

MATERIALS AND METHODS

All animals were cared for as described in the *Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching* (FASS, 2010). Calves were received in 4 blocks of 48 calves 5 wk apart. Calves were purchased from a commercial dairy farm and transported 3.5 h to the Nurture Research Center nursery in southwest Ohio. The nursery consisted of individual calf pens (1.2 m $\times$ 2.4 m) with a coarse rock, tile-drained base bedded with wheat straw in a naturally ventilated barn with curtain sides and no added heat. The nursery trial (d 0 to 56) was conducted from January to July where the average ambient temperature in the nursery was 10°C (range from -11 to 32°C) and the average relative humidity was 77% (range from 24 to 100%). The grower trial (d 56 to 112) was conducted from March to September with an average ambient temperature of 18°C (ranged from -1 to 26°C) and an average humidity of 80% (ranged from 24 to 100%).

In the nursery trial, 192 male Holstein calves initially 42.6 ± 1.16 kg of BW and 3 to 4 d of age were assigned to 1 of 8 treatments in a randomized complete block design with $2 \times 2 \times 2$ factorial arrangement of treatments. Factors tested included 2 levels of spray-dried egg yolk inclusion (0 or 10% on as-fed basis; Ballas Egg Products Corp., Zanesville, OH), 2 levels of MR feeding rate, and 2 levels of starch concentration in calf starter (10 or 43% starch on DM basis). The low MR rate was 0.66 kg of DM fed in 2 equal meals twice daily (0630 and 1400 h) for 39 d followed by 0.33 kg of DM fed once daily (0630 h) for 3 d. The high MR rate was 0.87 kg of DM fed in 2 equal meals twice daily for 5 d, 1.08 kg of DM for 37 d, and 0.43 kg of DM fed once daily for 7 d. Milk replacers were formulated to contain 27% CP and 17% fat (DM basis; Table 1) and were diluted with water to 14% DM before feeding. Calf starters were formulated to provide 20% CP (DM basis; Table 2) and were either a complete pellet (10% starch) or textured with whole corn and whole oats (43% starch). Starter and water were offered for ad libitum intake throughout

the trial. On d 56 at the start of the grower trial, calves were randomly assigned to group pens (4 calves/pen) maintaining nursery MR feeding rate and starter starch concentration while stratifying egg yolk MR treatments within pen (2 calves each from 0 and 10% egg yolk MR per pen). Group pens had 6.5 m² of outside pen space and 1.4 m² of resting area per calf within an opaque plastic hutch and the resting area was bedded with straw with no added heat. Calves were fed calf starter (same as in nursery trial) blended with 5% chopped grass hay for ad libitum intake with unrestricted access to water.

On the day of arrival at 1600 h and the morning after arrival, all calves were fed 0.66 kg of DM from 0% yolk MR. The day after arrival at approximately 1200 h (d 0), calves were weighed and randomly assigned to treatments. At this time, blood was sampled intravenously, serum was separated by centrifugation at 3,000 × *g* (VWR, Batavia, IL) and 20°C for 15 min, and serum total protein concentration was estimated using an optical refractometer (Atago U.S.A. Inc., Bellevue, WA). Feces were scored daily using a 1 to 5 scale with 1 being normal and 5 being watery (modified from Kertz and Chester-Jones, 2004). Fecal scores >2 were considered abnormal. Medical treatments were recorded daily and consisted of antibiotic treatments under veterinary supervision that were based on lethargy or rectal temperatures >39.4°C. Calves received oral electrolytes for diarrhea when fecal scores were >2; however, electrolytes were not counted as a medical treatments. Calves were weighed on d 0, 7, 14, 21, 28, 35, 42, 49, and 56 during the nursery trial and on d 84 and 112 of the grower trial. Body condition score (1 being thin and 5 being obese; modified from Wildman et al., 1982 by palpating the transverse processes of the spine by one experienced technician) and hip widths were measured with a caliper on d 0, 14, 28, 42, 56, 84, and 112.

Feed samples were taken from every other bag (22.7 kg) of MR or starter and every bale of hay and composited by trial (nursery or grower). Composites of feeds were analyzed (AOAC International, 2000) for DM (oven method 930.15), ash (oven method 942.05), CP (Kjeldahl method 988.05), fat (alkaline treatment with Röse-Gottlieb method 932.06 for MR; diethyl ether extraction method 2003.05 for starters and hay), Ca and P (dry ashing, acid digestion, and analysis by inductively coupled plasma, method 985.01), NDF with ash without sodium sulfite or α-amylase (Van Soest et al., 1991), ADF with ash (Robertson and Van Soest, 1981), starch (α-amylase method; Hall, 2009), and sugar (colorimetric method; Dubois et al., 1956). Geometric mean particle size distribution (ASAE, 1983) was measured using dry (chopped hay) and wet (starters)

sieving methods (Shaver et al., 1988) using a vibratory sieve shaker.

In the nursery trial, data were analyzed as a randomized complete block design with a 2 × 2 × 2 factorial arrangement of treatments and repeated measures by the MIXED procedure in SAS (version 8, SAS Institute Inc., Cary, NC). Calf (1 calf/pen) was the experimental unit. In the grower trial, data were analyzed as a randomized complete block design with a 2 × 2 factorial arrangement of treatments and repeated measures. Pen was the experimental unit. When there were interactions of main effects, treatment means were separated using a protected LSD test. An auto-regressive type 1 covariance matrix was employed as determined using Akaike's information criterion. Block of calves was considered random in all models. Significance was determined at $P \leq 0.05$ and statistical trends were determined at $0.10 > P > 0.05$.

Table 1. Ingredient composition and nutrient analyses of 2 milk replacers

Item	No yolk	High yolk
Ingredient, % as-fed		
Whey	49.83	52.41
Dry fat, 7% CP, 60% fat	22.71	13.64
Whey protein concentrate, 80% CP	22.67	19.28
Emulsifier blend ¹	1.65	1.65
NeoTec5G premix ²	1	1
Dicalcium phosphate 18.5% P	0.38	—
DL-Methionine	0.36	0.33
Calcium carbonate	0.3	0.54
Flavor	0.3	0.3
L-Lysine	0.29	0.34
Flow agent	0.2	0.2
Vitamin, trace mineral premix ¹	0.17	0.17
Choline chloride	0.1	0.1
Bovatec 150 FP ³	0.03	0.03
Clarify 8% ⁴	0.01	0.01
Dried egg yolk ⁵	—	10
Analyzed nutrient, % as-fed		
DM	95.4	95.5
Analyzed nutrient, % of DM		
CP	27.1	27.8
Sugar	16.6	16.4
Starch	6.4	7
Fat	19	20.1
Ash	7	6.9
Ca	0.79	0.76
P	0.66	0.66
Digestible energy, ⁶ Mcal/kg	5	5.1
ME, ⁶ Mcal/kg	4.8	4.9

¹Provimi North America, Brookville, OH.

²Blend of fatty acids and nutrients, Provimi North America.

³Zoetis, Florham Park, NJ.

⁴Wellmark International, West Schaumburg, IL.

⁵30% CP, 56% fat, Ballas Egg Products Corp., Zanesville, OH.

⁶Calculated using NRC (2001) equations.

Table 2. Ingredient composition and nutrient analyses of starters and hay fed to calves from 0 to 112 d of age

Item	Low starch Nursery	Low starch Grower	High starch Nursery	High starch Grower	Grass hay Grower
Ingredient, % as fed					
Soybean hulls	41.32	41.32	—	—	—
Wheat middlings	30	30	5.62	5.62	—
Soybean meal	17.99	17.99	23.91	23.91	—
Maltodextrin	2.5	2.5	0.7	0.7	—
Molasses	2.5	2.5	3.00 ¹	3.00 ¹	—
Fat	2	2	0.26	0.26	—
Vitamin, trace mineral, NeoTec premix ²	0.75	0.75	0.75	0.75	—
Salt	0.6	0.6	0.6	0.6	—
Ameri-Bond 2x ³	0.5	0.5	—	—	—
Calcium carbonate	0.44	0.44	1.27	1.27	—
Monocalcium phosphate	0.33	0.33	0.78	0.78	—
Clarifly 0.67% ⁴	0.07	0.07	0.07	0.07	—
Corn, whole	—	—	37.00 ¹	37.00 ¹	—
Oats, whole	—	—	25.00 ¹	25.00 ¹	—
Alfalfa meal	—	—	0.7	0.7	—
Magnesium oxide	—	—	0.3	0.3	—
Bovatec 3 ⁵	1	1	—	—	—
Bovatec 91 ⁶	—	—	0.03	0.03	—
Analyzed nutrient, % as fed					
DM	88.7	88.5	87.4	87.6	87.1
Analyzed nutrient, % DM					
CP	22.2	22.3	20.2	19.9	10.8
ADF	24.6	24.2	8	8.1	40.6
NDF	41.8	41.5	17.1	17.2	60
Sugar	5.5	5.6	6.4	6.5	7.2
Starch	10.1	10.3	43.1	43.5	3.8
Fat	3.9	3.8	3.3	3.4	2.4
Ash	9	8.9	6.9	6.8	8.3
Ca	0.94	0.93	1	1.02	0.66
P	0.58	0.57	0.69	0.68	0.24
Digestible energy, ⁷ Mcal/kg	3.3	3.3	3.6	3.6	2.6
ME, ⁷ Mcal/kg	2.6	2.6	2.7	2.7	2.1
Mean particle size, ⁸ μ m	824	849	2,105	2,187	2,536

¹These ingredients were not within the pellet that contained the other ingredients.

²Premix with vitamins, trace minerals, fatty acids, and nutrients (Provimi North America, Brookville, OH).

³Pellet binder, Borregaard LignoTech, Sarpsborg, Norway.

⁴Wellmark International, West Schaumburg, IL.

⁵Blended by Provimi North America from Bovatec 91.

⁶Zoetis, Florham Park, NJ.

⁷Calculated using NRC (2001) equations.

⁸Geometric mean particle size (ASAE, 1983).

RESULTS

During the 0- to 56-d nursery trial, main effect and week interactions were observed ($P < 0.001$) for calf starter intake and BW gain, with a tendency ($P < 0.09$) for an interaction for hip width change (Figure 1). Initial calf measurements did not differ ($P > 0.05$) for any main effect (Table 3). Calves fed 0% yolk MR had greater ($P < 0.05$) ADG, starter intake, feed efficiency, hip width change, and BCS change and lower ($P < 0.05$) fecal scores than calves fed 10% yolk MR. Calves fed the high MR rate had greater ($P < 0.05$) ADG, feed efficiency, hip width change, BCS change, fecal scores, abnormal fecal score days, and medical treatment days and lower starter intake than calves fed the

low MR rate. Calves fed high-starch starter had greater ($P < 0.05$) ADG, starter intake, hip width change, BCS change, and fecal scores and lower medical treatment days than calves fed the low-starch starter.

During the 56- to 112-d grower trial, calf performance changed ($P < 0.05$) depending on 28-d phase (Table 4). From d 56 to 84, calves previously fed the high MR rate with low starch or the low MR rate with high starch had the greatest ADG and feed efficiency, but from d 84 to 112 calves previously fed the high MR rate and low starch had the lowest ADG and were the least feed efficient. Treatment means are shown in Table 5, and main effect means are shown in Table 6. Calves fed the low-MR, high-starch treatment had the greatest ($P < 0.05$) ADG and change in hip width of the 4 treat-

a) Starter intake; SEM = 0.0653 kg/d, $P < 0.001$ for week by treatment interaction.

b) Accumulating BW gain; SEM = 3.3 kg, $P < 0.001$ for week by treatment interaction.

c) Accumulating hip width change; SEM = 0.068 cm, $P < 0.09$ for week by treatment interaction.

Figure 1. Starter intake (a), accumulating BW gain (b), and accumulating hip width change (c) of calves fed 6 feeding programs ($n = 24$ calves) by week over the nursery trial. In the 3-letter combination, the first letter represents low (L) or high (H) yolk concentration, the second letter represents milk replacer rate (L or H), and the third letter represents starter starch concentration (L or H). Low (solid line) was 0% dried egg yolk in the milk replacers, whereas high (broken line) was 10%. The low milk replacer rate (thin line) was 0.66 kg of DM fed in 2 equal meals for 39 d followed by 0.33 kg of DM fed in the 0100 h meal for 3 d. The high rate (thick line) was 0.87 kg of DM fed in 2 equal meals twice daily for 5 d, followed by 1.08 kg of DM fed in 2 equal meals twice daily for 37 d, followed by 0.43 kg of DM fed in the 0100 h meal for 7 d. Starters contained either 10% starch (circle) or 43% starch (square). (a) Starter intake; SEM = 0.0653 kg/d, $P < 0.001$ for week by treatment interaction. (b) Accumulating BW gain; SEM = 3.3 kg, $P < 0.001$ for week by treatment interaction. (c) Accumulating hip width change; SEM = 0.068 cm, $P < 0.09$ for week by treatment interaction.

Table 3. Performance of calves fed milk replacers (MR) with 2 levels of egg yolk at 2 rates with starters containing 2 levels of starch over a 56-d nursery trial (n = 24 calves)

Item	0% Yolk	10% Yolk	Low MR ¹	High MR	Low starch ²	High starch	SEM	P-value for main effects and interactions					
								Yolk	MR	Starch	Yolk × MR	Yolk × starter	MR × starter
Initial serum protein, mg/dL	5.6	5.5	5.5	5.6	5.5	5.5	0.16	0.32	0.23	0.54	0.95	0.23	0.66
Initial BW, kg	42.3	42.9	42.2	43.0	42.5	42.8	1.16	0.37	0.30	0.69	0.26	0.10	0.38
Final BW, kg	73.6	70.5	67.4	76.7	70.2	73.9	1.98	0.01	0.001	0.002	0.34	0.81	0.03
Initial hip width, cm	17.4	17.5	17.4	17.5	17.5	17.4	0.23	0.59	0.20	0.87	0.15	0.41	0.38
Final hip width, cm	21.2	20.8	20.6	21.4	20.9	21.1	0.23	0.02	0.001	0.13	0.95	0.85	0.08
Initial BCS ³	2.1	2.1	2.1	2.1	2.1	2.1	0.03	0.08	0.44	0.09	0.15	0.58	0.72
Final BCS	2.3	2.2	2.2	2.3	2.2	2.3	0.04	0.15	0.001	0.01	0.25	0.66	0.75
MR intake, kg/d	0.659	0.659	0.470	0.847	0.659	0.659	—	—	—	—	—	—	—
Starter intake, kg/d	0.519	0.454	0.582	0.391	0.439	0.534	0.049	0.04	0.001	0.004	0.53	0.78	0.08
CP intake, kg/d	0.288	0.279	0.252	0.315	0.278	0.288	0.0081	0.06	0.001	0.07	0.07	0.09	0.08
ME intake, ⁴ Mcal/d	4.54	4.43	3.82	5.14	4.34	4.64	0.141	0.36	0.001	0.003	0.08	0.11	0.12
ADG, kg/d	0.558	0.492	0.449	0.601	0.494	0.556	0.022	0.001	0.001	0.001	0.68	0.20	0.01
Feed efficiency ⁵	0.576	0.363	0.354	0.584	0.463	0.475	0.0162	0.001	0.001	0.24	0.001	0.07	0.08
ADG, g/Mcal of ME intake	1.94	1.76	1.78	1.91	1.78	1.93	0.058	0.03	0.07	0.08	0.09	0.12	0.13
Hip width change, cm	123	111	117	117	114	120	3.523	0.04	0.36	0.06	0.11	0.09	0.09
BCS change	0.2	0.1	0.1	0.2	0.1	0.2	0.03	0.003	0.001	0.05	0.16	0.31	0.37
Fecal score ⁶	2.0	2.1	2.0	2.1	2.0	2.1	0.05	0.03	0.001	0.003	0.89	0.95	1.00
Abnormal fecal days, ⁷ no.	0.5	0.4	0.3	0.6	0.5	0.4	0.02	0.05	0.005	0.001	0.76	0.36	0.29
Medical days, ⁸ no.	1.9	2.2	1.8	2.3	2.3	1.7	0.18	0.36	0.02	0.45	0.14	0.25	0.06
							0.37	0.23	0.04	0.01	0.33	0.76	0.94

¹The low MR rate was 0.66 kg of DM fed in 2 equal meals for 39 d followed by 0.33 kg of DM fed in the 0100 h meal for 3 d. The high MR rate was 0.87 kg of DM fed in 2 equal meals twice daily for 5 d, followed by 1.08 kg of DM fed in 2 equal meals twice daily for 37 d, followed by 0.43 kg of DM fed in the 0100 h meal for 7 d.

²Starters contained either 10% starch (low) or 43% starch (high).

³1 to 5 point system with 1 being thin and 5 being obese, modified from Wildman et al. (1982).

⁴Calculated using NRC (2001) equations.

⁵Feed efficiency was calculated as gain divided by the sum of milk replacer and starter intake.

⁶Feces were scored daily using a 1 to 5 scale with 1 being normal and 5 being watery, modified from Kertz and Chester-Jones (2004).

⁷Days with fecal scores ≥3.

⁸Days where calves were treated with antibiotics based on rectal temperatures >39.4°C and lethargy.

ments. Ending BW were greatest ($P < 0.05$) for calves fed the high-starch treatments, intermediate ($P < 0.05$) for calves fed the high-MR, low-starch treatment, and least ($P < 0.05$) for calves fed the low-MR, low-starch treatment. Ending hip widths were least ($P < 0.05$) for calves fed the low-MR, low-starch treatments versus the other treatments. For main effects, calves fed the low MR rate had greater ($P < 0.05$) hip width change than calves fed the high MR rate. Calves fed high-starch starter had greater ($P < 0.05$) ADG, hip width change, BCS change, and feed efficiency than calves fed low-starch starter.

Over the 112 d, experimental units changed from calf in the nursery trial to pen in grower trial, so statistics could not be used to compare total intake and growth. Over the 112 d, MR intake was 26 kg and starter intake 166 kg for a total DMI of 192 kg for calves fed the low MR rate. These calves gained 7.9 cm of hip width and 80 kg of BW with a feed efficiency of 0.42 kg of BW gain/kg of total DMI (G:F). Over the 112 d, MR intake was 42 kg and starter intake 165 kg for a total DMI of 213 kg for calves fed the high MR rate. These calves gained 8.2 cm of hip width and 87 kg of BW with a feed efficiency of 0.41 G:F. Whereas BW gain appeared to favor calves fed more MR, hip width change and feed efficiency were numerically similar.

When making similar comparisons of calves fed the low- and high-starch starters over the 112 d, MR intake was the same (37 kg) and starter intake was appeared numerically greater for calves fed high starch (173 vs. 159 kg). Calves fed the low-starch starter gained 7.4 cm hip width, 77 kg of BW, and had a feed efficiency of 0.39 G:F. Calves fed the high-starch starter gained 8.7 cm hip width, 91 kg of BW, and had a feed efficiency of 0.43 G:F, appearing to perform better than calves fed the low-starch starter.

DISCUSSION

Diets with 10% egg yolk were inferior to diets without egg yolk with respect to any growth measurement in the current study. Quigley (2002) reported inclusion of 10 and 20% SDWE in a 24% CP, 22% fat (DM basis) MR did not support the same ADG as MR without egg when fed at increasing and decreasing amounts from 0 to 6 wk of age to average 0.53 kg of MR DM/d. Touchette et al. (2003) reported 5% SDWE in a 21% CP, 19% fat (DM basis) MR could support the ADG of a conventional MR without egg when fed at 0.44 kg of MR DM/d from 0 to 6 wk of age. However, when fed conventional MR with 10 or 20% SDWE, ADG declined compared with MR without egg. Little is understood regarding why negative effects of including egg prod-

Table 4. Performance of calves during 2 phases of the 56-d grower trial when fed starters with 2 starch concentrations or 2 previously fed milk replacer (MR) rates (n = 12 pens)¹

Item	Phase 1						Phase 2						Diet × phase		Phase	
	High MR ²			Low MR ²			High MR			Low MR			SEM		P-value	
	High starch ³	Low starch ³		High starch	Low starch		High starch	Low starch		High starch	Low starch					
DMI, kg/d	2.28	2.15		2.18	1.91		2.89	2.91		2.83	2.61		0.12	0.23	0.001	
DMI, % of BW	2.57	2.41		2.61	2.50		2.47	2.56		2.49	2.58		0.107	0.004	0.95	
ADG, kg/d	0.80	0.90		0.91	0.74		1.24	0.88		1.28	1.00		0.057	0.02	0.001	
Feed efficiency ⁴	0.355	0.429		0.420	0.394		0.433	0.322		0.461	0.392		0.0277	0.03	0.90	
Hip width change, cm	2.1	2.2		2.5	2.2		2.5	1.9		3.0	1.7		0.14	0.02	0.76	
BCS change ⁵	0.03	0.01		0.1	0.0		0.5	0.3		0.4	0.4		0.038	0.61	0.001	

¹Phases were 28 d (56 to 84 d, 84 to 112 d). Performance differed by phase, and treatment × phase interactions were observed ($P < 0.05$).

²The low MR rate was 0.66 kg of DM fed in 2 equal meals for 39 d followed by 0.33 kg of DM fed in 0100 h meal for 3 d. The high MR rate was 0.87 kg of DM fed in 2 equal meals twice daily for 5 d, followed by 1.08 kg of DM fed in 2 equal meals twice daily for 37 d, followed by 0.43 kg of DM fed in 0100 h meal for 7 d.

³Starters contained either 10% starch (low) or 43% starch (high) and were each fed with 5% chopped grass hay as a TMR.

⁴Feed efficiency was calculated as ADG divided by DMI.

⁵1 to 5 point system with 1 being thin and 5 being obese, modified from Wildman et al. (1982).

Table 5. Treatment means for performance of calves from 56 to 112 d (grower trial) when fed starters with 2 starch concentrations or 2 previously fed milk replacer rates (n = 12 pens)¹

Item	High MR ²		Low MR ²		SEM
	High starch ³	Low starch ³	High starch	Low starch	
Initial BW, kg	77.5	76.0	70.3	66.2	1.646
Final BW, kg	134.7 ^c	125.8 ^b	131.4 ^c	114.7 ^a	1.696
Initial hip width, cm	21.4	21.4	20.7	20.5	0.185
Final hip width, cm	26.0 ^b	25.5 ^b	26.2 ^b	24.4 ^a	0.207
Initial BCS ⁴	2.4	2.3	2.2	2.2	0.032
Final BCS	2.9	2.6	2.8	2.6	0.076
DMI, kg/d	2.59	2.53	2.5	2.26	0.117
DMI, % of BW	2.52	2.48	2.55	2.54	0.103
ADG, kg/d	1.02 ^b	0.89 ^a	1.09 ^c	0.87 ^a	0.019
Feed efficiency ⁵	0.394	0.375	0.440	0.393	0.0173
Hip width change, cm	4.6 ^c	4.1 ^b	5.4 ^d	3.9 ^a	0.11
BCS change	0.5	0.3	0.6	0.4	0.05

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

¹Phases were 28 d (56 to 84 d, 84 to 112 d). Performance differed by 28-d phase, and treatment $\times$ phase interactions were observed ($P < 0.05$) as shown in Table 4. When main effects interacted ($P < 0.05$), treatment means were separated with a protected LSD test.

²The low milk replacer rate (MR) was 0.66 kg of DM fed in 2 equal meals for 39 d followed by 0.33 kg of DM fed in 0100 h meal for 3 d. The high rate was 0.87 kg of DM fed in 2 equal meals twice daily for 5 d, followed by 1.08 kg of DM fed in 2 equal meals twice daily for 37 d, followed by 0.43 kg of DM fed in 0100 h meal for 7 d.

³Starters contained either 10% starch (low) or 43% starch (high) and were each fed with 5% chopped grass hay as a TMR.

⁴1 to 5 point system with 1 being thin and 5 being obese, modified from Wildman et al. (1982).

⁵Feed efficiency was calculated as ADG divided by DMI.

Table 6. Main effect means for performance of calves from 56 to 112 d when fed starters with 2 starch concentrations or 2 previously fed milk replacer (MR) rates (n = 12 pens)¹

Item	Low MR ²	High MR	Low starch ³	High starch	SEM	P-value		
						MR	Starch	Starch $\times$ MR
Initial BW, kg	68.3	76.8	71.1	73.9	1.646	0.001	0.06	0.37
Final BW, kg	123.1	130.3	120.3	133.1	1.696	0.001	0.001	0.02
Initial hip width, cm	20.6	21.4	21	21.1	0.185	0.001	0.67	0.56
Final hip width, cm	25.3	25.8	25	26.1	0.207	0.021	0.001	0.002
Initial BCS ⁴	2.2	2.3	2.2	2.3	0.032	0.001	0.001	0.53
Final BCS	2.7	2.7	2.6	2.8	0.076	0.08	0.001	0.78
ADG, kg/d	0.98	0.96	0.88	1.06	0.019	0.23	0.001	0.02
Hip width change, cm	4.7	4.3	4	5	0.11	0.001	0.001	0.001
BCS change	0.5	0.4	0.4	0.5	0.05	0.24	0.003	0.99
DMI, kg/d	2.38	2.56	2.39	2.55	0.117	0.14	0.2	0.43
CP intake, kg/d	0.496	0.533	0.478	0.552	0.0202	0.06	0.05	0.39
ME intake, Mcal/d	6.31	6.78	6.45	6.63	0.2598	0.06	0.11	0.42
DMI, % of BW	2.55	2.5	2.51	2.54	0.103	0.67	0.81	0.92
Feed efficiency ⁵	0.417	0.385	0.384	0.417	0.0173	0.07	0.07	0.42
ADG, g/g of CP intake	1.98	1.80	1.84	1.92	0.076	0.04	0.12	0.53
ADG, g/Mcal of ME intake	155	142	136	160	5.9	0.04	0.03	0.51

¹Phases were 28 d (56 to 84 d, 84 to 112 d). Performance differed by 28-d phase, and treatment $\times$ phase interactions were observed ($P < 0.05$) as shown in Table 4. Treatment means are shown in Table 5.

²The low milk replacer rate (MR) was 0.66 kg of DM fed in 2 equal meals for 39 d followed by 0.33 kg of DM fed in 0100 h meal for 3 d. The high rate was 0.87 kg of DM fed in 2 equal meals twice daily for 5 d, followed by 1.08 kg of DM fed in 2 equal meals twice daily for 37 d, followed by 0.43 kg of DM fed in 0100 h meal for 7 d.

³Starters contained either 10% starch (low) or 43% starch (high) and were each fed with 5% chopped grass hay as a TMR.

⁴1 to 5 point system with 1 being thin and 5 being obese, modified from Wildman et al. (1982).

⁵Feed efficiency was calculated as ADG divided by DMI.

ucts in calf MR are observed. One of the predominant phospholipids in egg yolk is phosphatidylcholine, which potentially sequesters Ca and other divalent cations due to the high phosphorylation of the molecule (Samaraweera et al., 2011). Ishikawa et al. (2007) reported including egg yolk protein at 20% of the diet for rats reduced protein (95.6 vs. 93.0%), Ca (74.8 vs. 63.3%), Mg (73.1 vs. 61.4%), and P (90.7 vs. 72.9%) digestibility compared with feeding casein at the same rate. It is possible that MR digestibility was reduced when egg yolk was included at 10% of the formula; however, we are not aware of digestibility data for calves when fed SDWE or egg yolk proteins. Our current research with 10% egg yolk agrees with prior research reporting that SDWE at $\geq 10\%$ of the MR was inferior to MR based on all-milk proteins.

In the current study, feeding high versus low rates of MR increased ADG, feed efficiency, hip width change, and BCS change in the first 2 mo; however, feeding calves low versus high rates of MR increased hip width from 2 to 4 mo of age. This pattern of BW and structural growth with high and low rates of MR is commonly reported where postweaning periods of approximately 2 mo were studied and many reported no difference in BW and structural growth measurements at the end of their postweaning periods between different amounts of milk or MR fed to calves (Nocek and Braund, 1986; Bar-Peled et al., 1997; Hill et al., 2007, 2010, 2013). Some have also reported increases in BW but not structural measurements at the end of the postweaning measurements. Osorio et al. (2012) reported 4% greater BW but no difference in hip widths at 20 wk of age between high and low rates of MR. Morrison et al. (2009) reported 6.5 kg heavier BW at 90 d (15% more ADG) with high versus low MR but no difference in structural measurements after weaning (56 d of age). Kiezebrink et al. (2015) reported greater BW up to 52 wk of age and greater withers heights up to 16 wk of age in heifers fed high versus low MR rates; however, BW and withers heights were similar thereafter. Raeth-Knight et al. (2009) reported that preweaning ADG and hip height gain advantages from feeding high versus low rates of MR were maintained to 6 mo of age. They reported calves fed the high rate of MR having 8.8 kg heavier BW and being 1.8 cm taller at the hips than calves fed a low rate of MR and 6.7 kg heavier BW and 1.1 cm taller at the hips than calves fed an intermediate rate of MR at 6 mo of age. In the current trial, final BW and hip widths for the main effect of MR feeding rate were 7.2 kg and 0.5 cm more, respectively, for calves fed high versus low MR rates. Change in BW and hip width over 4 mo was 7.4 kg (+9%) and 0.3 cm (+4%) more for calves fed high versus low MR rates.

A concern when comparing milk and MR feeding rates is the potential effect of weaning age. An older weaning age should and can increase ADG of calves in the first 2 mo of life by allowing for more consumption of milk or MR that is high in energy and highly digestible relative to calf starter, especially when large amounts of milk or MR are fed (Eckert et al., 2015; Meale et al., 2015; Wood et al., 2015). The weaning process has been shown to increase gut permeability, an occurrence that is likely a stress to the calf's physiology (Meale et al., 2015). It is also unknown whether changes in gut permeability around weaning are repeatable in research or are affected by weaning age. It is known that calves fed a large amount of MR will have lower digestibility of starter postweaning than calves fed moderate amounts of MR (Hill et al., 2010, 2016b,c) and this difference in digestion appears to persist for at least 4 wk. This reduces postweaning growth of calves. However, much of the research comparing weaning age of calves fed large amounts of MR has only measured BW gain and not structural growth. Gain in BW is both gain in carcass and gain in gut tissue and gut fill, which are poor indicators of actual lean tissue growth immediately after weaning. The use of only BW to measure growth is especially concerning with large MR feeding programs when starter intake increases rapidly from amounts of 100 to 200 g/d up to more than 1 kg/d within a week after weaning when digestion is compromised and low (Hill et al., 2010, 2016b; Rosenberger et al., 2017). Additionally, many comparisons are only made for 1 to 3 wk postweaning (Eckert et al., 2015; Wood et al., 2015; Rosenberger et al., 2017). When comparing the effect of weaning at 6 or 8 wk of age using a 7-d weaning strategy on calves fed up to 1.1 kg/d of MR DM, structural growth postweaning did not differ; however, BW gain was greater for calves weaned at 8 wk up to 12 wk of age (Dennis et al., 2017a,b). Overall BW gain and BW at 16 wk of age were similar for calves weaned at 6 or 8 wk of age when fed up to 1.1 kg/d of MR DM (Dennis et al., 2017a,b). Duration of weaning may alleviate some potential negative effects around weaning for calves fed high amounts of milk or MR. Abrupt weaning over 4 d reduced postweaning intake of starter, whereas gradual weaning over 10 d was suggested to be optimal in maximizing starter intake in programs with large amounts of MR were fed (Sweeney et al., 2010). A recent comparison of weaning over 7 or 14 d to complete weaning by 8 wk of age reported greater OM digestibility at 12 wk of age for calves weaned over 14 d, but no statistical differences in BW or hip width gain to 16 wk of age between weaning treatments (Dennis et al., 2017a,b).

In the current study, during the first 2 mo of age, efficiency of DM use for ADG was greater for high versus

low MR rates, similar to Osorio et al. (2012). Efficiency of CP use for ADG tended to be greater for high versus low MR rates; however, efficiency of ME use did not differ between MR rates. From 2 to 4 mo of age, the reverse was true, as calves fed the low rate of MR were more efficient than those fed the high rate of MR. Over the entire 4 mo, these efficiencies tended to be not different to slightly better for calves fed less versus more MR. It is counterintuitive for calves fed more of a highly digestible MR to have poorer feed efficiency than calves fed less MR. It appears that this difference is best explained by feeding more MR slowing rumen development during the preweaning period (Terré et al., 2007a,b; Suarez-Mena et al., 2011) and reducing the digestibility of the dry feeds (Terré et al., 2007a,b; Hill et al., 2010, 2016c; Chapman et al., 2016). This slowing of rumen development by feeding more MR is likely the reason why growth and efficiency measurements from 2 and 4 mo of age are less for calves fed more versus less MR. With starter intakes between calves fed the 2 MR rates being similar, if digestibility was less in calves fed high versus low MR rates, gut fill might be inflating BW and ADG in calves fed the high MR rate. This could explain the changes in ADG during wk 6, 7, and 8, shown in Figure 1. Calves fed more MR also had more medical treatments for respiratory sickness. Similarly, Hengst et al. (2012) reported more respiratory sickness for calves fed more versus less MR. Others have reported less immune function preweaning as indicated by less T-helper cell function (Foote et al., 2005, 2007), less leukocyte function (Nonnecke et al., 2003), and less L-selectin (Obeidat et al., 2013) when calves were fed more versus less MR.

Calves fed high-starch starters had greater ADG, starter intake, hip width change, and BCS change in both pre- and postweaning to 4 mo of age. This has been reported previously (Hill et al., 2008, 2012; Suarez-Mena et al., 2011; Terré et al., 2013) and supported by recent measurements in 2- to 4-mo-old calves where digestibility of high-starch starters was greater than low-starch starters (Hill et al., 2016c). In this report, we did not estimate gut fill or report empty BW gain, we only reported ADG. Gut fill and gut tissue has been greater in high-fiber diets fed to calves between birth and 20 wk of age (Jahn et al., 1970; Jahn and Chandler, 1976; Jahn et al., 1976; Fokkink et al., 2011; Khan et al., 2011) and this can inflate ADG estimates of high- versus low-fiber diets.

To summarize, 10% egg yolk in the MR reduced ADG, hip width change, and starter intake from 0 to 56 d by 11 to 13%. Feeding the high MR rate increased ADG during the first 56 d of age, but resulted in lesser hip width change from 56 to 112 d of age compared with the low MR feeding rate. High MR feeding rates

reduced starter intake in the first 56 d compared with the low MR feeding rate. Low-starch pelleted starters were consumed in lesser amounts during the first 56 d compared with high-starch texturized starters. Calves fed high-starch starters had the greatest ending BW and hip widths. In this trial, the high-starch starter program was more important to calf performance over the initial 4 mo of a calf's life than the high MR rate program.

CONCLUSIONS

Feeding the MR with dried egg yolk reduced calf growth. Feeding the MR up to 1.08 kg of DM/d improved growth in the first 56 d but reduced growth in the next 56 d compared with feeding 0.66 kg of DM/d. Feeding the 43% starch texturized starter improved growth in the first and second 56-d periods compared with the 10% starch pelleted starter. Growth (BW and structural growth) over the first 112 d of calf life was over 2-fold greater from feeding the high- versus low-starch starter than feeding the high versus low MR rate.

ACKNOWLEDGMENTS

This research was fully funded by Provimi, Brookville, Ohio.

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