Jersey calf performance in response to high-protein, high-fat liquid feeds with varied fatty acid profiles: Intake and performance¹

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ABSTRACT

The objective of this study was to determine whether altering the fatty acid (FA) profile of milk replacer (MR) with coconut oil, which contains a high concentration of medium-chain FA, to more closely match the FA profile typically found in whole milk from Jersey cows, would improve Jersey calf performance. Male ($n = 18$) and female ($n = 32$) Jersey calves were assigned at birth to 1 of 4 liquid diets: (1) pasteurized Jersey saleable whole milk [pSWM; 27.9% crude protein (CP) and 33.5% fat]; (2) 29.3% CP and 29.1% fat MR, containing 100% of fat as edible lard (100:00); (3) 28.2% CP and 28.0% fat MR, containing 80% of fat as lard and 20% as coconut oil (80:20); and (4) 28.2% CP and 28.3% fat MR, containing 60% of the fat as lard and 40% as coconut oil (60:40). Calves were fed their respective liquid diet twice daily during wk 1 through 7 and once daily until weaning (approximately wk 8). Calves had ad libitum access to grain and water, and calves were monitored 1 wk postweaning. Average daily gain and body weight did not differ by treatment. Calves fed pSWM tended to have greater hip height (HH) than calves fed 80:20 (80.5 vs. 79.7 cm). Coconut oil tended to have a quadratic effect on HH, with calves fed 100:00, 80:20, and 60:40 at 79.2, 79.7, and 78.5 cm, respectively. No difference was observed in withers height between pSWM and 80:20. Coconut oil had a quadratic effect on withers height, with calves fed 100:00, 80:20, and 60:40 at 76.6, 77.5, and 76.5 cm, respectively. Change in HH from birth to 9 wk tended to be greater for calves fed pSWM than calves fed 80:20 (0.218 vs. 0.194 cm/d). Calves fed pSWM had higher milk dry matter intake (DMI) than calves fed 80:20 (0.580 vs. 0.518 kg/d). No effect of coconut oil was observed on milk DMI. Grain DMI and total DMI did not differ among treatments. Calves

fed pSWM had an increase in days with a fecal score >2 compared with calves fed 80:20 (4.24 vs. 2.00 d). Coconut oil had a quadratic effect on fecal score, with calves fed 100:00, 80:20, and 60:40 scoring 4.00, 2.00, and 3.63 d, respectively. Respiratory score did not differ among treatments. In conclusion, DMI and average daily gain were similar among treatments. However, differences among treatments in skeletal growth and fecal scores are indicative of some possible benefits of medium-chain FA on calf health and performance.

Key words: dairy calf nutrition, coconut oil, fatty acid, medium-chain fatty acid

INTRODUCTION

Prior to 1956, the primary liquid feed fed to dairy calves was whole milk (Otterby and Linn, 1981; Davis and Drackley, 1998). However, many dairy farms have turned to the lower-cost feed alternative of feeding milk replacer (MR) to meet the nutritional needs of calves. According to the US Department of Agriculture (USDA), more dairy farms feed MR (70.2%) at some point during the preweaning phase than pasteurized (1.4%) or unpasteurized (28.0%) saleable whole milk (SWM; USDA NAHMS, 2007). Most MR fed to calves on US dairy farms have been formulated to target the needs of Holstein calves, as they represent most of the dairy cattle in the United States. However, due to the fact that milk composition varies among dairy breeds, some companies have formulated MR products to provide Jersey calves with a liquid feed that more closely matches the characteristics of whole milk of the Jersey breed.

The fat source most often used in MR, even those formulated for Jersey calves, is edible lard (USDA APHIS, 2007). Edible lard has a FA profile that is very different from milk fat in that it lacks short- (<6 carbon FA) and medium-chain FA (MCFA; 6 to 12 carbon FA). This presents a dilemma because milk from Jersey cows contains approximately 140.7% more capric acid (C10:0) and 134.7% more lauric acid (C12:0) than Holstein milk (Morales et al., 2000). Coconut oil, in contrast with lard, is a rich source of MCFA, especially lauric acid (Palmquist, 1988).

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Experimental milk replacers containing coconut oil have been used in previous studies with Holstein calves (Jenkins et al., 1985; Piot et al., 1999; Graulet et al., 2000; Hill et al., 2007; Mills et al., 2010), but no data have been reported on MR containing coconut oil as a fat source in experiments with Jersey calves. Despite coconut oil being slightly more expensive than edible lard (increase in cost of MR by \$0.07/kg for each 20% replacement of lard with coconut oil), it is readily available and increased weight gain and health of calves could justify the costs. Given the differences in Jersey and Holstein milk, a need exists in the US dairy industry to further optimize MR formulations fed to Jersey calves, which could possibly be done by including coconut oil as a fat source.

With an MR diet containing 28% protein and 28% fat, it was hypothesized that feeding 20% of the total fat as coconut oil to Jersey calves would result in (1) similar performance compared with Jersey calves fed pasteurized Jersey SWM, (2) improved performance compared with Jersey calves fed a currently available Jersey MR product with lard as the fat source, and (3) improved performance compared with Jersey calves fed an MR diet with 40% of total fat as coconut oil.

MATERIALS AND METHODS

Calves, Diets, and Management

All protocols involving calves were approved by the Agricultural Animal Care and Use Committee (protocol no. 2010A00000186) at The Ohio State University (Columbus). Calves were placed on the trial as they were born at the Waterman Dairy Farm at The Ohio State University, beginning November 2010, until 50 calves were reached on June 2011. Calves were followed from birth to 9 wk (d 63) of age. Female ($n = 32$) and male ($n = 18$) Jersey calves were used in this study. The study was conducted as a randomized complete block design. Calves were blocked by sex, date of birth, and parity of dam, and assigned to 1 of 4 liquid feeds.

One liquid feed was heat-treated SWM from the host Jersey herd at the Waterman Dairy Farm. Whole milk in the bulk tank was agitated for 5 min and collected twice daily. Prior to feeding, the whole milk was heated in a batch pasteurizer (Platinum Pasteurizer model DT-10G; Dairy Tech Inc., Windsor, CO), at 72°C for 30 s. From this point forward, the heat-treated milk will be referred to as pasteurized SWM (**pSWM**). The other 3 liquid feeds were MR varying in FA profile. These 3 MR were intended to be isonitrogenous and isocaloric, with dried whey, whey protein concentrate, dried whey product, dried skim milk, and dried milk protein included as protein sources. The MR diets dif-

fered only in FA profile, which was a result of the fat sources used. Diet **100:0** contained only edible lard as the fat source (Cow's Match-Jersey Blend; 28% protein and 25% fat, as-fed basis; Land O'Lakes Animal Milk Products, Shoreview, MN). Diet **80:20** contained edible lard (80%) and coconut oil (20%) as fat sources, and diet **60:40** contained edible lard (60%) and coconut oil (40%) as fat sources. All MR diets were formulated and blended by Land O'Lakes Animal Products Company (Shoreview, MN) and were nonmedicated. The MR was reconstituted to 15% milk powder (ca. 14.3% solids) and fed at 40.0 to 43.0°C according to label directions (described below).

All calves received 1.9 L of maternal colostrum from Johnes's disease-negative dams as soon as possible following birth via bottle, and again within 6 h, as part of the normal herd practice. In the instance that good-quality maternal colostrum was not available, replacement colostrum (bovine IgG, colostrum replacement; Land O'Lakes Animal Milk Products, St. Paul, MN) was fed to the calf. Following 2 feedings of colostrum, calves were fed their assigned liquid diet via bottle for approximately 3 to 4 feedings. As long as the calf was suckling well from the bottle, they were transitioned to an open bucket for the remainder of the experiment. Calves were fed twice daily at 0600 and 1800 h. During the first week of life, all calves were fed 1.9 L of liquid at each feeding. During wk 2 through 8 of life, calves were fed 2.27 L of liquid at each feeding. Calves were housed outdoors in individual hutches placed on loose gravel and bedded with straw. Daily ambient temperature and relative humidity were recorded at the Columbus station of the Ohio Agricultural Research and Development Center. Temperature-humidity index (**THI**) was calculated using ambient temperature (T , °F) and relative humidity (RH) in the equation: $T - [0.55 - (0.55 \times RH/100)] \times (T - 58)$ (Zimbelman and Collier, 2011).

Calves had ad libitum access to water at all times. In addition, all calves were given access to a common texturized grain (22% CP; AMPLI-Calf Jersey Blend, Land O'Lakes/Purina, St. Louis, MO), and the grain was medicated with 44 g/t of monensin (Elanco, Indianapolis, IN). Beginning in April, the grain was also medicated with 6.6 g/t of the insecticide diflubenzuron (ClariFly; Wellmark International, Schaumburg, IL). To avoid any confounding effects of grain on blood metabolite concentrations monitored for another research project (Swank, 2012), calves were not offered grain on evenings preceding blood collection days (d 7, 14, 21, 28, 35, 42, 49, 56, and 63). Grain was offered the next morning following a single blood draw, except in the cases of d 7, 21, and 42, when 4 blood samples were taken throughout a 12-h period and grain was withheld

for a full 24 h. Otherwise, calves had ad libitum access to grain. Grain orts were recorded daily at the evening feeding and liquid feed orts (if any) were recorded at both feedings.

Weaning

When calves reached d 49 of age, they were reduced to once daily liquid feeding (morning only) to further promote grain consumption. On d 56 of age, as long as the calf was consuming at least 0.9 kg/d of grain for 3 consecutive days, the calf no longer received milk at any feeding and was considered to be fully weaned. Calves were monitored for 1 wk following weaning to determine how well they transitioned to an all grain diet.

Growth and Health Monitoring

All calves were weighed at birth and on a weekly basis thereafter until 9 wk of age. In addition, hip height (HH) and withers height (WH) measurements were taken at birth and at 3, 7, and 9 wk of age. Body temperature measurements of all calves were taken and recorded at the morning feeding for the first 6 d of life. A 4-point scale was used for daily fecal scoring (Diaz et al., 2001). Any calf with a fecal score of 3 or greater was offered 1.89 L of oral electrolytes (Entrolyte H.E.; Pfizer Animal Health, New York, NY) via bottle at 1200 h and again after the evening feeding.

In addition to oral electrolytes, scouring calves received 50 mL of Bismu-Kote (Vedco Inc., St. Joseph, MO) by oral administration 2 times per day until diarrhea resolved. Approximately 2 mo into the trial, per veterinarian recommendation, 60 mL of Bio-sponge (an intestinal adsorbent; Platinum Performance Inc., Buellton, CA), administered twice daily, replaced Bismu-Kote as the oral treatment of diarrhea. Bio-sponge was given until diarrhea resolved, with a maximum of 7 d of dosing. Body temperatures of scouring calves were taken at each feeding. If a calf's body temperature was $\geq 39.4^{\circ}\text{C}$, 2 mL of Flu-nix (Agri Laboratories Ltd., St. Joseph, MO) was administered intravenously. When a calf's feed intake or behavior was negatively affected by illness, or a calf's fever did not readily reduce in response to treatment with Flu-nix, the calf received 2 mL of Excenel (Pharmacia & Upjohn Co., Pfizer Inc., New York, NY) intramuscularly once per day for 5 d.

A 6-point scale was used for daily respiratory scoring (Diaz et al., 2001). If a calf was deemed to have a respiratory infection, they were treated subcutaneously with 1 dose of 4 mL of Nuflor (Intervet Inc., Merck Animal Health, Summit, NJ).

Blood Collection and Serum Protein and IgG Analyses

For determination of total serum protein and IgG concentrations as indicators of passive transfer of immunoglobulins, a single blood sample (~ 7 mL) was collected from each calf via jugular venipuncture within 24 h of birth and after 2 colostrum feedings. Blood tubes were placed immediately on ice until they were centrifuged at $2,000 \times g$ at 4°C for 20 min. Protein content was determined in fresh serum samples by a portable refractometer (Jorvec; Jorgensen Laboratories Inc., Loveland, CO). The IgG concentrations were analyzed in frozen (-20°C) serum samples by radial immunodiffusion (bovine IgG test kit; Kent Laboratories, Triple J Farms, Bellingham, WA).

Feed Analysis

Whole milk was sampled daily before pasteurization, preserved with bronopol, and submitted weekly to a commercial laboratory (DHI Cooperative Inc., Columbus, OH) for analysis of fat, protein, lactose, and other solids by infrared spectroscopy (B2000 infrared analyzer; Bentley Instruments Inc., Chaska, MN); MUN (Skalar SAN Plus segmented flow analyzer; Skalar Inc., Norcross, GA); and SCC using a Bentley Somacount 300 instrument (Bentley Instruments Inc.). In addition, approximately 45 mL of whole milk was collected daily, pooled twice weekly, and centrifuged at $5,000 \times g$ for 30 min at 4°C to remove the fat portion for later FA analysis. Grain and the 3 MR were sampled weekly, composited by month, and analyzed for nutrient content. Two grams of the MR were dried at 100°C for 5 h. Grain composites were dried at 55°C for 48 h and ground through a 1-mm screen (Wiley mill; Arthur H. Thomas Co., Philadelphia, PA). Grain and MR samples were analyzed for DM (AOAC, 1990) and CP ($N \times 6.38$; AOAC, 1990; Kjeldahl N, Foss 2200 Kjeltac Auto Distillation unit; Foss North America Inc., Eden Prairie, MN). The NDF content of grain was analyzed using an ANKOM²⁰⁰ fiber analyzer (Ankom Technology, Macedon, NY) based on procedures of Van Soest et al. (1991) using heat-stable α -amylase and sodium sulfite. Starch content of grain was analyzed using an enzymatic procedure using heat-stable α -amylase and amyloglucosidase (Mathew, 2008). The glucose in the starch assay was analyzed colorimetrically using glucose oxidase-peroxidase (Mathew, 2008). Mineral concentrations of grain were analyzed using inductively coupled plasma emission spectrometry by The Ohio State University Service Testing and Research (STAR) Laboratory (Wooster, OH). Grain also was analyzed

for ash content (AOAC, 1990). The fat in whole milk and MR were analyzed for FA content by GLC (5890A; Hewlett Packard Co., Palo Alto, CA) using a 2-step methylation process (Sukhija and Palmquist, 1988). The internal standard used for FA analysis of MR was 19:0 (Nu-Chek Prep Inc., Elysian, MN); no standard was used for FA analysis of whole milk. Grain samples were methylated using a 1-step protocol similar to that described by Sukhija and Palmquist (1988) and were then analyzed using GLC as described for whole milk and MR.

Statistical Analysis

Data were analyzed as a randomized complete block design with block as a random effect, using PROC MIXED of SAS (SAS Institute, 2004). Preplanned orthogonal contrasts were used to compare treatment means: pSWM versus 80:20, and linear and quadratic effects of coconut oil (0, 20, and 40). Body weight, HH, and WH measurements were analyzed as repeated measures. Compound symmetry was used as the covariate matrix. Initial measurements taken at birth for BW, HH, and WH were used for covariate adjustment of data. Treatment $\times$ week interactions were evaluated and when interactions did not occur ($P > 0.10$), the averages across all weeks were reported. Significant differences were declared at $P \leq 0.05$ and a trend at $P \leq 0.10$.

RESULTS

Feed Composition

The chemical composition of grain, pSWM, and the 3 MR varying in FA profile (100:00, 80:20, and 60:40) are shown in Table 1. Whole milk protein and fat are reported on an as-fed basis, as well as a DM basis. Although the MR were intended to be isonitrogenous and isocaloric, CP and fat varied slightly by MR. The CP concentrations of pSWM, 100:00, 80:20, and 60:40 were 27.9, 29.3, 28.2, and 28.2% (DM basis), respectively. The fat concentration of pSWM was 33.5% on a DM basis, whereas the fat concentrations of 100:0, 80:20, and 60:40 were 29.1, 28.0, and 28.3%, respectively. The higher-than-expected fat concentrations resulted in about a 1:1 protein:fat ratio in the MR. Fatty acid compositions for pSWM and the 3 MR also are reported in Table 1. The pSWM contained 12.5% of FA as MCFA. The 80:20 MR contained approximately 10.1% of FA as MCFA. The 60:40 diet exceeded all diets with 18.3% of FA as MCFA, whereas the 100:0 diet contained the lowest concentration of MCFA (1.26%). The lauric acid

concentration of the 80:20 diet (6.75%) was higher than that of the pSWM (4.24%) and 100:00 (0.40%) diets but lower than that of the 60:40 diet (12.8%). The concentrations of C18:2, 18:3, and 20:1 were higher in the MR diets than for pSWM, and the concentrations of these FA decreased as coconut oil displaced lard in the MR.

Weather

The mean ambient high and low temperatures, as well as low and high THI for each month of the trial are listed in Table 2. Across the trial, high ambient temperatures ranged from 0.09 to 32.5°C, whereas low temperatures ranged from -7.69 to 20.9°C. The high THI ranged from 33.6 to 89.6 and the low THI ranged from 26.0 to 67.1.

Serum Protein and IgG, and Body Temperature

Total serum protein and serum IgG concentrations and body temperature for the first 6 d of life are listed in Table 3. No effect of treatment was observed on either total serum protein or IgG concentrations. No difference in body temperature between 80:20 and pSWM was found. A linear decline in body temperature occurred for calves fed increasing amounts of coconut oil.

Growth

The BW and ADG did not differ by treatment (Table 4). Although a tendency ($P = 0.06$) existed for a linear decrease in ADG from 56 to 63 d of age for the coconut oil inclusion, this was a short period and was not associated with any changes in grain DMI (Table 5). The HH of calves fed pSWM tended to be higher than that of calves fed 80:20 (80.5 vs. 79.7 cm, respectively). A tendency existed for coconut oil to have a quadratic effect on HH of MR-fed calves, with 100:00, 80:20, and 60:40 at 79.2, 79.7, and 78.5 cm, respectively. Feed efficiency was similar among the treatments, with an average gain:feed ratio of 0.578. No difference existed in WH between pSWM and 80:20; however, a quadratic effect of coconut oil was observed on WH, with 100:00, 80:20, and 60:40 at 76.6, 77.5, and 76.5 cm, respectively. Change in HH from birth to 9 wk tended to be greater for pSWM than 80:20. No effect was observed of diet on change in WH from birth to 9 wk. No treatment by week interaction existed for HH; however, a treatment by week interaction was observed for WH (Figure 1). At wk 7, pSWM calves were significantly taller at the withers than calves fed 80:20. In addition, at 7 wk, a

Table 1. Chemical composition of grain, pasteurized saleable whole milk (pSWM), and 3 milk replacers varying in FA profile

Variable	Grain	pSWM ¹	Milk replacer ²		
			100:00	80:20	60:40
DM (%)	94.9	14.1	95.8	95.1	95.6
CP (% of DM)	23.8	27.9 (3.70)	29.3	28.2	28.2
NDF (% of DM)	16.2	—	—	—	—
Fat (% of DM)	—	33.5 (4.72)	29.1	28.0	28.3
Starch (% of DM)	36.4	—	—	—	—
Ash (% of DM)	7.52	—	—	—	—
Lactose (%)	—	4.73	—	—	—
Other solids (%)	—	5.67	—	—	—
MUN (mg/dL)	—	13.9	—	—	—
SCC ($\times 1,000$ /mL)	—	261	—	—	—
P (%)	0.51	—	—	—	—
K (%)	1.18	—	—	—	—
Ca (%)	1.13	—	—	—	—
Mg (%)	0.23	—	—	—	—
FA (% of fat)					
4:0	—	3.66	1.67	1.82	1.75
6:0	0.53	3.04	0.35	0.54	0.67
8:0	1.18	1.60	0.16	1.61	2.86
10:0	0.22	3.66	0.35	1.24	1.99
12:0	0.35	4.24	0.40	6.75	12.78
14:0	0.59	12.17	2.30	4.99	7.42
14:1	—	0.90	0.11	0.13	0.14
15:0	—	1.22	0.20	0.22	0.21
16:0	19.3	34.3	24.1	22.2	20.0
16:1	0.49	1.52	1.76	1.53	1.30
18:0	5.21	11.3	13.3	11.9	10.6
<i>trans</i> 18:1	0.89	2.36	0.77	0.91	1.07
<i>cis</i> 18:1	23.6	17.5	35.8	30.5	26.2
18:2	41.3	2.04	15.27	12.47	10.32
18:3 and 20:1	3.06	0.21	1.05	0.70	0.47
Other	3.17	0.34	2.46	2.43	2.16
MCFA ³	2.87	12.54	1.26	10.14	18.31

¹Numbers in parentheses are on an as-fed basis and as reported by DHI; true protein values were determined by DHI and adjusted to a CP value assuming 6% NPN (DePeters and Ferguson, 1992).

²Milk replacers: 100:00 = 100% edible lard and 0% coconut oil milk replacer (MR; Cow's Match-Jersey Blend; Land O'Lakes Animal Milk Products, Shoreview, MN); 80:20 = 80% edible lard and 20% coconut oil MR; 60:40 = 60% edible lard and 40% coconut oil MR.

³MCFA = medium-chain FA (6- to 12-carbon FA).

quadratic effect of coconut oil was observed on WH, with calves fed 100:0, 80:20, and 60:40 at a WH of 76.9, 78.0, and 76.6 cm, respectively. At wk 9, a quadratic

effect of coconut oil was observed on WH, with calves fed 100:0, 80:20, and 60:40 at a WH of 80.3, 80.9, and 79.6 cm, respectively.

Table 2. Mean ambient temperature (temp.) and temperature-humidity index (THI) by month throughout the trial

Month	High temp. ¹ (°C)	Low temp. ¹ (°C)	High THI ¹	Low THI ¹
November 2010	11.9	0.43	53.6	38.5
December 2010	0.70	−5.91	36.6	28.1
January 2011	0.09	−7.69	33.6	26.0
February 2011	4.62	−4.05	41.5	31.5
March 2011	10.6	0.88	51.6	40.2
April 2011	18.8	6.91	65.5	47.9
May 2011	23.6	13.6	74.0	56.8
June 2011	28.7	17.0	82.6	61.4
July 2011	32.5	19.9	89.6	65.2
August 2011	32.2	20.9	89.5	67.1

¹Weighted for the number of calves on the trial each day of each month of the trial.

Table 3. Least squares means of total serum protein and serum IgG within 24 h of birth and after 2 colostrum feedings, and average body temperature during first 6 d of life for calves fed the 4 different liquid diets

Item	Diet ¹				SEM	Contrast ² (<i>P</i> -value)		
	pSWM (n = 12)	100:00 (n = 13)	80:20 (n = 13)	60:40 (n = 12)		pSWM vs. 80:20	Linear	Quadratic
Total serum protein (g/100 mL)	6.38	6.33	6.38	6.56	0.25	1.00	0.52	0.84
Serum IgG (mg/dL)	2,580	2,431	2,761	2,788	175	0.47	0.16	0.48
Body temperature (°C)	38.7	38.9	38.8	38.7	0.1	0.30	0.02	0.80

¹pSWM = pasteurized saleable whole milk; 100:0 = 100% edible lard and 0% coconut oil milk replacer (MR; Cow's Match-Jersey Blend; Land O'Lakes Animal Milk Products, Shoreview, MN); 80:20 = 80% edible lard and 20% coconut oil MR; 60:40 = 60% edible lard and 40% coconut oil MR.

²pSWM vs. 80:20 = comparison of means of pSWM and 80:20. Linear and quadratic effects of coconut oil (0, 20, and 40%) were also determined.

Intakes

Weaning age did not differ by treatment, with calves across all treatments weaning at an average age of 57.5 d (Table 5). Milk DMI of calves fed pSWM was higher than that of calves fed 80:20 (0.580 vs. 0.518 kg/d). No linear or quadratic effects of coconut oil were observed on milk DMI. Grain and total DMI did not differ among treatments. Calves across all treatments had an average grain DMI of 0.438 kg/d (Figure 2) and an average total DMI of 0.971 kg/d (Figure 3). The CP intake of calves did not differ by treatment, with calves consuming an average of 0.252 kg of CP/d (Table 5). Fat intake from grain was similar among the treatments (Table 6), but fat intake was higher for calves fed pSWM than those fed 80:20 because of the higher milk DMI (Table 5) and the higher concentration of fat in the milk (Table 1). A quadratic response to fat intake from the liquid

portion of the diet occurred for inclusion of coconut oil, with calves fed 80:20 having the lowest fat intake due to a combination of slightly lower DMI from MR and fat concentration in the liquid portion of the diet. Total fat intake followed a similar pattern among treatments as for fat intake from the liquid. Intakes of all FA were higher for calves fed pSWM than those fed 80:20 except for C12:0 and $\geq$ C18:1. Increasing inclusion of coconut oil linearly increased intake of short-chain FA and MCFA and decreased intakes of long-chain FA, except for *trans* C18:1.

Health

Calves fed pSWM had an increase in days with a fecal score >2 (Table 7) compared with calves fed the 80:20 diet (4.24 vs. 2.00 d). Coconut oil had a quadratic effect on scouring days. Calves fed 100:00, 80:20, and

Table 4. Least squares means for BW, ADG, gain:feed ratio, hip height (HH), change in HH (cHH), withers height (WH), and change in WH (cWH) for calves fed the 4 different liquid diets

Variable ¹	Diet ²				SEM	Contrast ³ (<i>P</i> -value)		
	pSWM (n = 12)	100:00 (n = 13)	80:20 (n = 13)	60:40 (n = 12)		pSWM vs. 80:20	Linear	Quadratic
Birth BW (kg)	26.8	26.8	26.5	26.4	0.9	0.82	0.74	0.95
Weaning BW (kg)	56.6	53.0	54.9	55.8	1.6	0.39	0.16	0.76
Final BW (kg)	62.6	60.0	61.4	60.7	1.8	0.64	0.78	0.62
Birth to weaning ADG (kg/d)	0.551	0.482	0.509	0.531	0.026	0.25	0.18	0.95
Weaning to wk 9 ADG (kg/d)	0.869	0.977	0.983	0.740	0.089	0.37	0.06	0.25
ADG (kg/d)	0.584	0.539	0.560	0.550	0.030	0.54	0.76	0.62
Gain:feed (kg/kg)	0.601	0.576	0.574	0.561	0.020	0.31	0.56	0.81
HH (cm)	80.5	79.2	79.7	78.5	0.4	0.10	0.13	0.06
cHH (cm/d)	0.218	0.200	0.194	0.185	0.010	0.08	0.28	0.87
WH (cm)	78.1	76.6	77.5	76.5	0.4	0.29	0.86	0.03
cWH (cm/d)	0.207	0.193	0.195	0.180	0.008	0.34	0.30	0.40

¹Average daily gain = ADG from birth to d 63 unless noted otherwise; gain:feed = ADG/total DMI; cHH and cWH were the changes from birth to d 63.

²pSWM = pasteurized saleable whole milk; 100:0 = 100% edible lard and 0% coconut oil milk replacer (MR; Cow's Match-Jersey Blend; Land O'Lakes Animal Milk Products, Shoreview, MN); 80:20 = 80% edible lard and 20% coconut oil MR; 60:40 = 60% edible lard and 40% coconut oil MR.

³pSWM vs. 80:20 = comparison of means of pSWM and 80:20. Linear and quadratic effects of coconut oil (0, 20, and 40%) were also determined.

Figure 1. Withers height from birth to 9 wk for calves fed pasteurized saleable whole milk (pSWM) or 1 of 3 milk replacers varying in FA profile (lard:coconut oil = 100:00, 80:20, and 60:40).

60:40 had fecal scores >2 for 4.00, 2.00, and 3.63 d, respectively. Treatment had no effect on days with respiratory score >3 .

DISCUSSION

Feed Composition

Although intended to be isonitrogenous and isocaloric, the 3 MR varied slightly in CP and fat concentrations. The whole milk was slightly lower in CP concentration and much higher in fat concentration compared with the 3 MR. As expected, the 100:00 diet contained a very low concentration of MCFA and the 60:40 diet contained approximately double the MCFA concentration of the 80:20 diet. The 80:20 diet contained a slightly lower MCFA concentration than pSWM but a greater concentration than that of the 100:00 diet.

Weather

The thermoneutral range for young dairy calves is approximately 10 to 20°C (Scibilia et al., 1987). For

approximately 5 mo of the study (November through March), the ambient temperature was below the thermoneutral range. During the month of April, the low temperature was below the thermoneutral range and the high temperature was within the thermoneutral range for calves. During May, June, July, and the first 5 d of August, high ambient temperatures were above the thermoneutral range, whereas lows were within thermoneutral range. Thus, when assessed from the standpoint of ambient temperature, most of this study was performed below thermoneutral temperatures for young calves and, as such, most the calves were exposed to cold stress conditions.

Cold-stressed calves mobilize body fat if energy is limiting in their diet (Schrama et al., 1993), yet newborn calves only have about 3% body fat (Davis and Drackley, 1998). In addition, the surface area of Jersey calves is rather large considering the calves' BW, thus exposing them to additional risks from cold stress compared with large breed calves. Interestingly, calves in our study born during the months of November, March, April, and May had an ADG of 0.590 kg/d,

Figure 2. Grain DMI for calves fed pasteurized saleable whole milk (pSWM) or 1 of 3 milk replacers varying in FA profile (lard:coconut oil = 100:00, 80:20, and 60:40).

whereas calves born during the months of December, January, and February had an ADG of 0.508 kg/d. Although an effect of season on ADG was observed, no interaction existed of season by treatment. Similar to the seasonal effects observed in our study, the ADG of Holstein bull calves fed only a liquid diet with 10,

17.5, or 25% fat and housed at -4°C were lower than those fed the same diets and housed at 10°C (Scibilia et al., 1987). However, adding a fat supplement at 113 g/d to the milk diet (27.6% fat whole milk and a 20% fat MR) of calves increased weight gain of cold-stressed calves (Jaster et al., 1990). The MR offered on our

Figure 3. Total DMI for calves fed pasteurized saleable whole milk (pSWM) or 1 of 3 milk replacers varying in FA profile (lard:coconut oil = 100:00, 80:20, and 60:40).

Table 5. Least squares means of weaning age, milk, grain, and DM and CP intakes for calves fed the 4 different liquid diets

Variable ¹	Diet ²				SEM	Contrast ³ (<i>P</i> -value)		
	pSWM (n = 12)	100:00 (n = 13)	80:20 (n = 13)	60:40 (n = 12)		pSWM vs. 80:20	Linear	Quadratic
Weaning age (d)	58.2	57.3	57.0	57.3	0.8	0.33	0.99	0.75
Liquid diet DMI (kg/d)	0.580	0.518	0.516	0.532	0.015	0.01	0.45	0.57
Birth to weaning grain DMI (kg/d)	1.63	1.78	1.76	1.74	0.12	0.46	0.83	0.98
Weaning to wk 9 grain DMI (kg/d)	1.70	1.81	1.78	1.87	0.10	0.59	0.68	0.66
Grain DMI (kg/d)	0.386	0.439	0.472	0.454	0.080	0.42	0.89	0.78
Total DMI (kg/d)	0.970	0.941	0.987	0.987	0.067	0.84	0.60	0.75
CP intake (kg/d)	0.246	0.252	0.256	0.255	0.014	0.59	0.86	0.87

¹Intakes are from birth to d 63, unless noted otherwise.

²pSWM = pasteurized saleable whole milk; 100:0 = 100% edible lard and 0% coconut oil milk replacer (MR; Cow's Match-Jersey Blend; Land O'Lakes Animal Milk Products, Shoreview, MN); 80:20 = 80% edible lard and 20% coconut oil MR; 60:40 = 60% edible lard and 40% coconut oil MR.

³pSWM vs. 80:20 = comparison of means of pSWM and 80:20. Linear and quadratic effects of coconut oil (0, 20, and 40%) were also determined.

study were formulated for the increased energy needs of cold-stressed calves in anticipation of conditions being below the thermoneutral range for a large portion of the study.

Serum Protein and IgG, and Body Temperature

In our study, total serum protein and serum IgG concentrations were used as indicators of passive transfer of immunity. Passive transfer of immunity was considered

to be adequate at an IgG concentration >1,000 mg/dL and total serum protein >5.2 g/100 mL (Weaver et al., 2000). The mean serum total protein and IgG concentrations did not differ by treatment and successful transfer was achieved across all treatments. One calf on the 100:00 diet had a serum protein concentration of 5.0 g/100 mL, but it did not exhibit any physical indications associated with the partial passive transfer of immunity. However, all calves had serum IgG concentrations >1,000 mg/dL.

Table 6. Fat intakes from grain and liquid portion of the diets and total intakes of fat and FA during the entire trial for calves fed the 4 different liquid diets

Item	Diet ¹				SEM	Contrast ² (<i>P</i> -value)		
	pSWM (n = 12)	100:00 (n = 13)	80:20 (n = 13)	60:40 (n = 12)		pSWM vs. 80:20	Linear	Quadratic
Days on trial	65.2	64.3	63.9	64.2	0.84	—	—	—
Grain fat intake (kg)	0.80	0.80	0.84	0.81	0.07	0.30	0.86	0.76
Liquid diet fat intake (kg)	11.8	9.19	8.79	9.12	0.11	<0.01	0.63	0.01
Total fat intake (kg)	12.6	9.99	9.63	9.93	0.12	<0.01	0.73	0.02
FA intake (kg)								
C4:0	0.40	0.15	0.16	0.16	0.002	<0.01	0.01	0.16
C6:0	0.34	0.03	0.05	0.06	0.002	<0.01	<0.01	0.03
C8:0	0.18	0.02	0.15	0.27	0.002	<0.01	<0.01	0.17
C10:0	0.40	0.03	0.11	0.18	0.002	<0.01	<0.01	0.33
C12:0	0.47	0.04	0.59	1.16	0.01	<0.01	<0.01	0.55
C14:0	1.35	0.21	0.44	0.67	0.008	<0.01	<0.01	0.58
C14:1	0.90	0.00	0.00	0.00	0.04	<0.01	0.98	0.99
C15:0	0.13	0.02	0.02	0.02	0.001	<0.01	0.99	0.99
C16:0	3.96	2.38	2.13	2.00	0.03	<0.01	<0.01	0.05
C16:1	0.17	0.16	0.13	0.12	0.002	<0.01	<0.01	0.01
C18:0	1.29	1.25	1.08	1.01	0.001	<0.01	<0.01	0.01
<i>trans</i> C18:1	0.27	0.08	0.09	0.10	0.001	<0.01	<0.01	0.33
<i>cis</i> C18:1	2.11	3.48	2.88	2.58	0.03	<0.01	<0.01	<0.01
C18:2	0.56	1.77	1.48	1.32	0.03	<0.01	<0.01	0.06
C18:3 and 20:1	0.04	0.12	0.08	0.06	0.002	<0.01	<0.01	<0.01
Other	0.06	0.25	0.23	0.22	0.002	<0.01	<0.01	0.68

¹pSWM = pasteurized saleable whole milk; 100:0 = 100% edible lard and 0% coconut oil milk replacer (MR; Cow's Match-Jersey Blend; Land O'Lakes Animal Milk Products, Shoreview, MN); 80:20 = 80% edible lard and 20% coconut oil MR; 60:40 = 60% edible lard and 40% coconut oil MR.

²pSWM vs. 80:20 = comparison of means of pSWM and 80:20. Linear and quadratic effects of coconut oil (0, 20, and 40%) were also determined.

Table 7. Least squares means of number of days with fecal score >2 and days with respiratory score >3 for calves fed the 4 different liquid diets

Item	Diet ¹				SEM	Contrast ² (<i>P</i> -value)		
	pSWM (n = 12)	100:00 (n = 13)	80:20 (n = 13)	60:40 (n = 12)		pSWM vs. 80:20	Linear	Quadratic
Fecal score >2 (d)	4.24	4.00	2.00	3.63	0.66	0.02	0.70	0.03
Respiratory score >3 (d)	0.414	0.384	0.144	0.143	0.230	0.39	0.94	0.40

¹pSWM = pasteurized saleable whole milk; 100:0 = 100% edible lard and 0% coconut oil milk replacer (MR; Cow's Match-Jersey Blend; Land O'Lakes Animal Milk Products, Shoreview, MN); 80:20 = 80% edible lard and 20% coconut oil MR; 60:40 = 60% edible lard and 40% coconut oil MR.

²pSWM vs. 80:20 = comparison of means of pSWM and 80:20. Linear and quadratic effects of coconut oil (0, 20, and 40%) were also determined.

The normal body temperature of a young dairy calf is between 38.6 and 39°C. The mean body temperatures for the first 6 d of life of calves across all treatments were within the normal range (Table 3). Although these temperatures were normal, a linear effect of coconut oil on body temperature was observed. Despite this effect, physiological differences would be unlikely between 38.7, 38.8, and 38.9°C, as this is a very minute change in body temperature, and these temperatures are within the normal range for a calf. A total of 8 calves (3 fed pSWM, 1 fed 100:00, 1 fed 80:20, and 3 fed 60:40) had an average body temperature below 38.6°C, but above 37.8°C, the body temperature at which calves were considered to be hypothermic. Interestingly, 7 of these calves were born during the months of December and January, the 2 coldest months of the trial. It has been suggested that environmental temperature has an effect on rectal temperature of young calves (Scibilia et al., 1987). A total of 5 calves (4 fed 100:00 and 1 fed 60:40) had an average body temperature above 38.9°C, but below 39.4°C, the body temperature at which a calf was considered to have a fever. Of these 5 calves, only 1 calf was born during a month in which ambient temperatures were above the thermoneutral range for calves.

Growth

In terms of BW and ADG, the feeding of MR containing coconut oil as 20% of total fat did not meet the expectations of the hypothesis that the growth of calves fed 20% coconut oil would exceed those fed 0 and 40% coconut oil. It also was hypothesized that calves fed the 80:20 MR would have similar growth to calves fed pSWM, which held true. Calves fed the 100:00 and 60:40 MR gained weight at similar rates as calves fed 80:20, which was not expected. Jenkins et al. (1985) observed that Holstein and Ayrshire calves consuming coconut oil as a fat source grew at a similar rate (0.519 kg/d) as calves fed animal fat. Calves in that trial received a 24% CP and 20% fat MR, and calves fed the coconut oil MR received coconut oil as the sole fat source. Mills

et al. (2010) found similar results when Holstein calves were fed only a liquid diet with MR containing 28% CP and 23% fat, with the calves fed coconut oil receiving 32% of the fat as MCFA. The calves fed coconut oil grew just as well as those fed a MR containing animal fat as the sole fat source, with an ADG of 0.94 kg/d. A study performed by Hill et al. (2007) also reported that coconut oil fed at 15% of fat in a 20% CP and 20% fat MR did not have an effect on ADG (0.565 kg/d) when fed as the only source of MCFA.

Hip height and WH responded in a quadratic fashion to coconut oil, with calves fed 80:20 being the tallest and calves fed 60:40 growing the least in height. Skeletal growth of calves fed pSWM versus 80:20 was similar. Also, change in WH and HH were not affected by level of coconut oil addition. If the growth of whole milk-fed calves is assumed to be ideal and given that they tended to grow more at the withers than calves fed 100:0, these results suggest that replacing edible lard with coconut oil at the rate of 40% could possibly limit skeletal growth of calves. Neither Hill et al. (2007) nor Mills et al. (2010) reported any height measurements, but Hill et al. (2007) did report no change in hip width for calves fed coconut MR compared with those fed animal fat MR.

Calves fed 60:40 gained weight at a similar rate as calves fed the other diets, yet grew more slowly in terms of skeletal growth by likely depositing excess energy as fat rather than partitioning this energy toward skeletal and muscular growth. Overall, the 80:20 diet did not have a major effect on the growth of calves over the 100:00 diet. In addition, calves fed 80:20 tended to grow slightly slower than calves fed pSWM, as evidenced by the tendency for HH and change in HH to be lower for calves fed 80:20, as well as ADG for calves fed 80:20 to be numerically lower than that of calves fed pSWM.

According to the NRC (2001), the amount of CP and fat consumed by calves in this trial allowed for a growth rate of at least 0.75 kg/d. As the ADG across all treatments ranged from 0.550 to 0.584 kg/d, diets did not limit growth, yet calves did not meet the potential growth rate. It is possible that growth rates on our

study fell short of those predicted by the NRC, as the nutrient requirements as expressed in the NRC may be more geared toward those necessary for Holstein calves rather than Jersey calves. In addition, growth rates may have been reduced given stress due to cold conditions or microbial pressure. Bascom et al. (2007) reported an ADG of 0.496 kg/d for Jersey bull calves fed whole milk as the sole diet with CP and fat concentrations of 24.3 and 33.4%, respectively, for 4 wk. Additionally, calves fed a 27% CP and 33% fat MR as the sole diet grew at a rate of 0.357 kg/d (Bascom et al., 2007). In another study, Jersey calves fed a 24% CP and 19% fat MR grew at a rate of 0.594 kg/d (Jensen, 2006). Klotz and Heitmann (2006) reported an ADG of 0.530 kg/d for Jersey calves fed a 23% CP and 17.5% fat MR. Thus, calves in our study grew at comparable rates to Jersey calves in other studies.

Intakes

Calves fed pSWM were offered the same volume of liquid diet as MR-fed calves. Yet, the DMI from the liquid diet and fat intakes were higher for calves fed pSWM compared with calves fed 80:20, resulting in higher energy intake. However, numerically and biologically, the difference in DMI was small. In this sense, pSWM calves did not consume a greater amount of total nutrients to partition toward growth. Because calves fed pSWM consumed more DM from the liquid portion of the diet, they would essentially require less energy from grain to achieve the same growth rate. The increase in fat intake of the calves fed pSWM over the fat intake of calves fed 80:20 was primarily due to the higher fat concentration of the pSWM. The quadratic effect of coconut oil on fat intake appears to be due to a combination of the small differences in DMI from the liquid diet and fat concentration of the 3 MR. Inclusion of the coconut oil resulted in higher C12:0 intakes than for calves fed pSWM, but C14:0 remained higher for calves fed pSWM.

Health

As mentioned previously, MR and pSWM on this study were nonmedicated. Medicated feed has been shown to reduce the severity, as well as the number of days, of scours in calves (Quigley et al., 1997). Further, Berge et al. (2009) found that overall morbidity in calves fed medicated MR was lower than that of calves fed nonmedicated MR.

Although calves on all diets scoured at some point during the preweaning period, calves fed 20% coconut oil scoured less than calves fed pSWM and calves fed 100:00. A tendency existed for calves fed 80:20 to scour

less than calves fed 60:40, with coconut oil having a quadratic effect on fecal score. The increased scouring days for calves fed pSWM could have been due to increased microbial pressure, as monthly quality control checks of the pasteurizer indicated that milk removed from the spout of the pasteurizer postpasteurization contained a high count of microbes. Mills et al. (2010) did not report any differences in fecal scores between coconut oil-fed calves and control calves. Hill et al. (2007) showed a reduction in fecal scores when coconut oil was fed in combination with canola oil. Most the calves in the present study with high fecal scores had diarrhea of an abnormal color. However, it was not determined whether scours were of a nutritional or infectious origin.

Evidence exists that MCFA, including lauric acid, which is the predominant FA in coconut oil, have antimicrobial properties (Petschow et al., 1996; Sun et al., 2002; Van Immerseel et al., 2004). In a study performed by Sun et al. (2002), lauric acid was found to have the highest antimicrobial effect on gram-positive bacteria compared with the other SFA ranging in carbon chain length from 4 to 14. However, gram-negative bacteria, including *Escherichia coli* 0157:H7 and *Helicobacter pylori*, have also been shown to be susceptible to lauric acid (Petschow et al., 1996; Sprong et al., 2001). It is possible that the concentration of lauric acid in the 80:20 diet was enough to help calves fight some of the infectious agents that may have caused scours in the calves. However, it is interesting that calves fed the 60:40 MR, which contained more coconut oil, had more scouring days than calves fed the 80:20 MR. A possible explanation could be an increasing resistance of harmful bacteria to coconut oil as the coconut oil concentration increases, as this has been shown to occur with antibiotics (Langford et al., 2003).

Implications

Growth. As the MR industry moves toward producing a product that more closely matches the characteristics of Jersey whole milk, it is important to better understand the effects this may have on calves in terms of growth, health, and DMI. From this study and others, it does not appear that coconut oil increases the ADG of Jersey calves compared with edible lard. Although the calves fed the 80:20 diet gained weight at similar rates to pSWM calves as hypothesized, they did not improve in ADG over the 100:00 MR. However, potential exists for experimentation with other sources of MCFA. In a study performed by Hill et al. (2011), researchers supplemented MR with a commercially available blend of butyric acid, coconut oil, and flax oil. This greatly increased the intake of 4:0, 10:0, and 12:0,

as well as the overall growth rate of calves consuming the MR supplemented with this FA mixture. It may be beneficial for future studies to evaluate the effect of different combinations of MCFA and short-chain FA on the growth of Jersey calves.

Coconut Oil as an Antibiotic Alternative. Approximately 57.5% of dairy farms feed a medicated MR to their calves (USDA NAHMS, 2007). There has been a lot of interest in reducing or eliminating the use of antibiotics in milk and milk replacers due to evidence that suggests that antibiotic use can lead to antibiotic resistance of harmful bacteria (Langford et al., 2003; Berge et al., 2009). As such, research has turned to providing alternatives to antibiotics, such as probiotics, MCFA and short-chain FA, to reduce the potential for scours (Abe et al., 1995; Decuyper and Dierick, 2003; Hill et al., 2011). Results from this study, as well as others presented in this discussion, suggest that coconut oil, particularly lauric acid, has the potential to act as an antimicrobial.

CONCLUSIONS

The DMI and ADG of calves were similar among treatments. Skeletal growth appeared to be greater for calves fed pSWM compared with those fed 80:20 and greater for calves fed 80:20 compared with calves fed 100:00 and 60:40. These data, in conjunction with fewer days with fecal score >2 for calves fed 80:20 compared with other treatments, indicates some possible benefits of MCFA on calf health and performance.

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