Extended colostrum feeding for 2 weeks improves growth performance and reduces the susceptibility to diarrhea and pneumonia in neonatal Holstein dairy calves

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ABSTRACT

The objective of this study was to determine the effect of partial replacement of whole milk with colostrum on the growth performance and health status of Holstein dairy calves. Neonatal heifer calves ($n = 144$; 2 d of age; 39.3 ± 0.82 kg of body weight, BW; mean $\pm$ SE) were assigned randomly to 3 groups with partial replacement of pasteurized whole milk with pasteurized colostrum at 0 (C0; 0 kg/d of colostrum + 5 kg/d of whole milk), 350 g (C350; 0.350 kg/d of colostrum + 4.650 kg/d of whole milk), or 700 g (C700; 0.700 kg/d of colostrum + 4.300 kg/d of whole milk) for 14 d; there were no refusals of liquid feed. From d 15 onward, the calves were fed with 5 kg/d of pasteurized whole milk, weaned on d 61, and monitored until d 81 of life. Throughout the study, the calves had free access to fresh clean water and calf starter. Partial replacement of whole milk with colostrum increased liquid feed dry matter intake (DMI) but decreased milk DMI; however, intakes of starter DMI, total DMI, metabolizable energy, crude protein, and ether extract were not affected by treatments. Overall, the C700 calves recorded greater weaning weight, final BW, heart girth change, feed efficiency, and average daily gain (ADG). The calves fed milk had a higher chance of having rectal temperature $\geq 39.4^\circ\text{C}$ and general appearance score ≥ 2 compared with those receiving colostrum in their milk. Diarrhea was more prevalent in C0 versus C700 calves. The occurrence of pneumonia tended to be higher in milk-fed calves compared with C350 and C700 animals. Colostrum feeding resulted in fewer days with a rectal temperature $\geq 39.4^\circ\text{C}$, general appearance ≥ 2 , diarrhea, and pneumonia. We computed Cliff's delta (effect sizes)

of the extended colostrum feeding (C350 vs. C0, C700 vs. C0, and C700 vs. C350) on starter and milk DMI, ADG, BW, and feed efficiency. In C350 calves, the effect sizes (Cliff's delta) for milk DMI, ADG, BW, and feed efficiency were positive and small, but negative in C700 calves. Compared with C350 treatment, C700 treatment resulted in greater final BW with moderate effect size. Positive and moderate effects of feeding colostrum (C700 vs. C0) were observed on postweaning ADG and final BW. The findings showed that the inclusion of 700 g of colostrum in 5 kg of milk may be beneficial to the growth and health of dairy calves.

Key words: calf, colostrum, health, weight gain

INTRODUCTION

Evidence suggests that metabolic programming begins during fetal life and continues well into postnatal life (Patel et al., 2009; Bartol et al., 2013). Research in several species indicates that delivery of milk-borne bioactive factors from mother to offspring in early life plays a pivotal role in the programming of later life events by affecting the cellular signaling mechanisms, immune system, and digestive tract growth and differentiation (Bagnell et al., 2009; Bartol et al., 2013; Bagnell and Bartol, 2019).

Bovine colostrum contains nutrients, several bioactive compounds including immunoglobulins, bioactive peptides (cytokines), lactoferrin, oligosaccharides, hormones, and growth factors (insulin-like growth factor-I, epidermal growth factor, and transforming growth factor), and immune-related microRNA, which play critical roles in the health and development of the neonate (Blättler et al., 2001; Scheuer et al., 2006; McGrath, 2016). Early feeding of colostrum is pivotal because of the progressive decline in the uptake of large molecules (e.g., IgG, IgA, and IgM) during the first days of life due to gut closure (Arthington et al., 2000). The less abundant constituents of the bovine colostrum such as monocyte differentiation antigen CD14, xanthine

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dehydrogenase or oxidase, glycosylation-dependent cell adhesion molecule 1, lactadherin, and clusterin (Zhang et al., 2015) may modulate the immune system (Wheeler et al., 2007). Therefore, increasing the duration of colostrum feeding may enhance calf immunity, health, and growth performance in later life.

Short-term feeding of colostrum stimulates morphological growth and functional maturation of the gastrointestinal tract (Bühler et al., 1998; Blum and Hammon, 2000; Hernández-Castellano et al., 2015), promotes the establishment of beneficial bacteria (Malmuthuge et al., 2015; Malmuthuge and Guan, 2017; Ma et al., 2019), enhances glucose uptake via gut absorptive capacity (Hammon et al., 2013), increases plasma glucagon-like peptide-1 concentrations (Inabu et al., 2019), and reduces calf morbidity and mortality (Connely et al., 2014; Barrett, 2016; Armengol and Fraile, 2016). Chamorro et al. (2017) suggested that feeding 150 g of 14% IgG powder in milk replacer for 14 d did not affect the weight gain but reduced disease occurrence and antibiotic therapy in dairy calves during the preweaning period.

There is a paucity of studies evaluating the effect of prolonged colostrum feeding during early life on the growth performance of dairy calves. We hypothesized that extended colostrum feeding affects the growth performance and health status of dairy calves. Therefore, the objective of this study was to evaluate the effect of partial replacement of pasteurized whole milk with pasteurized colostrum (0, 350, and 700 g/d) for 2 wk on performance and health indicators in Holstein dairy calves.

MATERIALS AND METHODS

This study was performed from October 31, 2018, to February 5, 2019, at Baharan Milk and Meat Co., Isfahan, Iran. All of the animal procedures were approved by the Animal Care and Use Committee of Shiraz University (IACUC # 201922) as set by the Iranian Council of Animal Care.

Climatic Conditions, Calves, Treatments, and Management

During 16 consecutive days, newborn calves were allotted to individual pens (9 calves daily; 3 calves per treatment per day). Air temperature (T ; °C) and relative humidity (%) in the calf barn were recorded daily (Hobo Pro Series Temp probes, Onset Computer Corporation, Pocasset, MA), and temperature-humidity index was computed according to NRC (2001) as shown in Figure 1A.

A total of 144 Holstein heifer calves (2 d of age; BW = 39.3 ± 0.82 kg; dam parity = 2.5 ± 0.45 ; mean $\pm$ SE) were weighed, housed in a naturally ventilated barn with individual pens (3.0 m $\times$ 1.2 m $\times$ 1.8 m; length $\times$ width $\times$ height), and monitored daily for any sign of diseases. Screened wood shavings with a minimum theoretical length cut of 50 mm were used to minimize dustiness in the housing environment. The bedding was refreshed every 2 d, and manure was removed daily to keep the pens visibly clean and dry. Calves were in a maternity pen during the first day of life and then transferred at random to the pens according to treatment allocations to receive daily: (1) 5 kg of pooled pasteurized whole milk without colostrum (**C0**; $n = 48$), (2) 0.350 kg of pooled pasteurized colostrum and 4.650 kg pasteurized whole milk (**C350**; $n = 48$), and (3) 0.700 kg of pooled pasteurized colostrum and 4.300 kg of pasteurized whole milk (**C700**; $n = 48$). These treatments were applied for 14 d, and the calves were fed daily with 5 kg/d of pooled pasteurized whole milk (warmed to $39.5 \pm 0.5^\circ\text{C}$ using a water bath) until d 56; this was followed by a step-down decrease (1 kg/d) in offered milk until weaning on d 61; there were no refusals of liquid feed. However, data recording continued until d 81.

Pasteurized whole milk (65°C for 30 min; Sanaye Boroodati Nasr Inc., Isfahan, Iran) and colostrum (60°C for 40 min; Davoodi Livestock Engineering Group, Isfahan, Iran) were mixed at ratios of ~14:1 (C350) and ~7:1 (C700) as treatment groups. Samples of whole milk, colostrum, and their blends (1 sample at each feeding time) were preserved with potassium dichromate, stored at 4°C, and sent to the Central Milk Testing Laboratory of the farm for determination of DM, fat, and protein concentrations using an infrared analyzer (MilkoScan 134 BN; Foss Electric, Hillerød, Denmark; Table 1). These values were used to calculate daily nutrient intake.

The quality of pooled colostrum samples was determined daily using a Reichert AR 200 Digital Hand-held Refractometer (Reichert Inc., Depew, NY). Daily colostrum (Brix value = $25 \pm 1.24\%$, range: 22–28%) obtained from healthy cows was pooled, pasteurized, and fed to calves at ~6.5% of birth weight at 1 and 12 h after birth. From d 2 onward, the calves were allocated to respective treatments and individually received 2.5 kg of liquid feed in the morning (0800 h) and 2.5 kg in the evening (1800 h). Twenty-four hours after the first feeding of colostrum, jugular blood samples were taken into Vacutainer tubes (BD Vacutainer, Franklin Lakes, NJ) containing spray-coated silica to determine serum total protein using a commercially available hand-held clinical refractometer (model ATA-2771; Atago Co.

Figure 1. (A) Temporal patterns of maximum (Max), minimum (Min), and average (Mean) temperature-humidity index (THI) during the study period. The average maximum THI, minimum relative humidity, and maximum temperature were 55.8 ± 3.7 , $30.6 \pm 12.8\%$, and $12.6 \pm 3.1^\circ\text{C}$, respectively. (B) Liquid feed (colostrum + whole milk) DMI (g/d) as influenced by incremental replacement of pasteurized whole milk with pasteurized colostrum in liquid feed for neonatal Holstein dairy calves during the preweaning period. Treatments were C0 = calves received daily 5 kg of pooled pasteurized whole milk from d 1 to 14 of the study; C350 = calves received daily mixture of 0.350 kg of pooled pasteurized colostrum and 4.650 kg of pooled pasteurized whole milk from d 1 to 14 of the study; and C700 = calves received daily mixture of 0.700 kg of pooled pasteurized colostrum and 4.300 kg of pooled pasteurized whole milk from d 1 to 14 of the study. From d 15 onward, all calves were fed individually with 5 kg/d of pasteurized whole milk, weaned on d 61, and monitored until d 81 of the study. The SEM = 2.60. Effects in model: treatment (Treat): $P = 0.001$; period (PD): $P = 0.001$; Treat $\times$ PD: $P = 0.001$. (C) Average daily gain (g/d) as influenced by incremental replacement of pasteurized whole milk with pasteurized colostrum in liquid feed for neonatal Holstein dairy calves during the study period. The SEM = 24.85. Effects in model were treatment (Treat): $P = 0.02$; period (PD): $P = 0.001$; Treat $\times$ PD: $P = 0.001$. For each time point, * denotes significant difference at $P \leq 0.05$. (D) Feed efficiency (ADG/total DMI) as influenced by incremental replacement of pasteurized whole milk with pasteurized colostrum in liquid feed for neonatal Holstein dairy calves during the study period. The SEM = 0.02. Effects in model were treatment (Treat): $P = 0.02$; period (PD): $P = 0.001$; Treat $\times$ PD: $P = 0.006$. For each time point, * denotes significant difference at $P \leq 0.05$.

Ltd., Tokyo, Japan). The bottom threshold (>5.5 mg/dL; Tyler et al., 1996) for passive transfer of immunoglobulins was equal in all treatment groups, and only

calves with a serum total protein level >5.5 mg/dL were included in the study. The average serum total protein concentration was 5.69 ± 0.16 , 5.89 ± 0.15 ,

Table 1. Average daily nutrient composition of colostrum and the experimental liquid feeds ($\pm$ SD)

Chemical composition	Colostrum	Treatment ¹		
		C0	C350	C700
DM, %	25.00 $\pm$ 1.24	11.83 $\pm$ 0.12	12.75 $\pm$ 0.18	13.67 $\pm$ 0.15
CP, % of DM	51.24 $\pm$ 1.62	23.63 $\pm$ 0.15	25.56 $\pm$ 0.25	27.50 $\pm$ 0.34
Fat, % of DM	19.80 $\pm$ 1.38	26.16 $\pm$ 1.04	25.71 $\pm$ 1.12	25.27 $\pm$ 1.20
ME, ² Mcal/kg of DM	5.25 $\pm$ 0.06	5.11 $\pm$ 0.03	5.12 $\pm$ 0.04	5.13 $\pm$ 0.05

¹Treatments: C0 = calves received daily 5 kg of pooled pasteurized whole milk from d 1 to 14 of the study; C350 = calves received daily mixture of 0.350 kg of pooled pasteurized colostrum and 4.650 kg of pooled pasteurized whole milk from d 1 to 14 of the study; C700 = calves received daily mixture of 0.700 kg of pooled pasteurized colostrum and 4.300 kg of pooled pasteurized whole milk from d 1 to 14 of the study. From d 15 onward, all calves were fed individually with 5 kg/d of pasteurized whole milk, weaned on d 61, and monitored until d 81 of the study.

²Calculated from NRC (2001).

and 5.80 ± 0.16 mg/dL (mean $\pm$ SD) in C0, C350, and C700, respectively. The calves had free access to water and starter feed (steel buckets) formulated according to the NRC (2001), allowing for at least 10% refusals. The ingredients and nutrient composition of the starter feed are given in Supplemental Table S1 (<https://doi.org/10.3168/jds.2020-18355>).

Feed Sampling and Analyses

Feed refusals were removed before the provision of fresh starter feed (at 1000 h). Individual feed intake was determined daily by weighing the amounts of starter feed offered and the amounts refused using a calibrated electronic scale (model PX3000; Pand Iran Co., Isfahan, Iran). Representative samples of alfalfa hay and basal starter feed ($n = 9$; pooled by feed type every 10 d) and refusals ($n = 8$; pooled by calf every 10 d) were taken before the morning feeding. The sample DM concentration was measured by drying at 100°C in a forced-air oven for 24 h (AOAC International, 2002; method 925.40). After mixing, the samples were ground to pass a 1-mm screen (Wiley mill, Ogawa Seiki Co. Ltd., Tokyo, Japan) and analyzed in triplicate for CP (Kjeltec 1030 Auto Analyzer, Tecator, Höganäs, Sweden; AOAC International, 2002; method 955.04), ether extract (**EE**; AOAC International, 2002; method 920.39), ash (AOAC International, 2002; method 942.05), and NDF using a heat-stable α -amylase (100 μ L/0.5 g of sample) and sodium sulfite (Van Soest et al., 1991). The NFC component was computed (NRC, 2001) as $100 - (\text{CP} + \text{NDF} + \text{EE} + \text{ash})$.

Growth and Skeletal Measurements

Body weight was measured on the first day of the study and every 10 d thereafter before the morning feeding using an electronic scale (model EES-500; Ette-

had Inc., Isfahan, Iran), which was calibrated by the manufacturer's agent before the initiation of the study and every month thereafter. Average daily gain (g/d) was calculated as the difference between BW taken at 10-d intervals divided by 10. Body weight was also used to compute weight gains during the preweaning (d 1–60), postweaning (d 61–81), and overall (d 1–81) periods. Feed efficiency (**FE**) was calculated as the ratio of ADG to DMI (liquid feed DMI + starter feed DMI).

Body size measurements, including the heart girth (chest circumference), withers height (distance from the base of the front feet to withers), body length (distance between the points of shoulder and rump), hip height (distance from the base of the rear feet to hook bones), and hip width (distance between the points of hook bones), were measured manually on the first day, at weaning (d 61), and at the end of study (d 81) as described by Pazoki et al. (2017). The measurements were taken by an individual who satisfied high interobserver reliability [Cohen's kappa coefficient (κ_w) > 0.86] for each measurement. The values were used to calculate the skeletal growth during preweaning (d 1–60), postweaning (d 61–81), and overall (d 1–81) periods.

Health Status

Calves were observed daily for health status based on their appetite to consume milk and starter, as well as their general appearance by a veterinarian blinded to the treatments, according to a referenced standard (Larson et al., 1977) modified by Heinrichs et al. (2003). The general appearance score was assigned as 1 = normal and alert; 2 = ears drooped; 3 = head and ears drooped, dull eyes, slightly lethargic; 4 = head and ears drooped, dull eyes, lethargic; and 5 = severely lethargic. The fecal score was determined daily at 0700 h based on fecal consistency (1 = normal; 2 = soft to loose; 3 = loose to watery; 4 = watery, mucous, and slightly

bloody; and 5 = watery, mucous, and bloody). Rectal temperature (**RT**) was measured daily between 1200 and 1400 h using a digital thermometer (model CT20; EmsiG GmbH, Hamburg, Germany) placed in the rectum for approximately 10 s. The general appearance was categorized as the number of days with a general appearance score ≥ 2 , the fecal score was categorized as the number of days with a fecal score ≥ 3 , and RT was categorized as the number of days with $T \geq 39.4^\circ\text{C}$ (as fever threshold). These categories were denoted as days with abnormal general appearance, fecal score, and RT, respectively.

Diagnosis of diarrhea and pneumonia was performed by a veterinarian, and treated following the standard procedures at the Baharan Milk and Meat Co. (Isfahan, Iran). Calves with diarrhea received a water-based oral rehydration salt solution (1 L/d per calf for 2 consecutive days; Rooyan-e-Isfahan Co., Isfahan, Iran) and sulfadimidine syrup (sulfadimidine sodium 33.3%; 15 mL/d per calf for 2 consecutive days; Fan-Avari Zisti Kimia Co., Arak, Iran). Nonresponding individuals were treated for 3 more days with enrofloxacin (10%; 5 mL per calf; Tolide Darouhai Dami Co., Tehran, Iran) and Pantrisol [trimethoprim (200 mg/mL) + sulfamethoxazole (200 mg/mL); 2.5 mL per calf; Makian Daru Co., Tehran, Iran]. To treat pneumonia, the calves were administered Dexacoid (dexamethasone; 5 mL per calf for 1 d; Nasr Pharmaceutical Co., Tehran, Iran), florfenicol (F-Nex 300; 10 mL per calf on d 1 and 3; Razak Laboratories Co., Karaj, Iran), and oxytetracycline (Oxyvet 10%; 10 mL per calf on d 1 and 3; Razak Laboratories Co.). After 1 d, the nonresponding individuals were treated for 2 more days with Pneumosin [tilmicosin (300 mg/mL); 10 mL per calf for 2 consecutive days; Nasr Pharmaceutical Co.].

Statistical Analyses

A pre-study power analysis for sample size estimation was performed for the primary response variables, including feed intake and ADG, based on previously reported values (Abdelsamei et al., 2005; DeVries and von Keyserlingk, 2009; Kargar and Kanani, 2019; Kargar et al., 2019). From the power test analysis, using $\alpha = 0.05$ and power = 0.85, the projected sample size was approximately a total of 48 calves (16 calves per treatment) for DMI and ADG. A total of 144 calves was enough to get a significant result with adequate probability (power) on growth performance across the treatments according to the power analysis performed by POWER PROC of SAS (version 9.4, SAS Institute Inc., Cary, NC). Repeated-measures data (feed intake and growth performance) were analyzed for preweaning (d 1–60), postweaning (d 61–81), and overall (d 1–81

of the study) periods using PROC MIXED of SAS. The model consisted of birth order of calves, treatment (**Treat**; C0, C350, or C700), period (**PD**; 1- or 10-d PD), and $\text{Treat} \times \text{PD}$ as the fixed effects, and calf within PD and temperature-humidity index as the random effects. The first-order autoregressive covariance structure was the best fit for these data as determined by the lowest Bayesian information criterion. Initial BW, initial skeletal size, and starter DMI were used as covariates in the BW, skeletal measurements, and ADG models, respectively. Data on initial BW, skeletal size, and gains were analyzed using the same model without the PD effect. Data were reported as least squares means, and the Tukey-Kramer adjustment was applied to account for multiple comparisons. The threshold of significance was set at $P \leq 0.05$; trends were declared at $0.05 < P \leq 0.10$.

Models for the occurrence of diarrhea ≥ 3 , pneumonia, $\text{RT} \geq 39.4^\circ\text{C}$, and general appearance ≥ 2 were tested by logistic regression using a binomial distribution in the GLIMMIX procedure in SAS. The odds ratio was used to compare the likelihood for calves on each treatment to experience any event. Frequency and duration of diarrhea and pneumonia and the number of days with diarrhea ≥ 3 , pneumonia, $\text{RT} \geq 39.4^\circ\text{C}$, and general appearance ≥ 2 were tested with a Poisson regression model using PROC GENMOD of SAS.

Cliff's delta (d ; effect sizes) of 8 parameters were calculated (Cliff, 1993) for comparison of 3 independent groups (C350 vs. C0, C700 vs. C0, and C700 vs. C350) using the scikits bootstrap package (<https://github.com/cgevans/scikits-bootstrap>). The Cliff's delta estimator was calculated as

$$d = \frac{\#(X_1 > X_2) - \#(X_1 < X_2)}{n_1 \times n_2}.$$

In this expression, X_1 and X_2 were scored within group 1 (e.g., C350 or C700) and group 2 (e.g., C0 or C350), and n_1 and n_2 were the sizes of the sample groups. The cardinality symbol $\#$ indicates the number of times a value from the test sample (e.g., C350 or C700) exceeds (or is less than) values in the control sample (e.g., C0 or C350). This statistic estimates the probability that the value selected from one of the groups is greater than a value selected from the other group, minus the reverse probability. Cliff's delta ranges from -1 to 1 . An effect size of $+1$ or -1 indicates the absence of overlap between the 2 groups, whereas a 0.0 indicates that group distributions overlap completely. Cliff's delta was, as per standard practice, referred to as negligible ($|d| < 0.15$), small ($|d| < 0.33$), moderate ($|d| < 0.47$), or large ($|d| > 0.47$) (Romano et al., 2006).

RESULTS

Intake and Growth Performance

Replacing part of the whole milk with colostrum increased liquid feed DMI but decreased milk DMI (Figure 1B; Tables 1 and 2). There was no effect of treatment on nutrient intake, but intake of nutrients increased ($P < 0.001$) with advancing age (Table 2).

Calves fed C700 had greater weaning and final BW compared with calves fed C0 ($P < 0.05$; Table 2); the C700 calves also recorded greater BW changes during the postweaning (+4.2 kg; $P = 0.01$) and overall (+8.1 kg; $P = 0.02$) periods. Compared with C0, the C700 calves had greater ADG (Figure 1C and Table 2) and improved FE (Figure 1D and Table 2) throughout the study. A Treat $\times$ PD interaction effect ($P = 0.001$) indicated greater ADG in C700 versus C0 calves on d

Table 2. Nutrient intake and growth performance as influenced by incremental replacement of pasteurized whole milk with pasteurized colostrum in liquid feed for neonatal Holstein dairy calves

Item	Treatment (Treat) ¹				P-value		
	C0	C350	C700	SEM	Treat	Period (PD)	Treat $\times$ PD
Pasteurized colostrum DMI (d 1–14), g/d	0 ^c	88 ^b	175 ^a	3.06	0.001	0.001	0.001
Pasteurized whole milk DMI (d 1–60), g/d	592 ^a	582 ^b	572 ^c	2.05	0.001	0.001	0.001
Liquid feed DMI (d 1–60), ² g/d	592 ^c	602 ^b	613 ^a	2.60	0.001	0.001	0.001
Starter feed DMI, g/d							
Prewaning (d 1–60)	664	581	626	43.40	0.40	0.001	0.30
Postweaning (d 61–81)	2,483	2,429	2,472	133.91	0.95	0.001	0.53
Overall (d 1–81)	1,119	1,043	1,088	67.69	0.72	0.001	0.89
Total DMI, ³ g/d							
Prewaning (d 1–60)	1,256	1,183	1,239	43.40	0.46	0.001	0.12
Postweaning (d 61–81)	2,483	2,429	2,472	133.91	0.95	0.001	0.53
Overall (d 1–81)	1,562	1,494	1,547	67.70	0.75	0.001	0.79
Total ME intake, Mcal/d							
Prewaning (d 1–60)	5.15	4.94	5.15	0.13	0.48	0.001	0.24
Postweaning (d 61–81)	7.97	7.80	7.94	0.42	0.95	0.001	0.53
Overall (d 1–81)	5.86	5.66	5.85	0.21	0.76	0.001	0.66
Total CP intake, g/d							
Prewaning (d 1–60)	273	265	282	8.72	0.37	0.001	0.12
Postweaning (d 61–81)	499	488	497	26.91	0.95	0.001	0.53
Overall (d 1–80)	330	320	336	13.60	0.72	0.001	0.14
Total ether extract intake, g/d							
Prewaning (d 1–60)	189	186	190	2.21	0.45	0.001	0.12
Postweaning (d 61–81)	127	124	126	6.82	0.95	0.001	0.53
Overall (d 1–81)	173	170	174	3.45	0.75	0.001	0.37
BW, kg							
Initial (d 1)	39.7	38.9	39.4	0.82	0.81	—	—
Weaning (d 61)	76.9 ^b	77.2 ^{ab}	80.5 ^a	1.54	0.04	—	—
Final (d 81)	94.8 ^b	97.4 ^{ab}	102.6 ^a	1.98	0.02	—	—
BW changes, kg/period							
Prewaning (d 1–60)	37.2	38.3	41.1	1.54	0.20	—	—
Postweaning (d 61–81)	17.9 ^b	20.2 ^{ab}	22.1 ^a	1.06	0.01	—	—
Overall (d 1–81)	55.1 ^b	58.5 ^{ab}	63.2 ^a	1.98	0.02	—	—
ADG, g/d							
Prewaning (d 1–60)	620 ^b	638 ^{ab}	685 ^a	27.10	0.04	0.001	0.11
Postweaning (d 61–81)	895 ^b	1,010 ^{ab}	1,105 ^a	52.47	0.01	0.41	0.007
Overall (d 1–81)	680 ^b	722 ^{ab}	780 ^a	24.85	0.02	0.001	0.001
Feed efficiency (ADG/total DMI)							
Prewaning (d 1–60)	0.49 ^b	0.54 ^{ab}	0.55 ^a	0.02	0.05	0.001	0.008
Postweaning (d 61–81)	0.36 ^b	0.42 ^{ab}	0.45 ^a	0.03	0.02	0.06	0.05
Overall (d 1–81)	0.44 ^b	0.48 ^{ab}	0.50 ^a	0.02	0.02	0.001	0.006

^{a–c}Means within a row with different superscripts are significantly different ($P \leq 0.05$).

¹Treatments: C0 = calves received daily 5 kg of pooled pasteurized whole milk from d 1 to 14 of the study; C350 = calves received daily mixture of 0.350 kg of pooled pasteurized colostrum and 4.650 kg of pooled pasteurized whole milk from d 1 to 14 of the study; C700 = calves received daily mixture of 0.700 kg of pooled pasteurized colostrum and 4.300 kg of pooled pasteurized whole milk from d 1 to 14 of the study. From d 15 onward, all calves were fed individually with 5 kg/d of pasteurized whole milk, weaned on d 61, and monitored until d 81 of the study.

²Liquid feed DMI (g/d) = pasteurized colostrum DMI + pasteurized whole milk DMI.

³Total DMI (g/d) = liquid feed DMI + starter feed DMI.

Table 3. Skeletal growth as influenced by incremental replacement of pasteurized whole milk with pasteurized colostrum in liquid feed for neonatal Holstein dairy calves

Item	Treatment (Treat) ¹			P-value	
	C0	C350	C700	SEM	Treat
Initial heart girth (d 1), cm	79.8	79.3	80.3	0.83	0.70
Heart girth changes, cm/period					
Prewaning (d 1–60)	19.5 ^b	22.0 ^{ab}	24.6 ^a	1.43	0.05
Postweaning (d 61–81)	9.7	8.4	10.4	1.41	0.49
Overall (d 1–81)	29.2 ^b	30.4 ^{ab}	35.0 ^a	2.10	0.04
Initial withers height (d 1), cm	79.4	76.9	78.5	0.98	0.21
Withers height changes, cm/period					
Prewaning (d 1–60)	15.2	15.1	15.2	0.67	0.93
Postweaning (d 61–81)	3.9	3.5	5.4	0.96	0.20
Overall (d 1–81)	19.1	18.6	20.6	1.12	0.44
Initial body length girth (d 1), cm	42.7	39.9	42.2	1.02	0.14
Body length changes, cm/period					
Prewaning (d 1–60)	17.0	17.4	17.0	0.49	0.80
Postweaning (d 61–81)	2.3	2.5	2.7	0.51	0.88
Overall (d 1–81)	19.3	19.9	19.6	0.46	0.68
Initial hip height (d 1), cm	81.2	78.1	80.2	1.04	0.12
Hip height changes, cm/period					
Prewaning (d 1–60)	14.9	15.4	14.4	0.66	0.52
Postweaning (d 61–81)	5.5	4.9	6.4	0.57	0.19
Overall (d 1–81)	20.4	20.3	20.7	0.74	0.91
Initial hip width (d 1), cm	12.8	12.9	12.9	0.17	0.77
Hip width changes, cm/period					
Prewaning (d 1–60)	3.8	3.7	3.4	0.18	0.27
Postweaning (d 61–81)	1.7	1.8	2.0	0.21	0.56
Overall (d 1–81)	5.5	5.5	5.4	0.24	0.95

^{a,b}Means within a row with different superscripts are significantly different ($P \leq 0.05$).

¹Treatments: C0 = calves received daily 5 kg of pooled pasteurized whole milk from d 1 to 14 of the study; C350 = calves received daily mixture of 0.350 kg of pooled pasteurized colostrum and 4.650 kg of pooled pasteurized whole milk from d 1 to 14 of the study; C700 = calves received daily mixture of 0.700 kg of pooled pasteurized colostrum and 4.300 kg of pooled pasteurized whole milk from d 1 to 14 of the study. From d 15 onward, all calves were fed individually with 5 kg/d of pasteurized whole milk, weaned on d 61, and monitored until d 81 of the study.

80 (Figure 1C and Table 2). There was also a significant Treat $\times$ P interaction effect ($P = 0.006$) showing increased FE in C700 versus C0 calves on d 30 and 80 (Figure 1D and Table 2). The C350 calves tended ($P \leq 10$) to have greater ADG and BW gain (during the postweaning and overall periods) and FE (throughout the study) compared with C0.

The withers height, body length, hip height, and hip width changes were not affected by the treatments, but C700 calves showed greater heart girth change during the preweaning (+5.1 cm; $P = 0.05$) and overall (+5.8 cm; $P = 0.04$) periods compared with the C0 calves (Table 3).

Health Criteria

Table 4 presents the logistic models for the occurrence of elevated RT ($\geq 39.4^\circ\text{C}$), general appearance score ≥ 2 , diarrhea (score ≥ 3), and pneumonia before weaning (d 1–60). The occurrence of elevated RT was higher in

calves fed milk compared with colostrum-supplemented calves [(C350 odds ratio = 6.70; $P = 0.001$) or (C700 odds ratio = 5.90; $P = 0.001$)]. Calves fed C0 had a higher chance of having general appearance score ≥ 2 compared with calves fed C350 (odds ratio = 19.64; $P = 0.001$) or C700 (odds ratio = 14.71; $P = 0.001$). The occurrence of diarrhea was lower in calves fed C700 compared with calves fed C0 (odds ratio = 1.67; $P = 0.04$) and C350 (odds ratio = 1.71; $P = 0.03$). The occurrence of pneumonia tended to increase in calves fed milk compared with colostrum-supplemented calves (C350 odds ratio = 1.88; $P = 0.06$ or C700 odds ratio = 1.88; $P = 0.06$).

Days with elevated RT ($\geq 39.4^\circ\text{C}$) and general appearance score (≥ 2) were greater in C0 than in C350 and C700 calves (Table 5; $P < 0.01$). Duration of diarrhea was lower ($P = 0.03$) in calves in the C700 treatment compared with C0 or C350 calves. Calves fed milk containing colostrum experienced fewer days with pneumonia ($P = 0.05$).

Table 4. Logistic model for rectal temperature $\geq 39.4^{\circ}\text{C}$, general appearance¹ ≥ 2 , diarrhea² ≥ 3 , or pneumonia occurrence during the preweaning period (d 1–60) as influenced by incremental replacement of pasteurized whole milk with pasteurized colostrum in liquid feed for neonatal Holstein dairy calves

Variable and comparison ³	Coefficient	SEM	OR ⁴	95% CI	P-value
Rectal temperature					
C0 vs. C350	1.9028	0.23	6.70	4.25, 10.57	0.001
C0 vs. C700	1.7762	0.22	5.90	3.82, 9.11	0.001
C350 vs. C700	−0.1266	0.29	0.88	0.49, 1.55	0.66
General appearance					
C0 vs. C350	2.9780	0.59	19.64	6.11, 63.12	0.001
C0 vs. C700	2.6890	0.52	14.71	5.30, 40.83	0.001
C350 vs. C700	−0.2890	0.76	0.74	0.16, 3.36	0.70
Diarrhea occurrence					
C0 vs. C350	−0.0254	0.22	0.97	0.62, 1.51	0.91
C0 vs. C700	0.5161	0.25	1.67	1.00, 2.78	0.04
C350 vs. C700	0.5416	0.25	1.71	1.03, 2.85	0.03
Pneumonia occurrence					
C0 vs. C350	0.6348	0.33	1.88	0.97, 3.64	0.06
C0 vs. C700	0.6348	0.33	1.88	0.97, 3.64	0.06
C350 vs. C700	0.0000	0.38	1.00	0.47, 2.11	1.00

¹1 = normal and alert; 2 = ears drooped; 3 = head and ears drooped, dull eyes, slightly lethargic; 4 = head and ears drooped, dull eyes, lethargic; 5 = severely lethargic (Heinrichs et al., 2003).

²1 = normal; 2 = soft to loose; 3 = loose to watery; 4 = watery, mucous, and slightly bloody; 5 = watery, mucous, and bloody (Heinrichs et al., 2003).

³Treatments: C0 = calves received daily 5 kg of pooled pasteurized whole milk from d 1 to 14 of the study; C350 = calves received daily mixture of 0.350 kg of pooled pasteurized colostrum and 4.650 kg of pooled pasteurized whole milk from d 1 to 14 of the study; C700 = calves received daily mixture of 0.700 kg of pooled pasteurized colostrum and 4.300 kg of pooled pasteurized whole milk from d 1 to 14 of the study. From d 15 onward, all calves were fed individually with 5 kg/d of pasteurized whole milk, weaned on d 61, and monitored until d 81 of the study.

⁴The odds ratio (OR) indicates the probability of either having elevated rectal temperature ($\geq 39.4^{\circ}\text{C}$), general appearance ≥ 2 , diarrhea ≥ 3 , or pneumonia for the experimental diets (C0 vs. C350; C0 vs. C700; C350 vs. C700). If the OR > 1, a given diet in the comparison is more likely to have elevated rectal temperature ($\geq 39.4^{\circ}\text{C}$), general appearance ≥ 2 , diarrhea ≥ 3 , or pneumonia than the other diet by a factor of the difference above 1. If the OR < 1, a given diet has a lower probability of occurrence than the other diet.

Table 5. Poisson regression for days with rectal temperature $\geq 39.4^{\circ}\text{C}$ and general appearance¹ ≥ 2 , and frequency and duration of diarrhea² ≥ 3 or pneumonia during the preweaning period (d 1–60) as influenced by incremental replacement of pasteurized whole milk with pasteurized colostrum in liquid feed for neonatal Holstein dairy calves

Item	Treatment (Treat) ³			P-value	
	C0	C350	C700	SEM	Treat
Days with rectal temperature $\geq 39.4^{\circ}\text{C}$	10.2 ^a	1.8 ^b	2.0 ^b	0.16	0.001
Days with general appearance ≥ 2	4.2 ^a	0.2 ^b	0.3 ^b	0.40	0.001
Diarrhea					
Frequency, times diagnosed	1.4	1.1	1.0	0.26	0.62
Duration, d	3.1 ^b	3.2 ^b	1.9 ^a	0.17	0.03
Pneumonia					
Frequency, times diagnosed	0.9	0.5	0.4	0.36	0.42
Duration, d	2.0 ^b	1.1 ^a	1.0 ^a	0.24	0.05

^{a,b}Means within a row with different superscripts are significantly different ($P \leq 0.05$).

¹1 = normal and alert; 2 = ears drooped; 3 = head and ears drooped, dull eyes, slightly lethargic; 4 = head and ears drooped, dull eyes, lethargic; 5 = severely lethargic (Heinrichs et al., 2003).

²1 = normal; 2 = soft to loose; 3 = loose to watery; 4 = watery, mucous, and slightly bloody; 5 = watery, mucous, and bloody (Heinrichs et al., 2003).

³Treatments: C0 = calves received daily 5 kg of pooled pasteurized whole milk from d 1 to 14 of the study; C350 = calves received daily mixture of 0.350 kg of pooled pasteurized colostrum and 4.650 kg of pooled pasteurized whole milk from d 1 to 14 of the study; C700 = calves received daily mixture of 0.700 kg of pooled pasteurized colostrum and 4.300 kg of pooled pasteurized whole milk from d 1 to 14 of the study. From d 15 onward, all calves were fed individually with 5 kg/d of pasteurized whole milk, weaned on d 61, and monitored until d 81 of the study.

Effect Size

We computed Cliff's delta (effect sizes) of the extended colostrum feeding (C350 vs. C0, Figure 2A; C700 vs. C0, Figure 2B; C700 vs. C350, Figure 2C) on starter DMI, ADG, BW, and FE. The effect sizes on starter DMI (but not overall DMI), ADG, BW, and FE for C350 versus C0 comparison were negligible to small. A positive, small effect of feeding colostrum was observed on postweaning ADG (C350 vs. C0). The effect sizes for C700 versus C350 and C700 versus C0 comparisons were positive. Positive, but negligible to small, effects of colostrum feeding were observed on starter DMI, preweaning and overall ADG, and FE. Also, positive and moderate effects of feeding colostrum (C700 vs. C0) were observed on postweaning ADG and final BW. Inclusion of colostrum in whole milk resulted in improved final BW with moderate effects, and with negligible to small effect sizes on starter DMI, ADG, and FE between 2 colostrum levels.

DISCUSSION

Most of the research on feeding colostrum to calves has largely focused on the short-term effects (a couple of days; Bühler et al., 1998; Lora et al., 2018; Sadri et al., 2020). The extended feeding of colostrum or transition milk to calves for several days may be commonplace on many dairy farms; however, the benefits of this practice on the growth performance of dairy calves during the pre- and postweaning stages remain unclear. The knowledge derived from the current study could increase the confidence of dairy farmers to extend feeding colostrum to dairy calves, thereby improving calf performance and well-being.

Calves fed milk containing colostrum had higher DMI from the liquid feed than calves that received milk only. Despite the fact that colostrum DMI and total liquid feed DMI were substantially higher when milk was partially replaced with colostrum, the total DMI was comparable among the treatment groups. Our findings showed that the partial replacement of milk with colostrum at 700 g/d for an extended period of 2 wk had a carryover effect on the postweaning ADG, resulting in improved final BW. Cliff's delta (a nonparametric effect size) is a robust and informative measure of effect size. Effect sizes are useful when effects expressed in different units need to be combined or compared. Beyond *P*-value interpretations, Cliff's delta was measured in this study to quantify the amount of difference between the 3 groups (C350 vs. C0, C700 vs. C0, and C700 vs. C350). In the current study, Cliff's delta confirmed that

the partial replacement of milk with colostrum at 700 g/d for an extended period of 2 wk improved the weight gain of dairy calves during both pre- and postweaning periods. Also, partially replacing milk with colostrum at 350 g/d tended to increase the postweaning ADG; however, the size of this effect was small. The amount of bioactive compounds supplied by a higher level of colostrum may explain why C700 calves achieved greater weight gain after the colostrum supplementation. Interestingly, replacing milk with colostrum at 700 g/d compared with 350 g/d resulted in greater final BW with a moderate effect size and substantiated the higher level of colostrum feeding on performance. In support of this observation, Yang et al. (2015) reported that calves that consumed colostrum gained more BW at d 8 of life in comparison with transition or bulk tank milk. Extended feeding of colostrum powder (70 g twice daily) to beef calves during the first 2 wk of life improved ADG at d 28 of age compared with calves fed milk replacer only (Berge et al., 2009). Chamorro et al. (2017) reported that feeding milk replacer enriched with 150 g of colostrum powder during the first 2 wk of life did not affect BW or ADG, but reduced the occurrence of abnormal feces, abnormal respiration, and antibiotic treatment before weaning period. In the current study, the greater ADG in colostrum-supplemented calves (especially at 700 g/d) may likely be due to the combined effects of greater FE and lower duration of diarrhea and pneumonia.

It is known that postnatal intestinal development in neonatal calves depends on the supply of nutrients, growth factors, and hormones and can be influenced by colostrum intake (Blum, 2006). Some of the bioactive factors in colostrum, including insulin and insulin-like growth factor-1, may have stimulatory effects via their receptors on the intestinal development and function in the neonate (Hammon and Blum, 1997; Blum, 2006). Jones et al. (2004) reported higher FE and a tendency to gain more BW in calves receiving IgG via maternal colostrum compared with calves that received the same amount via colostrum substitute during the first week of life. In the current study, colostrum-supplemented calves (especially at 700 g/d) utilized the nutrients more efficiently; however, the small effect size suggested that the improved ADG may be minimally related to the FE, and that other factors may have mediated the improvement in ADG. Blättler et al. (2001) showed that extended colostrum intake for the first 3 d of life increased the intestinal surface area (villi length and villi width). Bühler et al. (1998) demonstrated that calves fed colostrum 2 times per day for 3 d increased the intestinal crypt depth and villous length compared

Figure 2. The Cliff's delta (d) indices of effect sizes (filled bars) of 2 independent groups (A: C350 vs. C0; B: C700 vs. C0; C: C700 vs. C350) for 8 parameters. Cliff's delta ranges from -1 to 1 and an effect size of $+1$ or -1 indicates the absence of overlap between the 2 groups, whereas a 0.0 indicates that group distributions overlap completely. Cliff's delta was as per standard practice referred to delta as negligible ($|d| < 0.15$), small ($|d| < 0.33$), moderate ($|d| < 0.47$), or large ($|d| > 0.47$). Treatments were C0 = calves received daily 5 kg of pooled pasteurized whole milk from d 1 to 14 of the study; C350 = calves received daily mixture of 0.350 kg of pooled pasteurized colostrum and 4.650 kg of pooled pasteurized whole milk from d 1 to 14 of the study; and C700 = calves received daily mixture of 0.700 kg of pooled pasteurized colostrum and 4.300 kg of pooled pasteurized whole milk from d 1 to 14 of the study. From d 15 onward, all calves were fed individually with 5 kg/d of pasteurized whole milk, weaned on d 61, and monitored until d 81 of the study.

with the calves fed milk replacer. Improved intestinal development may be associated with improved capacity for the absorption of nutrients and better growth performance in colostrum-fed calves (Yang et al., 2015). Overall, the improvement of FE in replacement heifers is beneficial to the dairy industry, as feed is a major cost in raising dairy replacements.

No direct measurements of gastrointestinal tract development and function were performed in the current study, but daily monitoring of fecal scores and medications allowed for a good determination of the health status of each calf individually. In this study, the odds ratios of having abnormal feces and abnormal respiration (tendency) during the preweaning period were higher for calves receiving only milk. Perhaps the localized protective effects of colostral antibodies or other bioactive compounds (Godden, 2008) that remained in the lumen improved the gut immune system or protected calves against the colonization of pathogens. A recent study reported a tendency toward reduced risk of diarrhea in dairy calves supplemented with 3 g of lactoferrin, an iron-binding protein also found in colostrum, for 3 d (Pempek et al., 2019). We found a significant decrease in the duration of pneumonia in calves receiving colostrum in their daily milk. In line with our findings, Conneely et al. (2014) reported that providing calves with further feedings of transition milk (for 2 or 4 subsequent feedings), following the initial feeding of colostrum, reduced the likelihood of being assigned a worse eye, ear, and nasal score. In another study, calves receiving 70 g of colostrum powder in the milk replacer for 14 d had less diarrhea and received fewer antimicrobial treatments than control calves (Berge et al., 2009). Results from another study suggested that although continuous administration of whole milk with immune colostrum from cows vaccinated with rotavirus to calves after 24 h of life did not result in further absorption of IgG, the presence of immunoglobulins and other bioactive molecules in colostrum prevented the infections caused by enteric viruses and bacteria (Snodgrass et al., 1982). Finally, our results indicated that partial replacement of milk with colostrum for an extended period of 2 wk could help the calves improve their health status in early life. However, an occasional shortage in high quality colostrum supply is inevitable at the dairy farm. Similar to colostrum, transition milk contains an abundance of bioactive compounds (Blum and Hammon, 2000; McGrath et al., 2016; Fischer et al., 2018). As such, transition milk may be an alternative to colostrum for dairy calves when extra colostrum is unavailable.

CONCLUSIONS

Our findings showed that the partial replacement of milk with colostrum during the first 14 d of life had the potential to cause greater weight gain in dairy calves that are fed only with whole milk; this was likely due to better FE and fewer days with diarrhea or pneumonia. The effect size demonstrated that feeding 700 g/d of colostrum improved FE, but the size of the effect as measured by Cliff's delta was small. Calves receiving colostrum performed similarly in terms of intakes of starter feed and total DM compared with calves receiving milk after the first colostrum intake. Further studies are needed to identify the molecular mechanisms involved in beneficial effects of such colostrum feeding protocols on calf growth and health.

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