Effect of concentrate supplementation during the dry period on colostrum quality and effect of colostrum feeding regimen on passive transfer of immunity, calf health, and performance

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ABSTRACT

The objectives were to evaluate the effect of (1) supplementing concentrates to multiparous Holstein cows during the dry period on colostral and milk immunoglobulin G (IgG) concentration; and (2) feeding calves colostrum at either 5 or 10% of their body weight (BW) on passive transfer of immunity, health, and performance. Holstein multiparous cows ($n = 37$) were assigned to 1 of 2 nutritional treatments during an 8-wk dry period: (1) offered *ad libitum* grass silage only (GS) or (2) offered *ad libitum* access to the same grass silage plus concentrate [total mixed ration in a 75:25 dry matter (DM) ratio], providing a mean concentrate DM intake of 3.0 kg/cow per day (GSC). Both treatment groups were offered identical levels of mineral and vitamin supplementation. Calves from these cows were weighed immediately after birth and fed either 5% (5BW) or 10% (10BW) of their BW in colostrum from their own dams within 2.5 h of birth. Calves in the 10BW group received their second feed of colostrum from first-milking colostrum. Concentrate supplementation during the dry period had no effect on colostral IgG concentration, first-milking IgG yield, or fat, protein, and lactose contents. However, cows in GSC produced a greater mean milk yield over the first 8 milkings compared with cows in the GS group. Concentrate supplementation had no effect on calf BW or BW gain, serum IgG, or apparent efficiency of absorption (AEA) at 24 h after birth. However, offspring from the GSC group had fewer cases of enteritis during the first 56 d of life compared with offspring from the GS group. Calves in the 10BW group had greater mean serum IgG concentration for the first 3 d following birth; however, at 24 h after birth, we observed no treatment effect on AEA. The rate of enteritis was greater for calves in the

5BW treatment compared with 10BW. The colostrum-feeding regimen had no effect on BW gain or on the incidence of pneumonia among calf treatment groups. In conclusion, concentrate supplementation regimens offered during the dry period had a positive effect on colostrum yield, and offspring from the GSC group had a reduced rate of enteritis. Feeding 10% of BW of colostrum versus 5% of BW resulted in a greater serum IgG concentration for the first 3 d postpartum, and 10BW calves had a reduced rate of enteritis. Overall, to achieve successful passive transfer, decrease the rate of enteritis, and increase efficiency in the dairy calf, we recommend that dairy calves be fed 10% of their BW in colostrum as soon as possible after birth.

Key words: calf, colostrum, concentrate, dry period, immunoglobulin G

INTRODUCTION

Bovine colostrum is the primary source of nutrients and immunity for the newborn calf (Quigley and Drewry, 1998). The process of colostrogenesis takes place several weeks before parturition; during this time, immunoglobulins are transferred from the dam's circulation into mammary secretions and subsequently the transfer of Ig ceases immediately before parturition (Brandon et al., 1971; Barrington and Parish, 2001). Previous research has focused primarily on dietary and management strategies for beef cows during their dry period on colostrum quality (Blecha et al., 1981; Hough et al., 1990; McGee et al., 2006). However, limited data are available for the dairy cow and the effect these strategies have upon their offspring (Funston et al., 2010; Nowak et al., 2012). Studies have been conducted on beef cows to investigate the effects of protein and energy restrictions (Blecha et al., 1981; Hough et al., 1990) on colostrum quality. However, further research is required because dairy cows face different metabolic challenges during the peripartum period compared with beef cows (Mann et al., 2016).

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The bovine dam has a syndesmochorial placenta, which prevents transmission of antibodies to the unborn calf while it is in the uterus (Weaver et al., 2000). Therefore, the calf is born agammaglobulinemic and is solely dependent on colostrum for the passive transfer of immunoglobulins, immune cells (Barrington and Parish, 2001), and for nutrients that only minimally cross the placenta such as fat-soluble vitamins (Spielman et al., 1946). Immunoglobulins are proteins that are produced in reaction to stimulation by antigens and that later destroy those antigens (Murphy et al., 2005). The transfer of passive immunity from cow to calf via colostrum is considered adequate when the IgG concentration in the serum of the calf exceeds 10 mg/mL in the first few days after birth (Godden, 2008; Logue and Mayne, 2014). Successful passive transfer has been related to lower veterinary costs during the preweaning stage, enhanced weight gain, improved performance, and prolonged existence in the milking herd (Weaver et al., 2000; Faber et al., 2005; Lorenz et al., 2011). However, recent findings from the All-Island Animal Disease Surveillance Report (AFBI-DAFM, 2013) showed 56% of calves to have undergone failure of passive transfer (FPT) based on blood samples submitted by private veterinary practitioners and on samples from dead calves submitted for postmortem. Several studies have examined the effect of colostrum volume on passive transfer of immunoglobulins, and recommendations on the volume of colostrum to feed to the newborn calf vary between breeds (Jaster, 2005; Conneely et al., 2014). Chigerwe et al. (2008) recommended that Holstein-Friesian calves of normal size should be fed 3 L of high-quality (IgG >50 mg/mL; McGuirk and Collins, 2004) colostrum via esophageal tube within 2 h of life. Jaster (2005) found that Jersey calves fed 2 L of good quality colostrum at 0 and 12 h had higher serum IgG₁ levels at 24 h than calves fed 4 L of colostrum at birth. Recent research has focused on feeding colostrum in a volume based on a percentage of BW (Conneely et al., 2014). In most dairy systems, the calf is removed from the dam immediately after birth, fed colostrum, and offered milk replacer or whole milk thereafter until weaning. Recently it has become popular to house calves in groups during the preweaning period; consequently, it is more difficult to detect disease (Chua et al., 2002), and the spread of disease is more frequent compared with that among individually penned calves. However, calves in group pens are generally fed via automated feeders, and feeding behavior can be recorded. This may be a useful tool for identifying sick calves in the early stages and can allow for early treatment (Borderas et al., 2009).

The objectives of this study were to investigate the effect of concentrate supplementation of dams during

the nonlactating period of approximately 8 wk on colostrum quality and yield and subsequent calf health and performance when fed different levels of colostrum according to BW.

MATERIALS AND METHODS

All procedures and treatments within this study were conducted under the United Kingdom Animals (Scientific Procedures) Act (1986; <http://www.legislation.gov.uk/ukpga/1986/14/contents>). The study was conducted at the Agri-Food and Bioscience Institute (AFBI) research dairy farm in Hillsborough, located in County Down, Northern Ireland (54°27' N, 6°4' W). The average ($\pm$ SD) daily air temperature during the experiment was 6.9°C, with a range of -0.5 to 13.4°C. The study population consisted of 37 multiparous Holstein cows that calved between February 9 and April 17, 2014. The mean ($\pm$ SD) birth weight of calves was 40.4 $\pm$ 6.2 kg; 19 of these calves were female and 18 were male.

Experimental Design

The experiment had a 2 $\times$ 2 factorial design, which included 2 dry-cow feeding treatments: (1) grass silage only (**GS**) or (2) grass silage plus concentrate (**GSC**), offered in the form of a mixed diet providing a nominal concentrate intake of approximately 3 kg/cow per day; and 2 first-feed colostrum treatments fed according to calf BW at birth: (1) 5% of BW of colostrum at birth (**5BW**) or (2) 10% of BW of colostrum at birth (**10BW**). Colostrum was defined as the first and second milkings after parturition, and transition milk referred to any subsequent milkings.

Dry-Cow Management

Cows were balanced according to BCS, previous 305-d milk yield, and parity (Little et al., 2016). Dry cows in the GS group received access to ad libitum medium-quality grass silage only, whereas cows in the GSC group were offered ad libitum access to a mixed diet containing the same medium-quality grass silage plus concentrates (mixed in a 75:25 DM ratio), which was intended to provide an average concentrate intake of approximately 3.0 kg/cow per day (Little et al., 2016). These diets were anticipated to be representative of typical UK on-farm management strategies and to offer approximately 100 and 130% of the cow's ME requirement during the dry period (ME intake of 106 and 138 MJ/d with the GS and GSC treatments, respectively), based on the equations contained in *Feed into Milk* (Agnew et al., 2004), the current UK ration-

Table 1. Chemical composition of dry-cow diet

Chemical composition	Treatment ¹	
	GS	GSC
Oven DM (g/kg of fresh weight)	233	883
VCODM ² (g/kg)	242	—
pH	3.89	—
Ammonia-N (g/kg of total N)	106	—
Composition of DM (g/kg)		
CP	148	187
Lactic acid	105.0	—
Acetic acid	23.8	—
ADF	329	73
NDF	556	215
Ash	107	36
Gross energy (MJ/kg of DM)	19.3	18.3
ME (MJ/kg of DM)	10.5 ³	—

¹Treatments: GS = grass silage only; GSC = grass silage plus concentrate.

²VCODM = volatile-corrected oven DM.

³Predicted using near-infrared reflectance spectroscopy.

ing system for dairy cows. Chemical composition of the silage and concentrate offered are shown in Table 1. The ingredient content of the concentrate offered (g/kg fresh basis) included soy hulls, 300 g/kg; corn, 238 g/kg; wheat, 127 g/kg; corn gluten, 150 g/kg; soybean meal, 80 g/kg; rapeseed meal, 70 g/kg; and Molaferm (United Molasses, Belfast, UK) 35 g/kg. During the 8-wk dry period, all cows received a dry-cow mineral and vitamin supplement (Trouw Nutrition, Cheshire, UK), which was included in the mix to achieve a target intake of 100 g/cow per day. In addition, 54 g/d of calcined magnesite (Trouw Nutrition) was included in the mix to achieve a target of 50 g/d of DM in the last 3 wk precalving (Little et al., 2016). Dry-cow rations were prepared daily using a mixer wagon (Redrock Varicut, Redrock, UK). As parturition approached, cows were moved from a group pen into individual straw-bedded pens.

Management of Calves

The birth of each calf was carefully observed and calves were removed approximately 15 to 20 min after parturition before suckling could occur. Calves were weighed and placed in a straw-bedded pen, where they were blood sampled and received their first feed of colostrum, according to the colostrum treatment group to which they were assigned. Each calf was randomly assigned to a colostrum treatment group depending on dry-cow nutrition status and calf sex, and fed their own dam's colostrum via esophageal tube within 2.5 h after birth. Cows in all treatment groups were given 5% of their BW of colostrum (from their own dam) at their second feeding via a teat feeder, 12 h after calving. Calves in the 10BW group received colostrum from the first milking after birth (stored at 4°C and heated to body temperature before feeding), whereas calves in the 5BW group were fed colostrum from the second milking. These experimental diets were designed to create a divergence in immunity between treatment groups (colostrum from the second milking generally has a lower IgG concentration than colostrum from first milking). Following the first and second colostrum feeds, all calves were fed 12.5% of their BW of transition milk from their own dam for the first 4 d of life. Calves were individually penned for the first 4 d of life, and were placed in a group pen on d 5, where they were fed Calf Gold milk replacer (Britmilk, Dumfries, UK) from an automatic milk feeder (Forster Technik Vario, Engen, Germany). Calves were gradually weaned (d 56) by the step-down method, and the feeding plan is shown in Table 2.

All calves were offered ad libitum concentrate and clean water from 5 d of age. Disbudding of calves took place at approximately 5 to 6 wk of age. After weaning, calves were removed from their original pen to another group pen on d 63 and fed grass silage plus 2 kg of

Table 2. Feeding plan for colostrum/transition milk and milk replacer (e.g., for 40-kg calf)

Age (d)	Colostrum treatment (L)		No. of feeds/d	Milk powder ¹ (g/L)
	5% of BW	10% of BW		
0	2 (first milk colostrum)	4 (first milk colostrum)	1	—
0.5	2 (second milk colostrum)	2 (first milk colostrum)	1	—
1	4.8 (transition milk)	4.8 (transition milk)	2	—
2	4.8 (transition milk)	4.8 (transition milk)	2	—
3	4.8 (transition milk)	4.8 (transition milk)	2	—
4	4.8 (transition milk)	4.8 (transition milk)	2	—
5–10	4 increasing to 5	4 increasing to 5	Automatic feeder	135
12–38	5	5	Automatic feeder	135
39–49	4	4	Automatic feeder	125
50–56	4 decreasing to 2	4 decreasing to 2	Automatic feeder	125

¹Milk powder was mixed with 1 L of water; that is, 1 L of water + 135 or 125 g of milk powder depending on age of calf.

concentrate/d until 70 d of age, when the experiment was complete.

All calves in the study were immunized at 3 wk of age against parainfluenza type 3 virus, bovine respiratory syncytial virus, and *Mannheimia* (*Pasteurella*) *haemolytica* serotype A1 using a commercial vaccine (Bovipast RSP, MSD Animal Health, Buckinghamshire, UK), and a booster was administered 4 wk later. All calves were also immunized against infectious bovine rhinotracheitis (IBR), using 1 dose of a live commercial vaccine (Bovilis IBR marker, MSD Animal Health, Milton Keynes, UK), which was administered intranasally at 6wk of age.

Data Collection

Colostrum and Blood Sample Collection. Colostrum yield was recorded for the first 8 milkings after parturition; two 200-mL samples were taken after yield was recorded. Samples were divided into eight 30-mL aliquots and frozen at -20°C for later analysis. Colostrum samples from milkings 1, 3, 5, and 7 were analyzed for IgG concentration, fat, protein, lactose, total viable count (TVFC), and SCC. Blood samples were collected from the tail vein of cows using a 10-mL serum Vacutainer (BD, Oxford, UK) at wk -5 , -3 , -1 precalving and $+2$ wk postcalving. Blood samples were collected from the calf via the jugular vein using a 10-mL serum Vacutainer tube (BD), at 0, 12, 24, 48, and 72 h after birth and d 7, 21, 35, 49, 56 and 70 after birth. A blood sample was taken from calves before colostrum intake at 0 h and subsequently before the second colostrum feed at 12 h and the third feed at 24 h after birth. All other blood sampling was performed between 0900 and 1030 h. All blood samples were stored at room temperature for a minimum of 1 h to allow clotting to occur. Samples were then centrifuged at $1,764 \times g$ for 15 min. Serum was decanted into 3 aliquots and stored at -20°C until analysis.

Health Data. Daily respiratory scores were conducted using a health scoring chart (McGuirk and Peek, 2014). Calves were scored on 5 aspects from d 0 to 56 including eyes, ears, cough, nasal discharge, and rectal temperature. Each aspect received a score from 0 to 3, 0 representing normal and 3 the most severely affected. Rectal temperatures were taken daily using a digital thermometer (Kruuse, Leeds, UK). A respiratory score was devised from the cumulative score from nasal discharge, eye or ear score, cough, and rectal temperature. A calf was considered to have a bovine respiratory disease (BRD) complex event if it had a respiratory score ≥ 5 . Fecal scores were measured daily on a scale of 0 to 3, where 0 = normal, 1 = mild, 2

= moderate, and 3 = severe. When a calf presented with a fecal score of 3 or had a fecal score of 2 for 2 or more days, it was considered to have enteritis. The number of drug treatments for each calf was recorded, and a treatment was classified as each time a drug was administered to a calf (i.e., a calf might receive a 3-d course of antibiotics for diarrhea; this was counted as 3 treatments. Calf ill health was defined in this study when a calf was presenting with diarrhea, pneumonia, or high temperature; an overall daily score was calculated using the Wisconsin scoring chart (McGuirk and Peek, 2014), and the calf was considered healthy at a score < 5 (Borderas et al., 2009).

Feed Intake and Behavior. Milk replacer and concentrate intakes were recorded daily by a calibrated automatic feeder (Forster Technik Vario) from d 5 to 56 and from d 5 to 63, respectively. Calf behavioral data were recorded, including drinking speed and number of visits to the feeder with and without the reward of milk replacer.

BW. Calves were weighed at birth and d 70 using a calibrated weigh scale (Eziweigh 5, Tru-Test, Auckland, New Zealand). Once calves were introduced to the automatic feeder on d 5, their weights were recorded daily using an automated weigh scale until d 63 (Forster Technik).

Sample Analysis

Colostrum and Serum IgG Analysis. Colostrum and serum (dam and calf) samples were thawed at 4°C overnight. Immunoglobulin G concentration was analyzed using an ELISA kit for bovine IgG from Bio-X Diagnostics (Jemelle, Belgium). The test was performed on colostrum (fat was removed through centrifuging before freezing; colostrum IgG data were reported on a fat-free basis) and sera samples. All kit components were brought to 21°C before use. The wash buffer was diluted 20-fold with distilled water. A calibration curve was developed and samples were diluted at 1/1,000 in PBS according to the manufacturer's instructions. Diluted samples were added to the test plate in duplicate and incubated at 21°C for 1 h. The test plate was then washed 3 times with the wash buffer; chromogen solution (100 μL) was added to each well and incubated away from light for approximately 10 min. Finally, stop solution (50 μL) was added to each well and the optical densities were recorded using a microplate spectrophotometer with a 450-nm filter. An interassay CV of < 0.15 was observed. The concentration of IgG in samples was calculated from the standard reference curve containing known concentrations of IgG provided in the test kit. Any sample that resulted in an IgG concentration that

Table 3. Chemical composition of diet fed to calves during the preweaning period

Chemical composition	Calf diet		
	Milk replacer	Concentrate	Straw
Oven DM (g/kg of fresh weight)	972	916	882
Composition of DM (g/kg)			
Nitrogen	36.6	29.6	5.7
NDF	—	347.5	869.3
ADF	—	175.9	530.5
Ash	75.1	75.4	47.3
Ether extract	201.9	42.4	13.9
CP (%)	22.8	18.5	3.6
Gross energy (MJ/kg of DM)	—	18.6	18.5

fell above or below the range of the standard reference curve was retested after further dilution according to the test kit recommendations.

Nutritional Composition and Bacterial Contamination of Colostrum and Milk. Colostrum/transitional milk fat, protein, and lactose contents were determined using the Milkoscan technique (model FT120, Foss Electric, Hillerød, Denmark). Only samples that could be processed within 24 h of calving were analyzed for TVC and SCC ($n = 152$). The TVC was determined by pour-plate method (Clark, 1967) and colonies were counted using a Stuart colony counter (Bibby Scientific Ltd., Stone, UK). The SCC of colostrum samples was analyzed using the Delta Somascope Lactoscope method (Delta Instruments, Drachten, the Netherlands) as described by Hanuš et al. (2014).

Dry-Cow Feed Analysis. Chemical composition of feedstuffs offered to dry cows is presented in Table 2. Grass silage samples were collected daily, dried at 85°C for 18 h to calculate oven DM content, and milled through a sieve (0.8-mm aperture). Every 2 wk, subsamples of the dried milled silages (collected twice weekly) were composited, and then analyzed for NDF, ADF, and ash. A sample of the fresh silage offered was collected weekly and analyzed for ME concentration, and a second fresh sample was analyzed for pH, gross energy, CP (nitrogen $\times 6.25$), ammonia-nitrogen, and fermentation acid (lactic acid and acetic acid) concentrations. To alter the oven DM of grass silage to a volatile-corrected DM basis, volatility coefficients were used. Once a week, a concentrate sample was collected, dried at 100°C for 24 h before milling through a sieve (0.8 mm), and composited every 2 wk. A subsample of concentrate was analyzed for NDF, ADF, ash, gross energy, and CP (nitrogen $\times 6.25$) concentrations (Little et al., 2016). The NDF and ADF concentrations were analyzed using a Fibertec analyzer (Fibertec FT122, Foss) based on the method by Cushnahan and Gordon

(1995). Ash concentrations were established following combustion in a muffle furnace at 550°C for approximately 10 h. Near-infrared reflectance spectroscopy was used to determine the ME concentration according to Park et al. (1998), and a bomb calorimeter was used to quantify gross energy concentration (Parr 6300 Bomb Calorimeter, Parr Instrument Co., Moline, IL). The Kjeldahl method (Tecator Kjeltac Auto 2400/2460 Analyzer/Sampler System, Foss) was used to analyze nitrogen concentration and ammonia-nitrogen as described by Steen (1989). Lactic acid and acetic acid concentrations were analyzed using single-column GLC with a flame-ionization detector (Varian Star 3400 CX GC, Varian Inc., Palo Alto, CA). Volatility coefficients were applied according to Porter and Murray (2001).

Calf Diet Analysis. Samples of milk replacer, starter ration, and straw bedding consumed by the calf were collected daily and bulked for each 2-wk period throughout the experiment. Chemical composition of feedstuffs is presented in Table 3. Milk replacer, concentrate, and straw were analyzed for oven DM, and the dried samples were analyzed for nitrogen as previously described by Steen (1989). The ADF and NDF concentrations were determined using a Fibertec analyzer (Fibertec FT122, Foss) based on the method by Cushnahan and Gordon (1995), and ash concentrations were determined following combustion in a muffle furnace at 550°C for approximately 10 h. Concentrate and straw samples were analyzed for gross energy (Porter, 1992).

Apparent Efficiency of Absorption. The apparent efficiency of absorption (AEA) was determined in this study to determine how much IgG the calves in each treatment group absorbed into their blood before closure of the gut at 24 h. The method used to calculate plasma volume was as described by Quigley et al. (1998): plasma volume = calf BW (kg) multiplied by 0.089. Data used to calculate the AEA was the 24-h serum IgG concentration and total IgG mass fed in the first 24 h [feed 1 (0 h) and feed 2 (12 h)]. The following formula was used to calculate the AEA (Quigley, 2002):

$$\text{AEA} = [\text{serum IgG (mg/mL)} \times \text{plasma volume (L)} / \text{total IgG intake (mg)}] \times 100.$$

Statistical Analysis

Statistical analyses were performed using GenStat (16th ed., 2015; VSN International, Hemel Hempstead, UK). Statistical differences were considered significant at $P < 0.05$. Repeated measures were used to analyze daily milk replacer and concentrate DMI, and drinking speed. Individual calf and days on feeder were fitted as

Table 4. Effect of concentrate supplementation and colostrum feeding regimen on birth weight, colostrum intake, colostral IgG concentration and yield, and apparent efficiency of absorption (AEA)

Item	Dry-cow treatment ¹		Colostrum treatment		SED ²	Significance ³		
	GSC	GS	5% of BW	10% of BW		N	V	N × V
Birth weight (kg)	40.1	40.7	39.9	40.9	2.14	0.77	0.64	0.53
Colostrum intake at first feed (L)	2.8	2.9	1.9	3.8	0.11	0.33	<0.001	0.52
First colostrum IgG (mg/mL)	55.2	53.3	58.8	49.7	7.17	0.64	0.27	0.03
IgG yield at first milking (g)	390.0	365.0	381.0	374.0	58.88	0.50	1.00	0.06
AEA at 24 h (%)	28.2	32.0	26.4	33.9	5.44	0.24	0.22	0.05

¹Dry-cow treatments: GSC = grass silage plus concentrate; GS = grass silage only.

²SED = SE of the difference.

³N = nutrition during dry period; V = volume of colostrum fed; N × V = interaction of nutrition and volume fed.

random effects in the model and a factorial arrangement of calf age, dry-cow treatment, and colostrum feeding regimens as fixed effects. The correlation between time points was modeled using autoregressive model of order 1. Colostrum yields and colostrum IgG concentration used the same form of model except different correlation models were used, ante dependence correlation and autoregressive correlation, respectively. Covariates included minutes after calving and sex, with only significant covariates retained in the final model for each response variable. A generalized linear model (GLM) was used to analyze any count variables, such as total number of drug treatments, and medical treatments. Fecal scores were analyzed using Poisson distribution with a logarithmic link function. Dry-cow treatments and colostrum feeding regimen as fixed effects, and dry-cow nutrition and colostrum feeding regimen were fitted as explanatory variables when analyzing fecal score. Total mean respiratory scores (rectal temperature, cough, nasal discharge, eyes, ears) and mean fecal scores were analyzed using the REML commands with a factorial arrangement of dry-cow nutrition and first-feed colostrum fitted as fixed effects. Body weight gain was analyzed using the same model, including birth weight as a covariate. The REML commands with a factorial arrangement were also used to analyze serum IgG and AEA of IgG at 24 h and feed efficiency pre-weaning. A factorial arrangement was fitted as fixed effects and calf was fitted as a random effect. When relevant, post hoc tests were carried out using Fisher's protected least significant difference test.

RESULTS

Concentrate supplementation had an effect ($P = 0.004$) on IgG concentration circulating in the dam's blood pre- and postparturition: on average, cows in the GSC group had a greater mean ($\pm$ SE) serum IgG (38.5 ± 2.1 mg/mL) concentration than cows in the GS

group (26.6 ± 0.75 mg/mL; Figure 1). Time pre- and postparturition did not significantly affect IgG concentration.

Calf birth weight was not significantly different between treatment groups (Table 4). The time at which calves received their first colostrum feed ranged from 10 min to 2.5 h after calving; on average, calves in each treatment group were fed within 1 h. The mean colostrum intake volume at the first feed for 5BW and 10BW calves was 1.9 L (1.4 to 2.0 L) and 3.8 L (2.6 to 4.0 L), respectively. The mean colostrum intake at the second feed (12 h after birth) for 5BW and 10BW calves was 1.9 L (1.35 to 2 L) and 1.9 L (1.3 to 2 L), respectively. The mean ($\pm$ SD) colostral IgG concentration fed to 5BW and 10BW calves at the second feed was 51.9 ± 27.77 and 54.0 ± 27.63 mg/mL, respectively.

We observed no difference in AEA at 24 h after birth between 5BW and 10BW calves, and concentrate supplementation had no effect on AEA (Table 4).

Figure 1. Effect of concentrate supplementation on dam's serum IgG concentration pre- and postparturition. Error bars represent standard error of the mean. GSC = grass silage plus concentrate; GS = grass silage only.

Table 5. Effect of dry cow treatment¹ on colostrum/transitional milk yields for first 8 milkings postparturition (1 to 8)

Milking no.	Colostrum/transitional milk yield (kg)		SD	P-value
	GS	GSC		
1	7.10	7.48	0.26	<0.001
2	3.80	4.87	0.76	
3	5.98	7.21	0.87	
4	7.99	11.42	2.43	
5	8.91	10.70	1.27	
6	9.89	13.13	2.29	
7	10.24	11.06	0.58	
8	11.95	14.16	1.56	

¹Dry-cow treatments: GSC = grass silage plus concentrate; GS = grass silage only.

Colostrum Yield and Quality

Cows in the GSC group produced a greater yield of colostrum than cows in the GS group ($P < 0.001$; Table 5). Concentrate supplementation did not affect colostrum IgG concentration, IgG yield, or concentrations of fat, protein, or lactose. Concentrate supplementation in the dry period did not affect ($P > 0.05$) SCC or TVC. We found mean colostrum SCC of $\log_{10}$ 2.8 and 2.9 from cows in GSC and GS groups, respectively, and mean TVC of $\log_{10}$ 5.3 and 5.2, respectively, from the first 8 milkings postparturition.

Time from Calving to Colostrum Collection

Increased time from calving until colostrum collection was associated with a significant decrease ($P < 0.001$) in colostrum IgG concentration, as shown in Figure 2. Between d 1 (milking 1) and d 2 (milking 3) postcalving, there was a 56% decrease in colostrum or milk IgG concentration.

Figure 2. Effect of the number of days postcalving on colostrum IgG concentrations. Means within bars with different letters (a–c) differ ($P < 0.05$). Error bars represent standard error of the mean.

Calf Serum IgG Concentration

Volume of colostrum fed at the first feed had an effect ($P < 0.05$) on calf serum IgG concentration during the first 3 d after birth, as shown in Table 6. Concentrate supplementation had no effect on calf serum IgG concentration.

Milk Replacer and Concentrate Intake

Neither concentrate supplementation nor colostrum feeding regimen affected ($P > 0.05$) milk replacer intake (Table 7). Concentrate supplementation during the dry period had no significant effect on the calves' concentrate intake. Calves in treatment 5BW consumed more concentrate than calves in treatment 10BW during d 5 to 28 ($P = 0.04$) and we observed a strong tendency for greater consumption from d 5 to 56 ($P = 0.05$; Table

Table 6. Effect of concentrate supplementation and colostrum feeding regimen on calf serum IgG (mg/mL) from 0 to 70 d of age

Time after birth (d)	Dry-cow treatment ¹		Colostrum treatment			Significance ³		
	GSC	GS	5% of BW	10% of BW	SED ²	N	V	N × V
0	0.7	0.8	0.7	0.8	0.08	0.16	0.23	0.96
0.5	18.4	17.3	14.6	21.1	2.16	0.60	0.004	0.94
1	18.1	17.0	14.1	20.9	2.43	0.58	0.008	0.73
2	20.8	20.7	16.6	24.9	3.93	0.85	0.04	0.84
3	14.6	15.8	13.4	17.0	1.55	0.56	0.02	0.90
7	11.0	11.0	9.8	12.2	1.42	0.96	0.09	0.74
21	7.0	7.8	6.6	8.2	1.07	0.48	0.15	0.88
35	7.6	11.6	8.9	10.3	1.43	0.02	0.19	0.01
49	12.5	10.8	12.3	11.0	1.38	0.30	0.35	0.12
56	19.7	18.0	18.7	19.0	2.61	0.57	0.93	0.32
70	12.6	12.3	12.1	12.9	1.51	0.83	0.56	0.87

¹Dry-cow treatments: GSC = grass silage plus concentrate; GS = grass silage only.

²SED = SE of the difference.

³N = nutrition during dry period; V = volume of colostrum fed; N × V = interaction of nutrition and volume fed.

Table 7. Effect of concentrate supplementation and colostrum feeding regimens on feed intake and behavioral data of calves

Item	Dry-cow treatment ¹		Colostrum treatment		SED ²	Significance ³		
	GSC	GS	5% of BW	10% of BW		N	V	N × V
Milk replacer intake (L/d)								
d 5–56	4.18	4.24	4.22	4.19	0.05	0.20	0.56	0.84
d 5–28	4.48	4.60	4.52	4.56	0.07	0.12	0.63	0.57
d 29–56	3.92	3.93	3.97	3.88	0.07	0.75	0.21	0.95
Drinking speed (mL/min)	840.00	896.00	853.00	883.00	37.95	0.24	0.26	0.99
Concentrate intake (kg/d)								
d 5–56	0.47	0.55	0.61	0.41	0.10	0.37	0.05	0.80
d 5–28	0.08	0.08	0.1	0.06	0.02	0.86	0.04	0.36
d 29–56	0.81	0.95	1.05	0.72	0.17	0.34	0.06	0.76
Concentrate intake at weaning (kg/d)	1.63	2.13	2.11	1.65	0.31	0.12	0.18	0.40
Feed efficiency (ADG/DMI) ⁴	0.62	0.65	0.60	0.67	0.07	0.51	0.49	0.13

¹Dry-cow treatments: GSC = grass silage plus concentrate; GS = grass silage only.

²SED = SE of the difference.

³N = nutrition during dry period; V = volume of colostrum fed; N × V = interaction of nutrition and volume fed.

⁴ADG/DMI = average daily weight gain/average DMI (milk replacer + concentrate intake).

7). However, we observed no significant difference between treatment groups at weaning.

BW and BW Gain

Concentrate supplementation and colostrum feeding regimen had no effect ($P > 0.05$) on BW or BW gain throughout the pre- and postweaning periods. However, we detected strong tendencies ($P = 0.05$) between d 0 and 56 and d 0 and 63 for calves in the 5BW group to perform better in terms of BW gain than calves in 10BW group (Table 8).

Disease and Illness

Mortality rate (2.7%) was low in this study, with only one calf dying during the experiment (treatment group GS-10BW). This calf died because of choking but no postmortem was carried out. Overall, independent of

treatment, we observed a high morbidity rate of 73% during the experiment (73% of calves were treated for either diarrhea or pneumonia). Calves in the 5BW group had a greater ($P = 0.003$) fecal score and a greater percentage suffered from enteritis compared with calves in 10BW group (Table 9). A much greater percentage of calves from the 5BW group experienced multiple enteritis incidences (27%) compared with calves from the 10BW group (5%); 5% of the offspring in the GSC group had multiple incidences compared with 27% in the GS group. We observed no difference ($P > 0.05$) between colostrum treatment groups in terms of respiratory score and rate of pneumonia. However, calves from the GSC treatment group had a greater ($P = 0.04$) average respiratory score and rate of pneumonia preweaning compared with calves in the GS treatment group.

We detected no differences ($P > 0.05$) between healthy and sick calves in terms of milk intake, drinking

Table 8. Effect of concentrate supplementation and colostrum feeding regimens on calf BW and BW daily gain from birth to 63 d of age

Item	Dry-cow treatment ¹			Colostrum treatment			Significance ³		
	GSC	GS	SED ²	5% of BW	10% of BW	SED	N	V	N × V
BW (kg)									
6–28 d	47.0	46.8	0.85	46.80	47.0	0.62	0.71	0.69	0.58
28–63 d	63.6	64.8	1.56	65.40	63.0	1.54	0.48	0.19	0.68
6–63 d	57.3	57.9	1.46	58.20	57.0	1.17	0.62	0.56	0.83
BW gain (kg/d)									
0–28 d	0.38	0.40	0.04	0.39	0.39	0.04	0.56	0.97	0.30
28–63 d	0.75	0.78	0.06	0.82	0.71	0.06	0.42	0.09	0.40
0–56 d	0.54	0.57	0.04	0.59	0.51	0.04	0.26	0.05	0.83
0–63 d	0.58	0.59	0.04	0.62	0.54	0.04	0.56	0.05	0.88

¹Dry-cow treatments: GSC = grass silage plus concentrate; GS = grass silage only.

²SED = SE of the difference.

³N = nutrition during dry period; V = volume of colostrum fed; N × V = interaction of nutrition and volume fed.

Table 9. Effect of concentrate supplementation and colostrum feeding regimens on mean health scores of calves

Health score	Dry-cow treatment ¹		Colostrum treatment			Significance ³		
	GSC	GS	5% of BW	10% of BW	SED ²	N	V	N × V
Respiratory (pneumonia) ⁴	1.83 (70%)	1.62 (65%)	1.75 (69%)	1.70 (70%)	0.10	0.04	0.83	0.86
Fecal (enteritis) ⁵	0.63 (60%)	0.65 (53%)	0.74 (53%)	0.54 (43%)	0.06	0.76	0.003	0.23
Treatments								
Pneumonia	2.06	1.15	1.57	1.87	0.49	0.06	0.54	0.40
Diarrhea	1.17	1.54	1.77	0.93	0.44	0.05	0.11	<0.001

¹Dry-cow treatments: GSC = grass silage plus concentrate; GS = grass silage only.

²SED = SE of the difference.

³N = nutrition during dry period; V = volume of colostrum fed; N × V = interaction of nutrition and volume fed.

⁴Pneumonia occurs when a calf presents with a respiratory score >5 (% of calves treated for pneumonia).

⁵Enteritis occurs when a calf presents with a fecal score of 3 or if it had a fecal score of 2 for 2 or more days (% of calves treated for enteritis).

speed, or visits to the feeder with and without reward of milk replacer. However, sick days did have an effect ($P = 0.002$) on milk intake: we observed an increase in milk intake in the days following illness (Table 10). We found antibiotic treatment to have a negative effect ($P = 0.04$) on milk intake at 2 d following administration of antibiotic treatment. Antibiotic treatment also negatively affected calves' drinking speed ($P = 0.007$). Antibiotic treatment had no effect ($P > 0.05$) on the number of visits to the feeder with reward of milk replacer. However, antibiotic treatment had a negative effect on the number of visits without reward of milk replacer.

DISCUSSION

The rationale of this study was to determine the effect of concentrate supplementation during the dry period on colostrum quality and subsequent passive transfer of immunity on calf health and performance when calves were offered different levels of colostrum at birth.

We found no significant difference between maternal IgG concentration and time that colostrogenesis occurred precalving. In contrast, Herr et al. (2011) found a rapid decline in serum IgG levels beginning 8 and 4 wk before parturition, respectively, both reaching a nadir at parturition. Serum IgG levels did not recover until the fourth week after parturition. This correlated with findings from Guy et al. (1994) and Murphy et al. (2005), who examined IgG₁ concentration pre- and postparturition in beef cows. The decrease in serum IgG₁ concentrations prepartum, in association with colostrogenesis, is much greater in dairy (Guy et al., 1994) and beef × dairy (McGee et al., 2005, 2006) cows compared with beef breed cows, which implies that more IgG₁ is transferred into the mammary secretion. This was confirmed by the significantly greater colostrum IgG₁ mass produced by these cow breed types (Guy et al., 1994; McGee et al., 2005) at first milking.

Concentrations of IgG₂ generally increase in cow blood prepartum (Olson et al., 1981; McCutcheon et al., 1991; McGee et al., 2005). The reason for the differences observed between studies may be due to the assay used for quantification; in this study, we measured total IgG rather than specifically IgG₁.

We found that supplementation with concentrate had a significant effect on maternal serum IgG concentration: cows in the GSC group had significantly greater serum IgG concentrations than those in the GS group. In this study, cows were provided with concentrate supplementation for 8 wk before parturition. Typically, rations provided during the early dry period are simple, often comprising a forage-based feed with a small amount of concentrate and a trace mineral salt. Such diets are fed for 4 to 6 wk and cows are then introduced to a close-up ration to provide extra nutrients for the remaining weeks before parturition (Quigley and Drewry, 1998). To our knowledge, no information has been reported on this; therefore, this finding warrants further investigation. Feeding the cow supplementary concentrate during the dry period (8 wk before parturition) had no effect on colostrum IgG concentration, which was in agreement with previous findings (Blecha et al., 1981; Hough et al., 1990; Nowak et al., 2012). Concentrate supplementation had no effect on the nutritional composition (fat, lactose, and protein) of colostrum produced in the current study, which was comparable to reports from Quigley and Drewry (1998) and Nowak et al. (2012). In the current study, we observed that cows in the GSC group had greater colostrum yields in the first 8 d postpartum than cows from GS group. Colostrogenesis begins as early as 5 wk before parturition (Brandon et al., 1971), and previous studies in sheep have shown that nutrition during the dry period can affect colostrum yield (O'Doherty and Crosby, 1996). In contrast, Duplessis et al. (2015) and Mann et al. (2016) reported no significant difference in colostrum yield at first milking from dairy cows when

Table 10. Effect of calf illness and sick days on milk intake, drinking speed, and visits to the feeder with and without reward of milk replacer

Item	Health status ¹		P-value	Sick days ²										P-value
	Sick	Healthy		-2	-1	0	1	2	3	4	5	6	7	
Milk intake (L)	4.57	4.57	0.77	4.1	4.5	4.6	4.5	4.6	4.8	4.5	4.7	4.7	4.7	0.002
Drinking speed (mL/min)	765	780	0.74	699	691	728	743	765	811	832	814	829	813	0.31
Visits without reward (no.)	7.1	6.7	0.90	5.4	5.4	5.0	6.1	6.9	8.5	7.7	8.8	9.6	7.3	0.17
Visits with reward (no.)	2.7	2.9	0.48	2.8	3.1	3.0	3.4	2.9	2.9	2.7	2.6	2.5	2.3	0.44

¹Sick calves were included if they had a health score greater or equal to 5. Healthy calves were identified if calves had a health score <5.

²Sick days define the number of days relative to the calf displaying signs of illness with d 0 being the first day of illness.

fed either a high- or low-energy diet during the dry period.

The mean ($\pm$ SE) IgG concentration of colostrum fed to all calves at their first feed was 54.4 ± 3.72 mg/mL. This was similar to the colostrum IgG concentration found in other studies (Gulliksen et al., 2008; Kehoe et al., 2011; Morrill et al., 2012), but much lower than that reported by Conneely et al. (2013). When comparing results, it is important to consider the laboratory method used to quantify immunoglobulins; Gelsinger et al. (2015) found a 50% difference between IgG values measured by ELISA and by single radial immunodiffusion method.

In the current study, we established that colostrum IgG concentration declined rapidly after calving; this was similar to findings reported by Foley and Otterby (1978) and Blum and Hammon (2000). It has been well documented that calves should receive sufficient colostrum to achieve passive transfer of immunity (Weaver et al., 2000; Uruakpa et al., 2002; Godden, 2008). In the present study, serum IgG concentrations were greater in 10BW than in 5BW calves for the first 3 d after parturition. However, Conneely et al. (2014) reported that calves fed 8.5% of their BW in colostrum within 2 h of birth had greater serum IgG concentrations at 24, 48, and 72 h of age compared with calves fed 7 or 10% of their BW in colostrum. In the current study, the mean IgG concentration measured in calf sera at 12, 24, 48, and 72 h of age, irrespective of treatment group, was >10 mg/mL. However, a significant proportion of these calves became sick, which may have been a consequence of all calves being group housed (suckling from one teat on an automatic feeder). Pneumonia and diarrhea are very contagious between animals and this may have encouraged transmission of disease (Johnson et al., 2011). At 24 h after birth, 13% of 5BW calves and 10% of 10BW calves had a serum IgG level <10 mg/mL. We determined that the large proportion of 5BW calves achieving passive transfer was due to the high-quality colostrum fed to this group and the time at which the calves received colostrum after birth. Nevertheless, 81% of calves in the 10BW group had a serum IgG level >15 mg/mL, and only 27% of the 5BW calves had serum IgG levels >15 mg/mL at 24 h of age.

We found no treatment difference on AEA at 24 h after birth. In contrast, Conneely et al. (2014) found the mean AEA of calves fed 8.5% of BW in colostrum to be greater than that of calves fed 10% of their BW in colostrum at their first feed. Besser et al. (1985) suggested that this might be due to a negative correlation between mass of IgG₁ fed and the calves' ability to absorb it into their bloodstream, which is further supported by Mokhber-Dezfooli et al. (2012). Stott et al. (1979) suggested that 2 L of colostrum should be

fed to Holstein calves to achieve maximum pinocytotic activation of absorptive cells and the greatest rate of absorption. In agreement, Jaster (2005) found that calves fed 2 L at birth and 2 L at 12 h compared with 4 L at birth had greater serum IgG concentrations. In the present study, AEA was not affected by concentrate supplementation during the dry period, which was supported by Halliday et al. (1978). However, data from beef calves suggest that absorption of IgG may be impaired when low protein diets are fed during the dry period (Hough et al., 1990). Moreover, recent findings have shown that calves exposed to heat stress when in utero also have reduced AEA (Tao et al., 2012).

Concentrate supplementation during the dry period did not affect the calves' birth weight, which is supported by findings from Budge et al. (2004), in which it was suggested that there has to be a strict and drawn-out reduction in maternal feed intake to compromise the weight of the newborn calf. No significant differences in BW gain were found between calves from cows fed different preparturient diets. In contrast, Martin et al. (2007) reported that heifer calves born to cows that received 0.45 kg/d of a 42% CP supplement in late gestation were heavier at weaning than offspring from nonsupplemented dams. Colostrum feeding regimen had no significant effect on calf BW or daily BW gain. However, between d 0 and 56 and d 0 and 63, a trend ($P = 0.05$) showed calves from 5BW group to have a greater BW gain than those in 10BW, perhaps due to their increased concentrate intake. In contrast, Faber et al. (2005) found that calves fed 4 L of colostrum compared with 2 L at their first feed had greater BW gain in the first 500 d of life. However, Krohn et al. (1999) found no difference in BW gain for calves offered 3 different colostrum treatments; the first group of calves were in a single box and had no contact with the dam, the second group allowed the cow and calf to be together but no suckling, and the third group allowed the cow and calf together and suckling. In the present study, we observed no difference between colostrum treatment groups and feed efficiency; to date, there is a dearth of literature available and this finding requires further investigation. In our study, calves were offered a restricted volume of milk replacer and there was no significant difference between treatment groups in volume of milk replacer consumed. The growth and antimicrobial factors found in colostrum may have a role in the efficiency and development of the dairy calf in terms of nutrition (Pakkanen and Aalto, 1997).

Concentrate supplementation and colostrum feeding regimen had no effect on milk replacer consumed in the preweaning period, which is in agreement with the findings of Quigley et al. (1995). In the current study,

calves in the 5BW group had greater concentrate intake during the preweaning period than calves in the 10BW group. Further research is required to investigate the effects of colostrum feeding regimens on gut health and development. However, we observed no significant difference between treatment groups after weaning when they were offered ad libitum concentrate until d 63. We found no difference in concentrate intake between dry-cow treatment groups. In the literature, there is a paucity of studies demonstrating the direct effects of maternal nutrition on feed intake of offspring, and further research is needed in this area.

Mortality rate in the current study was low compared with that in a study conducted in the United States, where the overall mortality was 3.5% (Windeyer et al., 2014), and in a Swedish study (3.1%; Svensson et al., 2006). However, the number of calves treated for enteritis and BRD was high in the current study (52.3%, 68.5%) compared with Windeyer et al. (2014), in which almost 22% of calves were treated at least once for BRD and 23% were treated for diarrhea. Torsein et al. (2011) also showed a positive association between diarrhea and poor passive transfer via colostrum. Consequently, good colostrum management is considered a vital element of the management of enteric disease (McGuirk, 2008). Compared with findings from the current study, Virtala et al. (1996) observed no apparent difference in IgG between BRD cases and controls. The high level of morbidity observed in the current study may be a result of group housing and consequent increased spread of disease between animals. This is in accordance with previous studies (Waltner-Toews et al., 1986; Virtala et al., 1999), which showed use of calf hutches to be associated with a lower incidence of BRD than other types of group housing. In addition to passive transfer status, it is important to recognize the overall existing farm issues to create prevention protocols to advance husbandry, vaccination, and hygiene strategies with the overall aim to reduce morbidity.

Calf ill health showed no significant differences between rewarded and unrewarded visits to the feeder; however, calves given antibiotics had a decrease in the number of visits without reward of milk replacer. This is in agreement with findings from Johnson et al. (2011), who reported that the routine use of antibiotics to treat calf diarrhea was linked to negative outcomes, and such use is therefore actively discouraged. Svensson and Jensen (2007) reported a significant difference between healthy and diseased animals ($P < 0.01$) such that healthy and diseased calves visited the feeder on 20 and 16 occasions, respectively, over a 24-h period. These findings are in agreement with Sowell et al. (1999), who demonstrated the feeding behavior of

group-housed steers. Borderas et al. (2009) reported that feed allowance affects feeding behavior associated with illness of milk-fed calves. In our study, calves were closely monitored and medical treatment was administered very quickly. If these calves had not been treated so promptly, we might have detected a difference. In the present study, we observed a reduction in drinking speed in calves with diarrhea or high rectal temperature and in calves given antibiotics. This corresponds with findings from Borderas et al. (2009), who reported that sick calves take longer to consume a smaller meal compared with healthy calves. Maatje et al. (1993) determined a decline in drinking speed to be a dependable indicator of ill health in calves. In contrast, Svensson and Jensen (2007) found no difference in drinking speed between healthy and diseased calves.

In the current study, we observed that offspring of cows in the GS group had greater rates of enteritis than offspring of cows in the GSC group. This is supported by Corah et al. (1975), who found a greater incidence of diarrhea in beef calves from cows that were offered a low-energy diet during the dry period compared with a high-energy diet. Funston et al. (2010) suggest that supplementation of concentrate to cows during the dry period provides the cow with nonstructural carbohydrates that are fermented to propionate in the rumen and transformed into glucose. Glucose is crucial for growth and development of the fetus (Funston et al., 2010). Therefore, it is possible that concentrate supplementation of the cow during the dry period is beneficial to fetus development. Wu et al. (2006) and Schoonmaker and Eastridge (2013) reported the importance of nutritional conditions during critical stages in fetus development in terms of long-term health issues and growth of the calf.

In the present study, the rate of enteritis was greater for 5BW calves than for 10BW calves. We believe that this may be due to the increased serum IgG concentration in calves during the first 3 d of life in 10BW calves compared with 5BW calves, and this is supported by Waldner and Rosengren (2009). This is comparable to previous research in which calves fed high-quality colostrum had less severe diarrhea of lesser duration compared with calves fed low-quality colostrum (Nocek et al., 1984). Relative to this, Faber et al. (2005) reported that calves fed 2 L compared with 4 L of colostrum at birth were at higher risk of disease. Reducing ill health early in life is important because calves that experience episodes of ill health have reduced growth (Donovan et al., 1998), reproduction (Correa et al., 1988; Furman-Fratczak et al., 2011), and milking performance (Heinrichs and Heinrichs, 2011), and increased veterinary costs (Faber et al., 2005).

CONCLUSIONS

Concentrate supplementation during the 8 wk before parturition had no effect on colostral IgG concentration, IgG yield, or fat, protein, and lactose contents. However, cows fed concentrate produced a greater yield of colostrum at birth and for the first 8 milkings postpartum. Concentrate supplementation had no effect on calf serum IgG concentration but did affect the rate of pneumonia, whereby offspring from cows in the GSC group had 10% more pneumonia cases than the GS treatment group. Feeding Holstein dairy calves 10% of their BW in colostrum at birth resulted in a greater IgG concentration in the calves' serum for the first 3 d postpartum compared with feeding only 5% of BW in colostrum. Calves had reduced rates of enteritis and medical treatments if they were fed 10% compared with 5% of their BW in colostrum at their first feeding after birth. Further research is necessary to investigate the potential effect of various dry-cow feeding strategies on colostrogenesis, fetal programming, gut maturation, and metabolism of the newborn calf. Overall, to achieve successful passive transfer, reduce rates of enteritis, and increased efficiency in the dairy calf, we recommend that dairy calves be fed 10% of their BW in colostrum as soon as possible after birth.

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