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Management-related factors in dry cows and their associations with colostrum quantity and quality on a large commercial dairy farm

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ABSTRACT

The objective of this observational study was to evaluate the association of management-related factors in dry cows and colostrum quantity and quality in Holstein cows on a large commercial dairy farm. This study was conducted from January 2018 to December 2020 on a commercial dairy farm in Germany, milking approximately 2,500 Holstein cows. Dairy personnel recorded colostrum quantity (n = 7,567) and evaluated colostrum quality in a subsample of animals (n = 2,600) using a digital Brix refractometer. Generalized linear mixed models were constructed to evaluate the association of management-related factors and colostrum quantity and quality. Models were run separately for primiparous or multiparous cows. The outcome variable was either colostrum quantity (kg) or quality (% Brix). Average colostrum quantity was 4.0 ± 2.5 kg, 5.1 ± 3.4 kg, and 5.5 ± 3.5 kg for cows in lactation 1, 2, and ≥3, respectively. In primiparous cows (n = 2,351), colostrum quantity was affected by month of calving (greatest in April = 4.1 kg, and lowest in November = 3.2 kg), sex of the calf (female singleton = 3.50 ± 0.26 kg; male singleton = 3.76 ± 0.27 kg; twins = 2.97 ± 0.66 kg), stillbirth (stillbirth = 3.14 ± 0.39 kg; no stillbirth = 3.68 ± 0.31 kg). In multiparous cows (n = 5,216), colostrum quantity was affected by month of calving (greatest in May = 5.5 kg, and lowest in October = 3.8 kg), calving ease (calving ease 0 = 4.23 ± 0.26 kg; score 1 = 4.77 ± 0.21 kg; score 2 = 4.98 ± 0.22 kg; score 3 = 5.30 ± 0.22 kg), sex of the calf (female singleton = 4.42 ± 0.21 kg; male singleton = 5.00 ± 0.21 kg; twins = 5.03 ± 0.30 kg), stillbirth (stillbirth = 4.24 ± 0.38 kg; no stillbirth = 5.39 ± 0.11 kg), milk yield in previous lactation (+0.1 kg increase for 1,000 kg more milk yield in previous lactation), days spent in the far-off group (0.05 ± 0.003 kg for every day), and days in the close-up pen (0.06 ± 0.010 kg for every day). Average colostrum quality was 25.1 ± 3.4% Brix, 24.7 ± 3.3% Brix, and 27.6 ± 4.4% Brix for cows in lactation 1, 2, and ≥3, respectively. In primiparous cows (n = 817), colostrum quality was affected only by month of calving. Colostrum quality in primiparous cows was greatest in December (26.8% Brix) and lowest in August (23.9% Brix). In multiparous cows (n = 1,783), colostrum quality was affected by parity (lactation 2 = 25.2 ± 2.7% Brix; lactation 3+ = 27.9 ± 2.7% Brix), month of calving (greatest in February = 27.5% Brix, and lowest in August = 25.7% Brix), milk yield in previous lactation, and colostrum quantity. We observed a seasonal pattern for colostrum quantity and quality. Future intervention studies using multiple farms need to elucidate whether management of the photoperiod or length of exposure to close-up diets, or both, can help to optimize colostrum production.
Key words: close-up diet, colostrum quality, colostrum quantity, dairy cow

INTRODUCTION

Efficient rearing of replacement heifers is critical for sustainability and overall economic performance of dairy operations. Neonatal diseases such as diarrhea, pneumonia, and navel infections affect economic viability due to costs associated with calf losses, treatments, and long-term negative effects on performance (Heinrichs and Heinrichs, 2011). Diarrhea (56.5%) and pneumonia (22.5%) are responsible for the majority of preweaning calf losses (USDA, 2007). As calves are born with a naïve immune system, adequate passive transfer of immunoglobulins by colostrum intake can be considered as the most critical factor for protection against infectious diseases (Godden et al., 2019). Failure of passive transfer of immunity has been associated with an increased risk for mortality (2.12-fold), pneumonia (1.75-fold), diarrhea (1.51-fold), and overall morbidity (1.91-fold; Raboisson et al., 2016). Apart from colostral IgG transfer, adequate colostrum intake during the first hours of life might have the potential to permanently affect the lifetime performance of a dairy cow (Faber et al., 2005; Soberon et al., 2012). Adequate colostrum in-

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take improved feed efficiency, reduced age at first calving, and might affect milk yield in first lactation (Jones et al., 2004; Faber et al., 2005). It has recently been shown that offering calves a second meal of colostrum 6 h after the initial feeding soon after birth resulted in improved average daily weight gain and reduced morbidity in preweaning dairy calves and tended to affect first-lactation milk yield (Abuelo et al., 2021). Overall, this highlights the importance of harvesting a sufficient quantity of high-quality colostrum.

Colostrogenesis occurs during the last weeks of gestation (Brandon et al., 1971). Among others, prepartum maternal nutrition (Mann et al., 2016) and nutritional management (Farahani et al., 2017) can affect colostrum production. Prepartum dairy cows have an increased need for energy and protein in response to synthesis of mammary tissue and colostrum as well as requirements for uterine and fetal development (Van Saun and Sniffen, 2014). Estimates from Bell et al. (2000) and NRC (2001) suggest that an additional 120 and 130 g/d, respectively, of metabolizable protein might be needed to meet AA needs for mammary tissue accretion in prepartum dairy cows. Van Saun and Sniffen (2016) recommended that prepartum diets provide 1,300 g/d of MP. Apart from the ration composition, nutritional management, such as length of exposure to prepartum diets, might affect colostrum production. Several studies reported IgG concentration in colostrum to be similar for cows with short dry periods compared with cows with conventional dry periods (Annen et al., 2004; Rastani et al., 2005; Watters et al., 2008; Klusmeyer et al., 2009). Cows with no dry periods, however, had reduced colostrum quality compared with conventional dry periods (Annen et al., 2004; Rastani et al., 2005; Klusmeyer et al., 2009). This indicates that the colostrogenesis period is not sufficient for gamma globulin accumulation in these cows (Collier et al., 2012).

Limited evidence exists regarding the effect of dry period length on colostrum quantity. Typically, the dry period comprises the last 60 d of gestation, consisting of the first 4 to 6 wk, called far-off, and the close-up period, starting around d 255 of gestation (Vieira-Neto et al., 2021). Reducing the dry period from 60 to 40 d decreased colostrum quantity (8.9 vs. 6.8 kg; Grusenmeyer et al., 2006). Cows with a 60-d dry period had greater colostrum production compared with cows with a 0-d or 30-d dry period (7.7 vs. 5.3 vs. 5.1 kg; Mayasari et al., 2015). However, only a few studies have examined the optimal length of exposure to prepartum diets and its effect on colostrum production. A longer duration (42 d vs. 21 d) of exposure to a close-up diet had no effect on colostrum quantity or quality (Weich et al., 2013; Lopera et al., 2018). A short stay in the close-up pen (10 d vs. 21 d), however, resulted in reduced colostrum quantity (Farahani et al., 2017). It is possible that optimum length of exposure to a prepartum diet differs between nulliparous heifers and parous cows, as nulliparous heifers have an increased demand for MP (Husnain and Santos, 2019).

The objective of this observational study was to evaluate the association of management-related factors in dry cows and colostrum quantity and quality in Holstein cows. We hypothesized that length of exposure to a prepartum diet is associated with colostrum quantity and quality.

MATERIALS AND METHODS

Animals, Facilities, and Housing

This observational study was conducted from January 2018 to December 2020 on a commercial dairy farm in Mecklenburg-Vorpommern, Germany, milking approximately 2,500 Holstein cows, with an average annual milk yield of 11,500 kg/cow. The cows were housed in a naturally ventilated transition management facility from drying off to the first 20 DIM. Cows and heifers were kept separately in sand-bedded freestall pens. Heifer and cow pens had 36 and 144 stalls, respectively, with ad libitum access to feed and water. Heifers were moved to a close-up pen within the transition management facility at d 264 of gestation. Cows were dried off 55 d before expected parturition and moved to the transition management facility. Around 21 d before expected calving, cows and heifers were moved to separate close-up pens. Dry cows were fed a TMR diet once daily, consisting of corn silage and grass silage as forage, with corn and canola meal-based concentrate, formulated to meet or exceed the dietary requirements for dry and lactating Holstein cows (NRC, 2001). The ration composition for far-off dry and close-up cows (Table 1) did not vary significantly across time. Feed was pushed up 10 times a day. Prepartum cows and heifers were fed a negative DCAD diet (−100 mEq/kg DM). Urine pH was assessed once a week in a subsample of 12 cows in the close-up group. During the study period, the average urine pH was 5.8 (±0.67; n = 3,332).

To improve colostrum quality, all prepartum cows were vaccinated during the dry period, and prepartum heifers before calving, against *Escherichia coli* and bovine rota- and coronavirus (Rotavec Corona, MSD Animal Health, Intervet Deutschland GmbH). The vaccination was carried out 3 to 12 wk before calving. Postpartum cows were milked 3 times daily (0600, 1400, and 2200 h).

Calving Management

Heifers and cows were moved on a weekly basis to the prepartum pen 21 d (±3) before expected parturition; there, animals were monitored every 30 min to detect signs of imminent parturition (i.e., restlessness, vaginal discharge with bloody traces, lying lateral with abdominal contractions, visible or broken amniotic sac, or feet of the emerging calf outside the vulva). When the amniotic sac was visible or broken outside the vulva, or the feet of the emerging calf were observed outside the vulva, the cows were moved into an individual maternity pen (3.5 × 3.5 m) bedded with fresh straw. In every animal, a vaginal examination was conducted to assess dilatation of the vulva and cervix, and furthermore position, posture, presentation, and vitality of the calf. If delivery took longer than 1 h after the appearance of the amniotic sac or calf feet outside the vulva, calving assistance was provided, to reduce calf losses (Schuenemann et al., 2011). Calving assistance was recorded using a 4-point scale (0 = not observed; 1 = no assistance; 2 = assistance by 1 person; 3 = assistance by at least 2 persons). Twins, cesarean sections, and stillbirths were recorded separately.

During vaginal examination, as well as calving assistance, the animals were restrained in headlocks, and the perineum was carefully cleaned with warm water and a 10% tincture of iodine solution (Braunol, B. Braun Melsungen AG). Before the examination or calving assistance, lubricant (MS Lubricant, MS Schippers GmbH) was applied generously to the obstetrical gloves and the cow's vagina.

Calves were separated from their dam immediately after calving and were weighed with an electronic scale (WA200 mobile platform scale, Meier-Brakenberg GmbH & Co. KG). All newborn calves were placed into a hutch (1.5 × 1 m) bedded with fresh straw for the first 24 h following birth. Navel dipping was performed using a 10% tincture of iodine solution (Braunol, B. Braun Melsungen AG). Approximately 30 min after calving, 4 L of pasteurized (Perfect Udder, Dairy Tech Inc.), pooled, high-quality colostrum (≥22% Brix; Bielmann et al., 2010) were fed via an esophageal tube feeder (Dairymac Drencher, Dairytop).

Harvest of Colostrum

Colostrum was harvested immediately after parturition in a separate milking parlor with a self-locking chute. Manual stimulation lasted 30 s and included pre-dipping, forestripping (removal of 2 streams of colostrum from each teat), and dry wiping using a clean paper towel. The lag time between manual stimulation and attachment of the milk unit clusters was 60 s. The vacuum of the milking equipment (Flo-Star MAX, Boumatic Robotics GmbH) was 45 kPa, and the milk-to-rest ratio was at 60:40. After colostrum harvest, the teats were dipped (Jod 5000, CID Lines N.V.). After each milking, the bucket, including the colostrum, was weighed with a digital hanging scale (digital hanging scale, model No. XY-2003, Etekcity Corporation, minimum weight 200 g and maximum weight 50 kg), and the weight of the bucket (3.48 kg) was subtracted. A vaginal obstetrical follow-up examination was carried out to identify vaginal injuries or presence of a second calf. Farm personnel assessed colostrum quality for cows that calved in 2020 using a digital Brix refractometer (HI 96801, Hanna Instruments Deutschland GmbH).

Data Collection and Statistical Analyses

Essential cow data such as cow ID, parity, gestation length, days in the far-off group, days in the prepartum pen, calving ease, stillbirth, date and time of parturition, calf birth weight, sex of calf, twin births, colostrum quantity, colostrum quality, linear somatic cell score at dry off, and 305-d milk yield in the previous lactation were obtained from the on-farm computer software (DairyComp 305, Valley Ag Software) and transmitted

Table 1. Chemical composition (% unless otherwise noted) of prepartum diets during the experiment from 2018 until 2020

Nutrient composition (DM basis)	Far-off			Close-up		
	2018	2019	2020	2018	2019	2020
CP	13.7	14.5	15.3	14.0	14.3	14.2
Ether extract	2.5	2.4	2.5	2.6	2.4	2.9
NDF	51.9	53.0	52.7	45.7	47.8	48.8
NFC[1]	25.1	23.1	22.5	29.3	27.4	25.4
Starch	10.9	9.9	12.6	16.9	14.9	15.1
Ash	6.8	7.0	7.2	8.7	7.7	8.9
DCAD,[2] mEq/100 g	16.3	6.8	6.0	−16.5	−16.9	−8.5

[1]Calculated as 100 − CP − ether extract − NDF − ash.

[2]DCAD = [(Na % of DM/0.023) + (K % of DM/0.039)] − [(S % of DM/0.016) + (Cl % of DM/0.0355)].

Table 2. Descriptive statistics for continuous variables from 7,567 Holstein cows enrolled from 1 commercial dairy farm

Variable	Lactation	Mean	SD	Range
Age at first calving (mo)	1	22.2	1.27	19.4–33.4
Dry period length (d)	2	48.2	12.1	14–133
	3+	54.9	19.0	17–146
Days in the far-off pen (d)	2	27.4	11.8	7–112
	3+	34.1	18.9	7–126
Days in the close-up pen (d)	1	19.6	5.9	1–41
	2	20.8	5.4	1–37
	3+	20.8	5.6	1–42
Gestation length (d)	1	274.3	4.2	257–293
	2	276.2	4.4	257–290
	3+	277.0	4.7	257–290
Previous 305-d milk yield (kg)	2	12,922	1,934	4,190–20,020
	3+	13,022	2,184	1,390–21,270
Colostrum quantity (kg)	1	4.0	2.5	0.5–17.0
	2	5.1	3.4	0.5–19.5
	3+	5.5	3.5	0.5–20.0
Colostrum quality[1] (% Brix)	1	25.1	3.4	16.5–39.0
	2	24.7	3.3	15.0–36.0
	3+	27.6	4.4	10.5–46.5

[1]Colostrum quality was assessed using a digital Brix refractometer for all cows calved in 2020 (lactation 1, n = 817; lactation ≥2, n = 1,783).

to Microsoft Excel (Office 2013, Microsoft Deutschland Ltd.).

Gestation length has been associated with health and productive and reproductive performance in dairy cows (Vieira-Neto et al., 2021). Cows with a gestation length shorter or longer than 3 standard deviations from the mean were removed as previously described (Vieira-Neto et al., 2021). Therefore, cows with a gestation length shorter than 257 d (n = 90) or longer than 293 d (n = 13) and cows that spent 0 d in the close-up pen (n = 181) were removed from the database. Gestation length was categorized as short (range between 257 and 269 d), normal (270–280 d), or long (281–293 d).

Statistical analyses were performed using SPSS for Windows (version 22.0, IBM Corp.). Four separate generalized linear mixed models were constructed using the GENLINMIXED procedure of SPSS to evaluate the association of management-related factors and colostrum quantity and quality for primiparous or multiparous cows. The outcome variable was either colostrum quantity (kg) or quality (% Brix). Cow was the experimental unit. According to the model-building strategies described by Dohoo et al. (2009), each parameter considered for the mixed model was separately analyzed in a univariable model, including the parameter as a fixed factor (i.e., categorical parameter) or covariate (i.e., continuous parameter). Only parameters resulting in univariable models with $P \leq 0.20$ were included in the final mixed model. Selection of the model that best fit the data was performed by testing each effect separately in a multivariable model and finding the model with the lowest value for the Akaike information criterion, using a backward elimination procedure that removed all variables with $P > 0.10$ from the model. Regardless of the significance level, days in the far-off

Table 3. Descriptive statistics for categorical variables (%) from 7,567 Holstein cows enrolled from 1 commercial dairy farm

	Parity	
Variable	Primiparous	Multiparous
Calving ease[1]		
0	2.6	7.6
1	53.8	59.1
2	18.4	15.3
3	25.2	18.0
Stillbirth		
Alive	95.8	98.6
Dead on arrival	4.2	1.4
Sex of calf		
Male singleton	31.5	48.8
Female singleton	67.8	48.1
Twins	0.7	3.1
Month of calving		
January	6.0	7.4
February	7.2	6.5
March	7.3	6.7
April	8.9	6.8
May	8.8	7.0
June	10.0	8.4
July	8.5	7.9
August	7.0	10.9
September	10.9	9.8
October	8.2	8.8
November	8.3	9.2
December	9.0	10.3

[1]Calving assistance was recorded using a 4-point scale (0 = not observed; 1 = no assistance; 2 = assistance by 1 person; 3 = assistance by at least 2 persons).

dry cow pen and close-up pen, as well as gestation length, were forced to remain in the model.

For primiparous cows, the initial model for colostrum quantity contained the following explanatory variables as fixed effects: age at first calving (continuous), month of calving (1–12), calving ease (score 0–3), calving day of the week (Monday–Sunday), stillbirth (alive vs. dead on arrival), sex of the calf (male singleton vs. female singleton vs. twins), gestation length (short vs. normal vs. long), and days in the close-up pen (**DINCU**; continuous).

For multiparous cows, the initial model for colostrum quantity contained the following explanatory variables as fixed effects: parity (2 vs. ≥3), month of calving (1–12), calving ease (score 0–3), calving day of the week (Monday–Sunday), stillbirth (alive vs. dead on arrival), sex of the calf (male singleton vs. female singleton vs. twins), gestation length (short vs. normal vs. long), milk yield in previous lactation (continuous), linear somatic cell score at dry off (continuous), days in the far-off group (continuous), and DINCU (continuous).

The initial model for colostrum quality contained the same explanatory variables as for colostrum quantity. Additionally, colostrum quantity (continuous) was included. We tested all biologically plausible 2-way interactions.

Figures were created with predicted responses for each cow contributing data for the statistical analysis of the specific dependent variable analyzed. The predicted values were obtained from the final models using fitted values with best linear unbiased estimates.

RESULTS

From January 1, 2018, through December 31, 2020, a total of 8,709 cows calved. After exclusion of 1,145 animals (13.1%) because of incomplete data sets, 7,567 animals were available for final statistical analyses. Of those 2,351 (31.1%), 1,958 (25.9%), and 3,258 (43.0%) were in lactation 1, 2, and ≥3, respectively. Descriptive statistics of cows used in the statistical analysis in this study are presented in Tables 2 and 3, considering parity. Average dry period length was 48.2 d and 54.9 d for cows in lactation 2 and ≥3, respectively. Average days spent in the close-up pen was 19.6 d, 20.8 d, and 20.8 d for cows in lactation 1, 2, and ≥3, respectively. A histogram of exposure to a prepartum diet stratified by parity is presented in Figure 1.

Colostrum Quantity

Average colostrum quantity was 4.0 kg, 5.1 kg, and 5.5 kg for cows in lactation 1, 2, and ≥3, respectively. A histogram of colostrum quantity is presented in Figure 2.

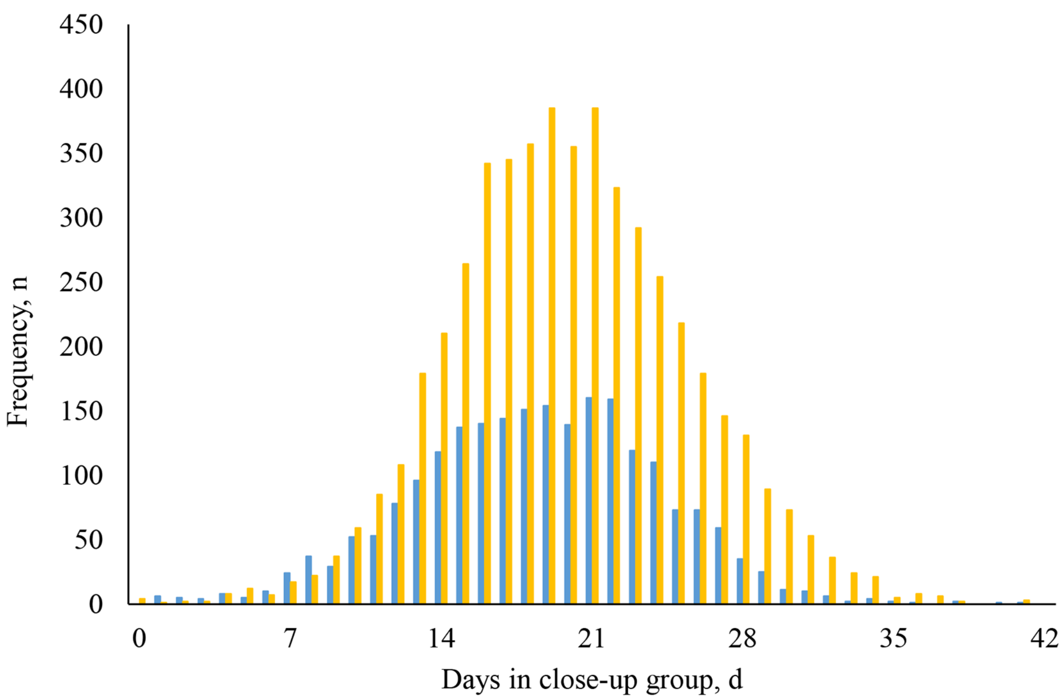

Figure 1. Frequency distribution of days in the close-up group for 7,567 cows from 1 commercial dairy farm. Blue bars represent primiparous cows (n = 2,351). Yellow bars represent multiparous cows (n = 5,216).

In primiparous cows (Table 4), colostrum quantity was affected by month of calving ($P = 0.004$), sex of the calf ($P = 0.050$), and stillbirth ($P = 0.036$). Age at first calving ($P = 0.079$) and calving ease ($P = 0.054$; calving ease 0 = 2.77 ± 0.44 kg; score 1 = 3.57 ± 0.32 kg; score 2 = 3.63 ± 0.33 kg; score 3 = 3.67 ± 0.32 kg) tended to affect colostrum quantity (Table 4). Gestation length ($P = 0.525$) and DINCU ($P = 0.239$) were not associated with colostrum quantity. Seasonal pattern of colostrum production in primiparous cows is

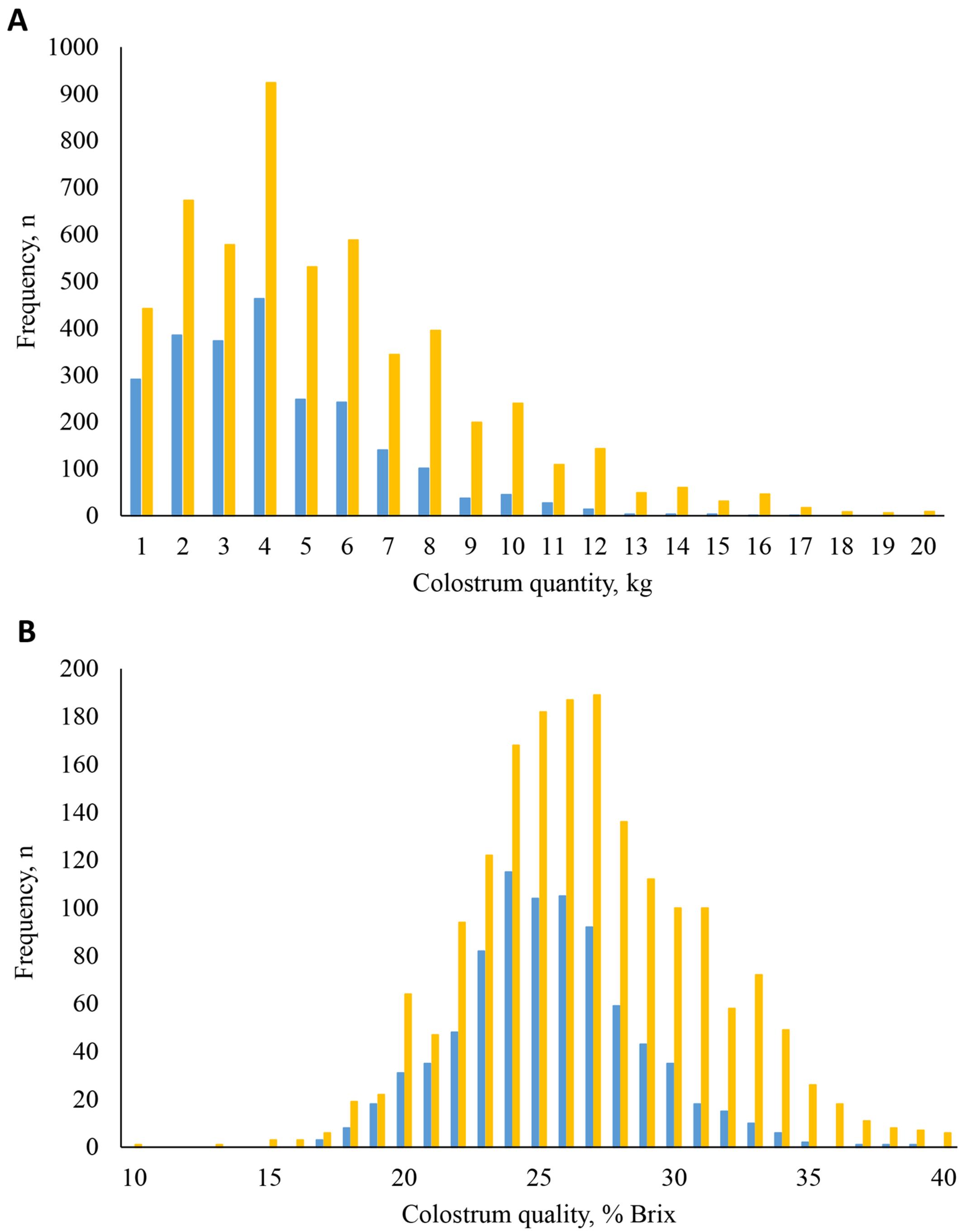

Figure 2. Frequency distribution of colostrum quantity (kg; panel A) for 7,567 Holstein cows (primiparous cows are displayed in blue, n = 2,351; multiparous cows are displayed in yellow, n = 5,216) that calved from January 1, 2018, to December 31, 2020, and colostrum quality (% Brix; panel B) for 2,600 Holstein cows (primiparous cows are displayed in blue, n = 817; multiparous cows are displayed in yellow, n = 1,783) that calved in 2020. Colostrum quality was assessed using a digital Brix refractometer.

presented in Figure 3. Colostrum quantity in primiparous cows was greatest in April (4.1 kg) and lowest in November (3.2 kg). Sex of the calf was associated with colostrum quantity (female singleton = 3.50 ± 0.26 kg; male singleton = 3.76 ± 0.27 kg; twins = 2.97 ± 0.66 kg). Stillbirth was associated with reduced colostrum quantity in primiparous cows (stillbirth = 3.14 ± 0.39 kg; no stillbirth = 3.68 ± 0.31 kg). A positive association tended to occur between age at first calving and colostrum quantity (+ 0.07 ± 0.04 kg for each month increase in age at first calving).

In multiparous cows (Table 5), colostrum quantity was affected by month of calving (P = 0.001), calving ease (P = 0.001), sex of the calf (P = 0.001), stillbirth (P = 0.003), milk yield in previous lactation (P = 0.001), days spent in the far-off group (P = 0.001), and DINCU (P = 0.001). Gestation length (P = 0.334) was not associated with colostrum quantity. Seasonal pattern of colostrum production in multiparous cows is presented in Figure 4. Colostrum quantity in multiparous cows was greatest in May (5.5 kg) and lowest in October (3.8 kg). We observed a linear increase in colostrum quantity with calving difficulty (calving ease 0 = 4.23 ± 0.26 kg; score 1 = 4.77 ± 0.21 kg; score 2 = 4.98 ± 0.22 kg; score 3 = 5.30 ± 0.22 kg). Sex of the calf was associated with colostrum quantity (female singleton = 4.42 ± 0.21 kg; male singleton = 5.00 ± 0.21 kg; twins = 5.03 ± 0.30 kg). Stillbirth was associated with reduced colostrum quantity in multiparous cows (stillbirth = 4.24 ± 0.38 kg; no stillbirth = 5.39 ± 0.11 kg). A positive association occurred between milk yield in previous lactation and colostrum quantity. An increase in milk yield in previous lactation by 1,000 kg was associated with an increase in colostrum quantity by 0.1 kg. Longer exposures to the far-off group (0.05 ± 0.003 kg for every day) and to the prepartum diet (0.06 ± 0.010 kg for every day) were associated with a linear increase in colostrum quantity (Figure 5).

Table 4. Association of colostrum quantity with management-related factors from 2,351 primiparous cows from 1 commercial dairy farm

Variable	Estimate (kg)	SE	95% CI Lower CI	95% CI Upper CI	P-value
Intercept	1.12	1.03	−0.90	3.15	0.275
Age at first calving	0.07	0.04	−0.01	0.157	0.079
Gestation length[1]					
Normal	Referent				
Short	−0.11	0.18	−0.47	0.25	0.551
Long	−0.20	0.22	−0.64	0.24	0.373
Calving ease[2]					
0	Referent				
1	0.80	0.32	0.17	1.42	0.013
2	0.86	0.33	0.20	1.51	0.010
3	0.90	0.33	0.26	1.55	0.006
Stillbirth					
Alive	Referent				
Dead	−0.54	0.26	−1.04	−0.03	0.036
Sex of calf					
Female	Referent				
Male	0.25	0.11	0.03	0.48	0.026
Twins	−0.53	0.63	−1.76	0.70	0.396
Days in the close-up group	0.01	0.01	−0.01	0.03	0.239
Month of calving					
January	Referent				
February	0.03	0.28	−0.51	0.58	0.897
March	0.06	0.28	−0.49	0.60	0.840
April	0.65	0.27	0.12	1.17	0.016
May	0.53	0.27	0.01	1.11	0.050
June	0.48	0.26	−0.03	1.00	0.066
July	0.25	0.27	−0.29	0.78	0.368
August	0.43	0.29	−0.13	0.99	0.134
September	0.17	0.26	−0.35	0.68	0.523
October	−0.17	0.27	−0.71	0.37	0.541
November	−0.20	0.27	−0.73	0.34	0.474
December	0.01	0.27	−0.53	0.53	0.998

[1]Gestation length was categorized as short (range between 257 and 269 d of gestation), normal (270–280 d), or long (281–293 d).

[2]Calving assistance was recorded using a 4-point scale (0 = not observed; 1 = no assistance; 2 = assistance by 1 person; 3 = assistance by at least 2 persons).

Colostrum Quality

Average colostrum quality was 25.1% Brix, 24.7% Brix, and 27.6% Brix for cows in lactation 1, 2, and ≥3, respectively. A histogram of colostrum quantity is presented in Figure 2.

In primiparous cows (n = 817; Table 6), colostrum quality was affected only by month of calving (P = 0.001). There tended to be a quadratic effect of DINCU (P = 0.057) on colostrum quality. Gestation length (**GL**) tended to be associated with colostrum quality (short GL = 24.9 ± 2.3% Brix; normal GL = 25.3 ± 2.3% Brix; long GL = 26.4 ± 2.3% Brix). Colostrum quality in primiparous cows was greatest in December (26.8% Brix) and lowest in August (23.9% Brix).

In multiparous cows (n = 1,783; Table 7), colostrum quality was affected by parity (P = 0.001), month of calving (P = 0.001), milk yield in previous lactation (P = 0.019), and colostrum quantity (P = 0.001). Stillbirth tended to affect colostrum quality (P = 0.089; stillbirth = 27.3 ± 2.8% Brix; no stillbirth = 25.9 ± 2.7% Brix). Gestation length (P = 0.133) and DINCU (P = 0.134) had no effect on colostrum quality. Cows in parity 3 or greater (27.9 ± 2.7% Brix) had better quality compared with cows in lactation 2 (25.2 ± 2.7% Brix). Colostrum quality in multiparous cows was greatest in February (27.5% Brix) and lowest in August (25.7% Brix). Milk yield in previous lactation was negatively associated with colostrum quality. An increase in milk yield in previous lactation by 1,000 kg was associated with a decrease in colostrum quality by 0.13% Brix. Also, colostrum quantity was negatively associated with colostrum quality. An increase in colostrum quantity of 1 kg was associated with a decrease in colostrum quality of 0.27% Brix (Figure 3).

DISCUSSION

The objective of this study was to evaluate the association of management-related factors in dry cows and colostrum quantity and quality in Holstein cows on one commercial dairy farm. In primiparous cows, length of exposure to a prepartum diet was not associated with

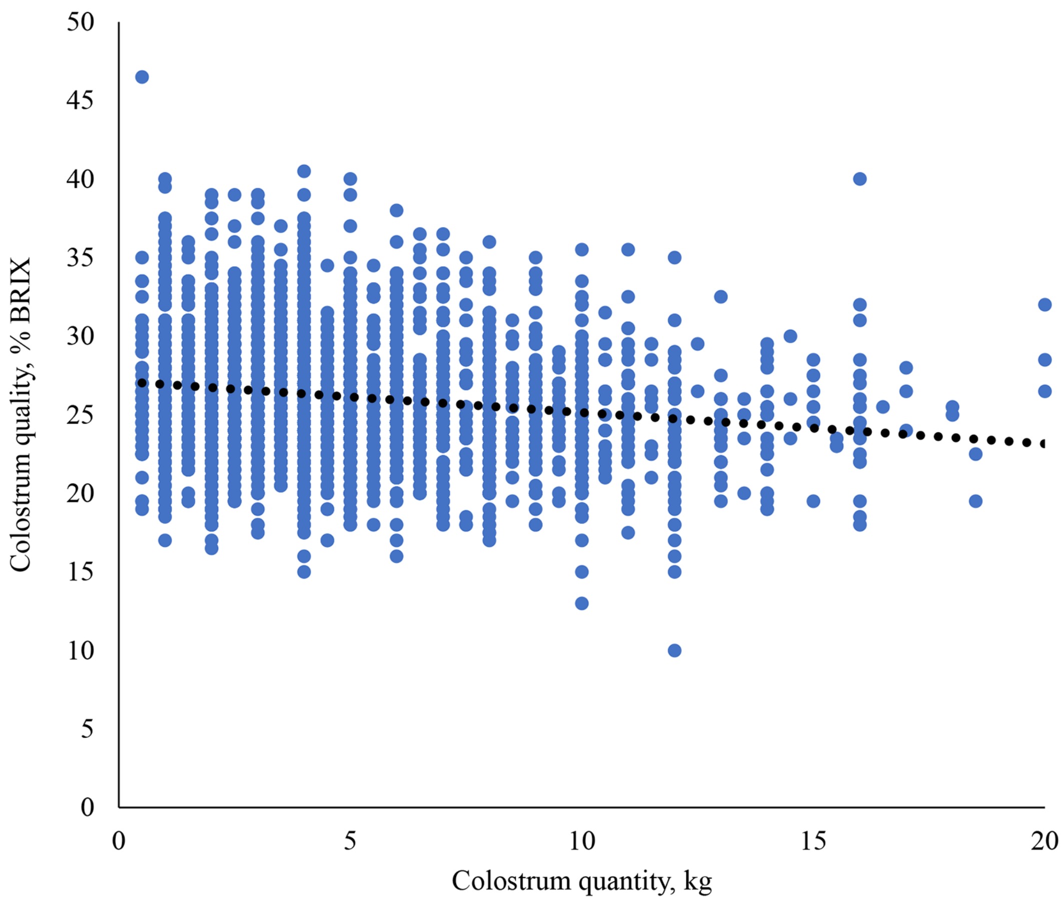

Figure 3. Association between colostrum quantity (kg) and colostrum quality (% Brix) for 2,600 Holstein cows that calved in 2020. Colostrum quality was assessed using a digital Brix refractometer.

colostrum quantity or colostrum quality. Colostrum quantity was affected by time of the year, sex of the calf, and stillbirth. Colostrum quality was affected only by time of the year.

In multiparous cows, however, length of exposure to the far-off and close-up diet was associated with colostrum quantity. Other contributing factors were time of the year, sex of the calf, stillbirth, calving ease, and milk yield in previous lactation. Colostrum quality was affected by parity, gestation length, milk yield in previous lactation, and colostrum quantity.

Typically, 2 diets in the dry period have been adopted by commercial dairy farms. The diet fed within the last 3 to 4 wk of gestation generally has higher energy and protein contents (Van Saun and Sniffen, 2014). The diets fed in this study resembled this approach. It has been shown that a prepartum diet with a negative DCAD leads to an improvement in periparturient mineral balance, reduced diseases risk, and improved milk yield, particularly in multiparous cows (Lean et al., 2019; Santos et al., 2019). In primiparous cows, feeding a negative DCAD diet prepartum had a negative effect on DMI and milk yield but was favorable for postpartum risk for retained placenta and metritis (Lean et al., 2019). Until recently little evidence has existed regarding the ideal duration of feeding such a prepartum diet. Two recent observational studies reported reduced morbidity and improved milk production when either Holstein cows (Vieira-Neto et al., 2021) or Jersey cows (Chebel, 2021) were exposed to a prepartum diet for 28 d. Shorter or longer exposure led to unfavorable outcomes. Unfortunately, none of these studies assessed the association of length of exposure to a prepartum diet on colostrum quantity or quality. Results from our

Table 5. Association of colostrum quantity with management-related factors from 5,216 multiparous cows from 1 commercial dairy farm

Variable	Estimate (kg)	SE	95% CI Lower CI	95% CI Upper CI	*P*-value
Intercept	0.13	0.44	−0.72	0.99	0.757
Gestation length[1]					
Normal	Referent				
Short	−0.28	0.22	−0.71	0.15	0.204
Long	0.12	0.14	−0.14	0.39	0.358
Calving ease[2]					
0	Referent				
1	0.54	0.17	0.20	0.88	0.001
2	0.75	0.20	0.35	1.14	0.001
3	1.06	0.19	0.68	1.44	0.001
Stillbirth					
Alive	Referent				
Dead	−1.15	0.39	−1.91	−0.40	0.001
Sex of the calf					
Female	Referent				
Male	0.58	0.09	0.40	0.76	0.001
Twins	0.61	0.28	0.05	1.16	0.032
Previous 305-d milk yield[3]	0.10	0.02	0.06	0.14	0.001
Days in the far-off group	0.05	0.01	0.05	0.06	0.001
Day in the close-up group	0.06	0.01	0.04	0.08	0.001
Month of calving					
January	Referent				
February	0.19	0.24	−0.28	0.66	0.417
March	0.18	0.24	−0.28	0.65	0.439
April	0.58	0.24	0.12	1.05	0.010
May	1.08	0.24	0.62	1.55	0.001
June	0.73	0.23	0.28	1.17	0.001
July	0.79	0.23	0.33	1.24	0.001
August	0.38	0.22	−0.04	0.81	0.075
September	−0.62	0.22	−1.05	−0.19	0.001
October	−0.66	0.22	−1.10	−0.22	0.001
November	−0.40	0.22	−0.83	0.03	0.069
December	0.27	0.22	−0.16	0.69	0.216

[1]Gestation length was categorized as short (range between 257 and 269 d of gestation), normal (270–280 d), or long (281–293 d).

[2]Calving assistance was recorded using a 4-point scale (0 = not observed; 1 = no assistance; 2 = assistance by 1 person; 3 = assistance by at least 2 persons).

[3]Milk yield in the previous lactation, ×1,000 kg.

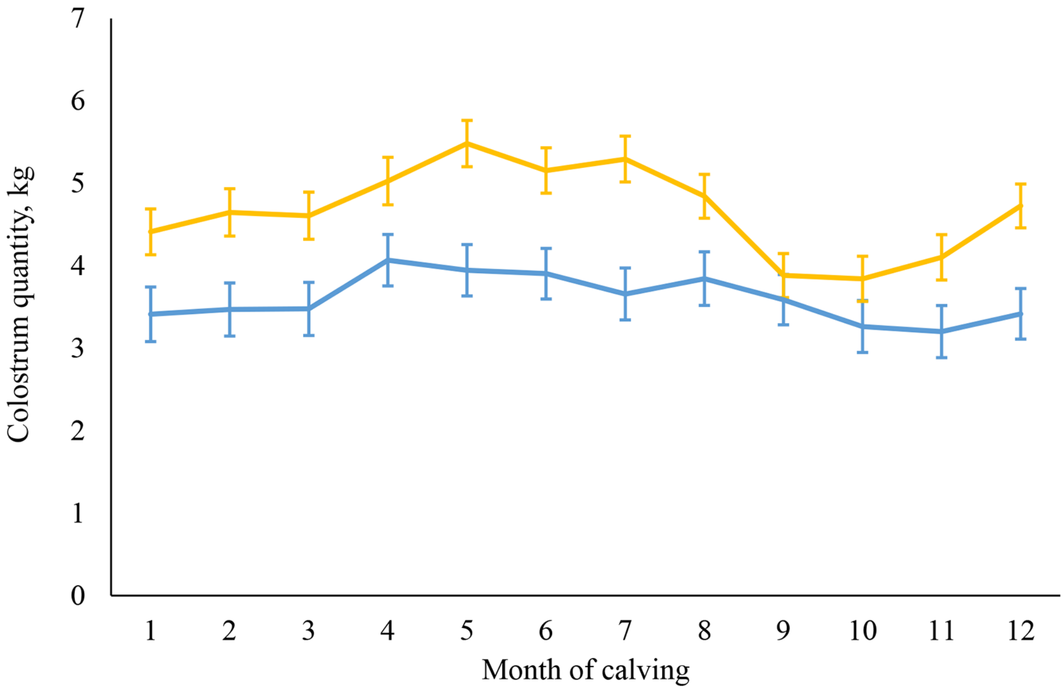

Figure 4. Seasonal pattern of colostrum quantity (kg ± SEM) for 7,567 cows from 1 commercial dairy farm. The blue line represents primiparous cows (n = 2,351). The yellow line represents multiparous cows (n = 5,216). From the final models for primiparous and multiparous cows, predicted colostrum quantity was plotted against month of calving (1–12 = January through December). In primiparous cows, the model contained the following fixed effects: month of calving ($P = 0.004$), sex of the calf ($P = 0.050$), stillbirth ($P = 0.036$), age at first calving ($P = 0.079$), calving ease ($P = 0.054$), gestation length ($P = 0.525$), days spent in the close-up pen ($P = 0.239$). In multiparous cows, the model contained the following fixed effects: month of calving ($P = 0.001$), calving ease ($P = 0.001$), sex of the calf ($P = 0.001$), stillbirth ($P = 0.003$), milk yield in previous lactation ($P = 0.001$), days spent in the far-off group ($P = 0.001$), days spent in the close-up pen ($P = 0.001$), and gestation length ($P = 0.334$).

Table 6. Association of colostrum quality with management-related factors from 817 primiparous cows from 1 commercial dairy farm; colostrum quality was assessed using a digital Brix refractometer

Variable	Estimate (% Brix)	SE	95% CI Lower CI	95% CI Upper CI	*P*-value
Intercept	23.48	2.83	17.93	29.04	0.001
Gestation length[1]					
Normal	Referent				
Short	−0.36	0.49	−1.33	0.60	0.463
Long	1.09	0.50	0.10	2.07	0.030
DINCU[2]	0.24	0.15	−0.05	0.53	0.107
DINCU × DINCU	−0.01	0.00	−0.01	0.01	0.057
Month of calving					
January	Referent				
February	−0.32	0.59	−1.48	0.84	0.584
March	−0.09	0.63	−1.32	1.15	0.887
April	−0.76	0.58	−1.91	0.39	0.193
May	−0.80	0.59	−1.96	0.37	0.180
June	−0.85	0.60	−2.03	0.33	0.157
July	−1.08	0.56	−2.17	0.01	0.053
August	−1.63	0.59	−2.78	−0.48	0.006
September	−0.58	0.55	−1.67	0.51	0.297
October	0.42	0.60	−0.77	1.60	0.490
November	0.98	0.62	−0.24	2.21	0.114
December	1.30	0.62	0.07	2.52	0.038

[1]Gestation length was categorized as short (range between 257 and 269 d of gestation), normal (270–280 d), or long (281 and 293 d).

[2]Days spent in the close-up group.

study suggest that length of exposure to a prepartum diet was associated with colostrum quantity in multiparous cows but not in primiparous cows. A linear increase in colostrum quantity occurred with increasing DINCU (10 d = 4.94 ± 0.19 kg; 20 d = 5.19 ± 0.06 kg; 30 d = 5.86 ± 0.12 kg). The designs of our study and of the cited studies do not allow attribution of effects to the length of exposure to DCAD diet, as other components were not accounted for.

We observed a negative association between DINCU and colostrum quantity. This is in agreement with a randomized controlled experiment in which a short stay in the close-up pen (10 d vs. 21 d) resulted in reduced colostrum quantity (Farahani et al., 2017). Contrary to our findings, 2 previous studies showed no effect on either colostrum quantity or quality when cows were fed a close-up diet with a negative DCAD for 42 d versus 21 d (Weich et al., 2013; Lopera et al., 2018). Mammary development and colostrogenesis at the end of gestation led to an increased demand for energy and protein (Van Saun and Sniffen, 2014). Therefore, short exposure to a well formulated prepartum diet might result in insufficient supply of nutrients. Apart from nutrient supply, a certain dry period length is necessary for mammary involution (Collier et al., 2012). Reducing the length of the dry period from 60 to 40 d decreased the quantity of colostrum (8.9 vs. 6.8 kg; Grusenmeyer et al., 2006). Cows with a 60-d dry period produced more colostrum compared with cows with a 0-d or 30-d dry period (7.7 vs. 5.3 vs. 5.1 kg; Mayasari et al., 2015). Dairy cows, specifically cows at the end of their first lactation, require a 60-d dry period length for normal mammary epithelial cell turnover and regeneration. Extending lactation during the last 8 wk of gestation changes the patterns of cell apoptosis and proliferation (Pezeshki et al., 2010). If lactation is sustained, old or senescent cells cannot be replaced with new cells, resulting in an epithelium with less prolific capacity. The majority of studies on customizing the dry period length have focused on milk production. Results from our study provide evidence that the same concept applies to colostrogenesis. Apart from DINCU, days spent in the far-off group had also an effect on colostrum quantity.

The seasonal pattern of colostrum quantity is similar to a study using observational data from a Jersey

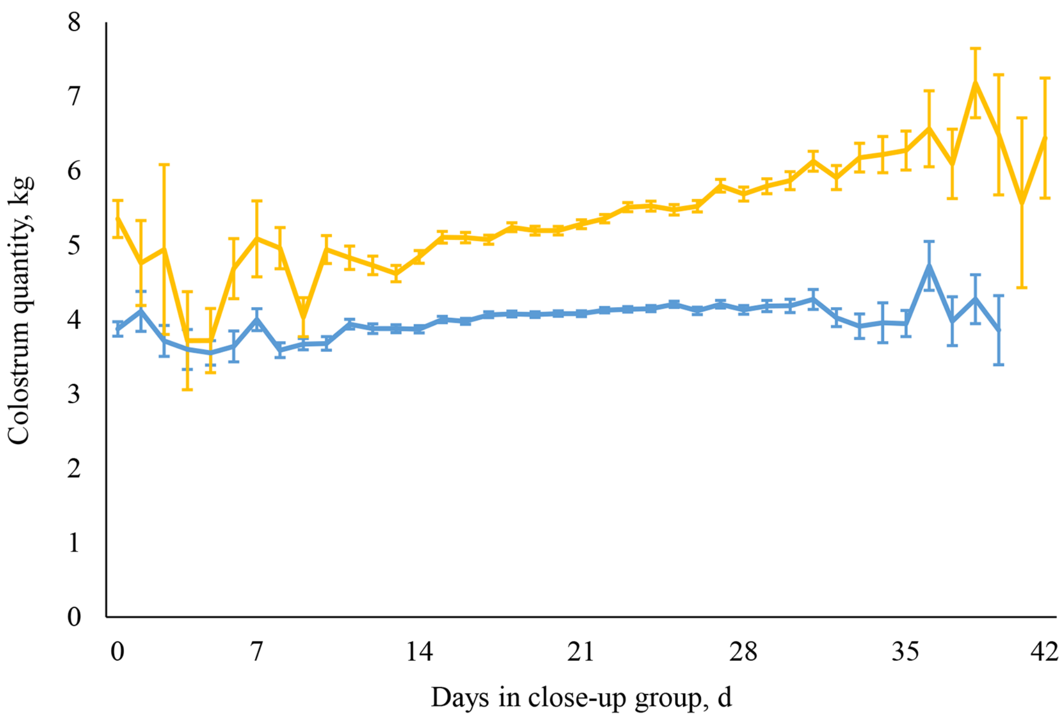

Figure 5. Association of days spent in the close-up pen and of colostrum quantity (kg ± SEM) for 7,567 cows from 1 commercial dairy farm. The blue line represents primiparous cows (n = 2,351). The yellow line represents multiparous cows (n = 5,216). From the final models for primiparous and multiparous cows, predicted colostrum quantity was plotted against month of calving. In primiparous cows, the model contained the following fixed effects: month of calving ($P = 0.004$), sex of the calf ($P = 0.050$), stillbirth ($P = 0.036$), age at first calving ($P = 0.079$), calving ease ($P = 0.054$), gestation length ($P = 0.525$), days spent in the close-up pen ($P = 0.239$). In multiparous cows, the model contained the following fixed effects: month of calving ($P = 0.001$), calving ease ($P = 0.001$), sex of the calf ($P = 0.001$), stillbirth ($P = 0.003$), milk yield in previous lactation ($P = 0.001$), days spent in the far-off group ($P = 0.001$), days spent in the close-up pen ($P = 0.001$), and gestation length ($P = 0.334$).

Table 7. Association of colostrum quality with management-related factors from 1,783 multiparous cows from 1 commercial dairy farm; colostrum quality was assessed using a digital Brix refractometer

Variable	Estimate (% Brix)	SE	95% CI Lower CI	95% CI Upper CI	*P*-value
Intercept	27.19	2.87	21.57	32.82	0.001
Gestation length[1]					
Normal	Referent				
Short	−0.59	0.38	−1.33	0.16	0.122
Long	−0.30	0.29	−0.86	0.26	0.294
Stillbirth					
Alive	Referent				
Dead	1.38	0.81	−0.21	2.98	0.089
Parity					
Lactation 2	Referent				
Lactation 3+	2.76	0.18	2.41	3.11	0.001
Colostrum quantity, kg	−0.27	0.03	−0.32	−0.22	0.001
Previous 305-d milk yield[2]	−0.13	0.05	−0.23	−0.02	0.019
Days in the close-up group	0.03	0.02	−0.01	0.07	0.134
Month of calving					
January	Referent				
February	1.12	0.48	0.18	2.07	0.020
March	−0.11	0.48	−1.05	0.83	0.814
April	0.39	0.47	−0.53	1.31	0.403
May	0.19	0.47	−0.73	1.11	0.686
June	−0.24	0.47	−1.17	0.68	0.606
July	−0.14	0.44	−1.01	0.72	0.746
August	−0.70	0.43	−1.54	0.15	0.106
September	0.78	0.45	−0.10	1.65	0.083
October	0.39	0.44	−0.48	1.26	0.382
November	−0.31	0.46	−1.21	0.59	0.499
December	0.94	0.45	0.06	1.82	0.037

[1]Gestation length was categorized as short (range between 257 and 269 d of gestation), normal (270–280 d), or long (281–293 d).

[2]Milk yield in the previous lactation, ×1,000 kg.

herd (Gavin et al., 2018). These authors speculated that photoperiod length and the associated hormonal patterns (i.e., melatonin and prolactin) were associated with colostrum quantity. The effect of photoperiod on the mammary gland is mediated by light signals in the eye that alter secretion of melatonin by the pineal gland (Hernandez et al., 2017). Long days lead to melatonin suppression, and short days are associated with a rapid increase in melatonin release. It has been shown that a short-day photoperiod in dry cows leads to an increase in milk production by 10% compared with dry cows experiencing a long-day photoperiod (Lacasse et al., 2014). None of those studies assessed colostrum quantity. Therefore, it remains speculative whether the mechanism behind the seasonal pattern of colostrum quantity is comparable to the effect of photoperiod on milk production during lactation.

We found a negative association between colostrum quantity and quality, which has been described previously (Pritchett et al., 1991; Sutter et al., 2019). The reason may be a dilutional effect of colostral IgG. The onset of lactation is associated with a higher secretion of lactose into the udder, which also involves a higher water diffusion, whereas the absolute amount of IgG remains the same (Baumrucker et al., 2010; Morin et al., 2010).

We observed a difference in colostrum quantity and quality among parities, with older cows producing more and better-quality colostrum. The concentration of colostral IgG increases with increasing parity until the fourth lactation (Gulliksen et al., 2008), probably due to longer exposure of older cows to antigens during their life. Several studies have reported that colostrum quality was significantly better among cows in the third lactation than among cows in second lactation (Conneely et al., 2013; Angulo et al., 2015; Sutter et al., 2019). Furthermore, the transfer of IgG into the udder might be linked to more advanced maturation of the mammary gland.

A genetic influence on colostrum quantity may also exist, as has been shown recently in Jersey cattle (Kiser et al., 2019). Interestingly, for Holstein cows, colostrum quantity does not appear to be heritable, but several aspects of colostrum quality may be (Soufleri et al., 2019). More research is needed to confirm these results.

This study was carried out on a single farm; therefore, the results need to be validated with a multicentric study design. Future studies should strive to implement a randomized controlled study design and need to evaluate the effect of short DINCU on colostrum quantity in more detail.

Colostrum quality was assessed using digital Brix refractometry only in a subsample of animals. The gold standard to assess IgG status in colostrum is radial immunodiffusion, despite well-known methodological challenges. In previous studies, the correlation between radial immunodiffusion and digital refractometry ranged from 0.64 to 0.87 (Bielmann et al., 2010; Vandeputte et al., 2014; Bartier et al., 2015; Morrill et al., 2015). Average colostrum quality in our study was 25.1% Brix, 24.7% Brix, and 27.6% Brix for cows in lactation 1, 2, and ≥3, respectively. This is in agreement with another observational study on a large Holstein farm using a digital Brix refractometer (Zentrich et al., 2019; median 23.2%, ranging from 9.3 to 42.0% Brix).

CONCLUSIONS

Using observational data from one farm, we found that colostrum quantity and quality were affected by calving month and some other cow factors. Length of exposure to far-off and close-up diets played a minor role for colostrum production in multiparous cows. Variation in colostrum production across the year might have the potential to affect calf morbidity and mortality through inadequate colostrum supply. Banking high-quality colostrum might be one option to address fluctuations. Future intervention studies using multiple farms need to elucidate whether management of the photoperiod or length of exposure to close-up diets, or both, can help to optimize colostrum production.

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