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Evaluation of factors associated with immunoglobulin G, fat, protein, and lactose concentrations in bovine colostrum and colostrum management practices in grassland-based dairy systems in Northern Ireland

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ABSTRACT

The objectives of this study were to investigate colostrum feeding practices and colostrum quality on commercial grassland-based dairy farms, and to identify factors associated with colostrum quality that could help inform the development of colostrum management protocols. Over 1 yr, background information associated with dairy calvings and colostrum management practices were recorded on 21 commercial dairy farms. Colostrum samples (n = 1,239) were analyzed for fat, protein, lactose, and IgG concentration. A subset was analyzed for somatic cell count and total viable bacteria count. Factors associated with nutritional and IgG concentrations were determined using both univariate and multivariate models. This study found that 51% of calves were administered their first feed of colostrum via esophageal tube, and the majority of calves (80%) were fed >2 L of colostrum at their first feed (mean = 2.9 L, SD = 0.79), at a mean time of 3.2 h (SD 4.36) after birth, but this ranged across farms. The mean colostral fat, protein, and lactose percentages and IgG concentrations were 6.4%, 14%, 2.7%, and 55 mg/mL, respectively. The mean somatic cell count and total viable count were 6.3 $\log_{10}$ and 6.1 $\log_{10}$, respectively. Overall, 44% of colostrum samples contained <50 mg/mL IgG, and almost 81% were in excess of industry guidelines (<100,000 cfu/mL) for bacterial contamination. In the multivariate model, IgG concentration was associated with parity and time from parturition to colostrum collection. The nutritional properties of colostrum were associated with parity, prepartum vaccination, season of calving, and dry cow nutrition. The large variation in colostrum quality found in the current study highlights the importance of routine colostrum testing, and now that factors associated with lower-quality colostrum on grassland-based dairy farms have been identified, producers and advisers are better informed and able to develop risk-based colostrum management protocols.
Key words: colostrum, dairy, immunoglobulin G, immunoglobulin, calves

INTRODUCTION

Colostrum is the first secretion produced from the bovine mammary gland postcalving (Jaster, 2005). It is composed of a range of compounds that are rich in nutritional, antimicrobial, and growth properties and are essential for stimulating cellular and humoral immune defense systems that the newborn calf needs to survive (Blum and Hammon, 2000). Colostrum contains 3 major immunoglobulin isotypes—IgG, IgA, and IgM—and a range of subclasses. Immunoglobulin G antibody is the most abundant isotype found in colostrum; it represents over 75% of the total Ig concentration (Korhonen et al., 2000), and consequently the quality of colostrum is assessed with reference to the concentration of this specific immunoglobulin class. Calves are born with a functional immune system, but it is considered naive until it is fully developed (Franklin et al., 2003). Calves will acquire adequate immunocompetence only through passive transfer of immunoglobulins from colostrum. However, absorption of immunoglobulins ceases 24 h after birth (Stott et al., 1979), and the quality of colostrum can vary between animals due to a number of physical and environmental factors (Quigley and Drewry, 1998). Previous research has determined that colostrum is of satisfactory quality if it contains >50 mg/mL of IgG (McGuirk and Collins, 2004).

Colostrum is the primary source of nutrients to the newborn calf (Blum and Hammon, 2000). Fat, protein,

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and lactose are readily available in colostrum and are necessary as metabolic fuels (NRC, 2001), essential for thermoregulation (Le Dividich et al., 1994; Morrill et al., 2012), and needed for protein synthesis and glucogenesis to ensure homeostasis (Quigley, 2001b). Colostrum is also a valuable source of the vitamins and minerals required for general maintenance functions and vital as cofactors for enzymes (Morrill et al., 2012), with a particular role in the supply of fat-soluble vitamins (Spielman et al., 1946). Bacterial contamination is also a good indicator of colostrum quality: industry guidelines recommend <100,000 cfu/mL in bovine colostrum, primarily to prevent transmission to the calf of a wide range of pathogens that have been identified in previous research (Doyle et al., 1987; Meganck et al., 2014).

Several studies have shown a wide range of variation in colostrum IgG concentration (Gulliksen et al., 2008; Morrill et al., 2012; Conneely et al., 2013), nutritional properties (Kehoe et al., 2007; Zarcula et al., 2010; Morrill et al., 2012), and bacterial properties (Elizondo-Salazar and Heinrichs, 2009a; Morrill et al., 2012) but no study has explored the variation in these properties on commercial grassland-based dairy farms over an extended period of time and investigated how animal and management factors may influence colostrum quality in this type of production system. The objectives of the current study were to investigate colostrum feeding practices and colostrum quality on commercial grassland-based dairy farms over a 1-yr period, and to identify factors associated with colostrum quality that would help inform the development of colostrum management protocols.

MATERIALS AND METHODS

Selection and Description of Herds

Commercial dairy farms (n = 21) geographically spread across Northern Ireland participated in this study between February 2013 and February 2014; herd size ranged from 85 to 425 lactating dairy cows. Producers were required to collect a colostrum sample from every cow as soon as possible after calving, demonstrate excellent record keeping, maintain a milk record, and show a high level of commitment to the research program. Colostrum feeding practices (Table 1) of the offspring (n = 1,177) of these cows were also monitored.

Data Collection and Description

Producers completed data collection sheets for each animal. Data collected included herd size; breed of cow; parity; estimated BW of cow precalving; cow immunization regimen; length of dry period; dry cow nutrition; season of calving; BCS at calving; calving difficulty score; colostrum yield; colostrum management, including quantity fed at first and second feed; duration of colostrum feeding; feeding method; and time interval from calving to sample collection. All producers were involved in a milk-recording scheme, and access was granted to obtain individual animal data on previous 305-d milk yield.

Sample Collection

The farmer collected maternal colostrum (250 mL, mixed thoroughly) from each animal at the time of first milking after parturition. Samples were labeled with farm identification number, dam freeze brand number, and date of calving. Samples were stored in a refrigerator on the farm and collected within 3 d for nutritional and IgG analysis or within 1 d for bacterial analysis. All samples were transported in a chilled container to the Agri-Food and Biosciences Institute, Hillsborough, where they were subsampled into 10 aliquots of 25 mL. Samples for bacterial analysis [SCC and total viable count (**TVC**)] were transported in a chilled container to the laboratory (Agri-Food and Biosciences Institute, Newforge) for immediate analysis. Samples for fat, lactose, and protein concentration analysis were stored in a refrigerator. The remaining aliquots (5 × 25 mL) were stored at −20°C for later IgG analysis.

Determination of Colostrum Quality

Nutritional and Bacterial Composition. Colostrum fat, protein, and lactose concentration were de-

Table 1. Colostrum feeding practices carried out on commercial dairy farms across Northern Ireland

Item	Observations (no.)	Mean	Lower quartile	Upper quartile	SD
Birth weight (kg)	1,177	40.9	35.0	45.0	8.39
Volume of colostrum fed at first feed (L)	883	2.9	2.5	3.5	0.79
Time from calving to first feed (h)	841	3.2	1.0	4.0	4.36
Length of time spent with dam (h)	1,066	12.5	3.0	20.0	11.24
Length of time colostrum fed (d)	427	3.2	3.0	4.0	1.24

termined using the Foss MilkoScan FT120 (Foss, Warrington, UK). Only samples that could be processed within 24 h of calving were analyzed for TVC (n = 119) and SCC (n = 117). We determined TVC using the pour plate method (Clark, 1967) and counted colonies using a Stuart colony counter (Bibby Scientific Ltd., Staffordshire, UK). We analyzed SCC using the Delta Somascope Lactoscope method (Delta Instruments, Drachten, the Netherlands) as described by Hanuš et al. (2014).

Immunoglobulin G. Colostrum samples were removed from a −20°C freezer and thawed in a fridge at 4°C overnight. The IgG concentration was then measured using an ELISA kit for bovine IgG from Bio-X Diagnostics (Jemelle, Belgium). The test was performed on colostrum that had the fat removed though centrifuging before freezing. 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 as per the manufacturer's instructions (BioX, Jemelle, Belgium). The samples were diluted in PBS, and the diluted samples were added to the test plate and incubated at 21°C for 1 h. The test plate was washed 3 times with the wash buffer, and then chromogen solution (100 μL) was added to each well and incubated away from light for approximately 10 min. Stop solution (50 μL) was then added to each well. The optical densities were recorded using a microplate spectrophotometer with a 450-nm filter (Tecan, Magellan, Switzerland), and 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 above or below the range of the standard reference curve was retested after further dilution according to the test kit recommendations. An interassay coefficient of variation of <15% was observed.

Statistical Analysis

We carried out univariate analyses to investigate the relationship between each response variable and each explanatory variable in turn (both continuous and categorical), using a linear mixed model methodology and the method of REML in GenStat (16th ed.; VSN International, Hemel Hempstead,, UK). Farm was fitted as a random effect, and the explanatory variables as fixed effects. We tested the following variables for association with IgG, fat, protein, and lactose concentration: herd size, season of calving, calving difficulty score (1 to 5), calving location, breed, parity, estimated live weight of cow precalving (kg), BCS at calving (1 to 5 scale), length of dry period (wk), first colostrum yield (L), second colostrum yield (L), immunization regimen (bovine viral diarrhea, leptospirosis, *Salmonella*, *Escherichia coli*, rotavirus, coronavirus, and clostridial disease), dry cow nutrition, description of supplements offered to dry cows, time interval from calving to colostrum collection (h), colostral TVC (cfu/mL), colostral SCC (10^3/mL), and previous 305-d milk yield (kg). For each response variable, we developed a multivariate model to examine more complex associations, again using the linear mixed model methodology with farm as a random effect in all models. Any explanatory variable that had a P-value <0.15 from the REML analysis and a minimum of 900 observations was considered a candidate for the multivariate models. The multivariate analysis was also restricted to a subset of units that had a non-missing value for all variables. In each case, we used backward elimination to establish the multivariate model. At each step, the least significant variable was removed from the model, and the procedure was terminated when all remaining variables were significant at $P < 0.05$.

We converted a range of variables into parametric and categorical variables for statistical analysis. Calving difficulty was indicated by group, where 1 = unobserved/unassisted, 2 = assisted without calving aid, and 3 to 5 = aided by calving aid or vet. Breed of cow was indicated as follows: 1 = Holstein, 2 = Friesian, 3 = Ayrshire, 4 = crossbreed (Jersey crossbreed, Swedish Red crossbreed, and a single Jersey cow grouped with Jersey crossbreeds for analytical purposes). Animals were also grouped by parity number: 1, 2, 3, 4, and ≥5. Season of calving was classified as follows: spring (March, April, and May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February). Immunizations were recorded as yes/no answers to whether the dry cow had received a certain vaccine or not. Likewise, dry cow diet was recorded as yes/no answers according to feed type (i.e., grass silage, concentrate, grazed grass, and straw). Length of dry period was classified as follows: <8, 8 to <12, 12 to <16 and ≥16 wk. Time interval from calving to colostrum collection was grouped as follows: <0.5, <1, <3, 3 to <6, 6 to <12, and ≥12 h. Cow BCS was determined using a scale of 1 to 5, where 1 was extremely thin and 5 was extremely fat (DEFRA, 2011).

RESULTS

Variation in Colostrum Quality

Concentration of IgG showed large variations between cows and farms (Figure 1), ranging from 1.4 to 204 mg/

Table 2. Immunological, nutritional, and bacterial analysis of bovine colostrum across 21 commercial dairy herds in Northern Ireland

Variable	Observations (no.)	Mean	Lower quartile	Upper quartile	SD
IgG (mg/mL)	1,239	55.0	38.1	67.8	25.75
Fat (%)	1,226	6.4	4.1	8.3	3.32
Protein (%)	1,226	14.0	11.6	16.6	3.67
Lactose (%)	1,226	2.7	2.3	3.1	0.55
SCC (log_{10})	117	6.3	6.0	6.5	0.41
TVC[1] (log_{10})	119	6.1	5.4	7.2	1.39

[1]TVC = total viable count.

mL IgG, with a mean concentration of 55 ± 25.5 mg/mL; 56% of the samples contained a minimum of 50 mg/mL IgG. We observed that 68% of farms produced an average colostral IgG concentration >50 mg/mL. The mean fat, protein, lactose, SCC, and TVC concentrations in colostrum were 6.5% (SD 3.3), 14% (SD 3.7), 2.7% (SD 0.6), 6.3 log_{10}, and 6.1 log_{10}, respectively (Table 2).

All variables in the survey were initially tested for association with fat, protein, lactose, and IgG concentration in colostrum. Results shown in Tables 2, 3, 4, and 5 were all independently associated with fat, protein, lactose, or IgG concentration in the univariate and multivariate analyses.

Factors Associated with Colostrum Quality in Univariate Analysis

Immunoglobulin G. Cows calving in the winter months produced colostrum with greater ($P = 0.002$) IgG concentration than cows calving in the autumn and spring months (Table 3). Cows with a dry period of 8 to <12 and ≥16 wk had higher IgG concentrations than cows with a dry period of less than 8 wk ($P < 0.001$; Table 3). Cows immunized against salmonella (58.7 mg/mL) had greater ($P = 0.02$) IgG concentrations than nonimmunized cows (51.1 mg/mL). Previous lactation 305-d milk yield had a significant effect on colostral IgG concentration ($P = 0.003$); as milk yield

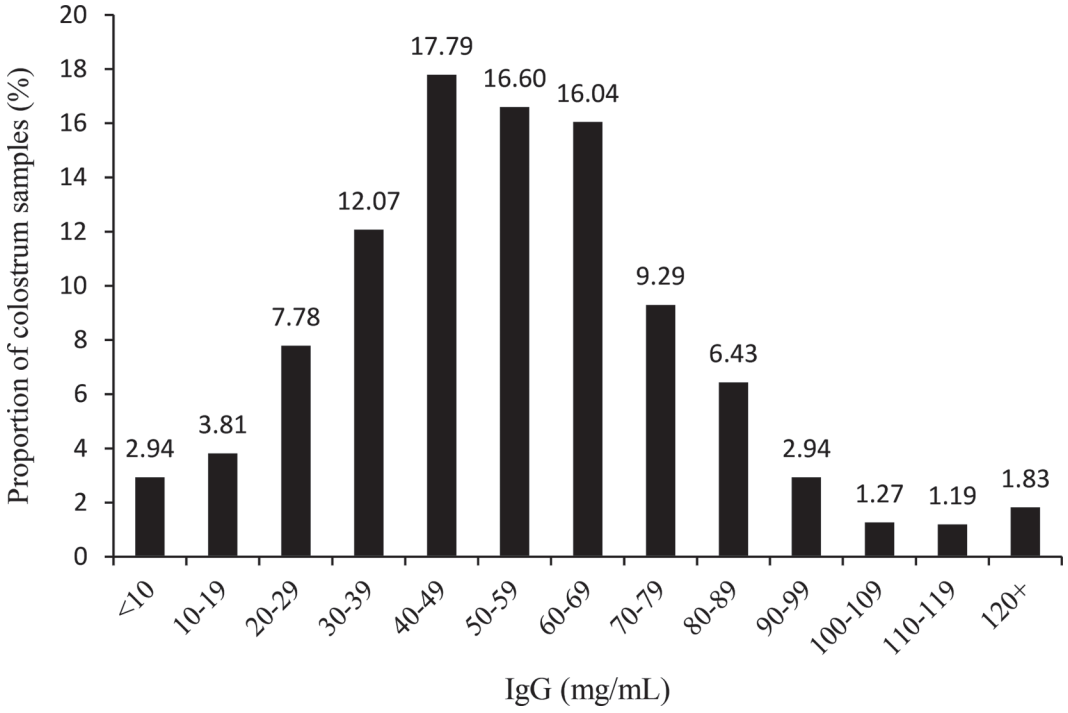

Figure 1. The distribution of IgG concentration (mg/mL) in colostrum samples from 1,239 dairy cows across Northern Ireland sampled between February 2013 and February 2014.

increased, the IgG concentration also increased. We observed no differences ($P > 0.05$) in IgG concentration between animals that were treated with a dry cow tube and those treated with a combination of dry cow tube and teat sealant at the drying off stage.

Nutritional Concentration. Colostral fat concentration was greatest in spring-calving cows ($P < 0.05$), compared with cows calving in the summer, autumn, or winter (Table 3). Fat concentration was also greater ($P = 0.03$) in colostrum from cows that were immunized against leptospirosis (6.8%) than from nonimmunized cows (5.9%). Colostral protein concentration was greater in cows with a dry period length of ≥16 wk than in cows that were dry for less than 8 wk ($P < 0.001$) (Table 3). Cows fed concentrates during the 0 to 3 wk period before parturition had a greater ($P = 0.02$) colostral fat concentration than non-concentrate-fed cows (Table 4). Cows vaccinated against infectious bovine rhinotracheitis (13.4%) had lower colostral protein concentration ($P = 0.04$) than nonvaccinated cows (14.4%). Calculated previous 305 d milk yield had a significant effect on colostral protein concentration ($P < 0.001$); as milk yield increased, protein concentration also increased. Colostral lactose concentration was greater ($P = 0.03$) in cows that were immunized against infectious bovine rhinotracheitis (2.8%) than in nonimmunized cows (2.7%).

Factors Associated with Colostrum Quality in Multivariate Analysis

Immunoglobulin G. Parity was associated with colostral IgG concentration ($P < 0.001$): cows with a parity of 5+ had greater colostral IgG concentration than lower-parity animals (Table 5). Colostral IgG concentration was significantly lower ($P = 0.01$) for samples collected later than 12 h after parturition (Table 5). Length of dry period, dry cow nutrition, estimated BW gain precalving, and season of calving had no effect ($P > 0.05$) on colostral IgG concentration.

Protein. Parity 5+ animals had the greatest colostral protein concentration compared with cows in their first and second parity (Table 5). Cows fed grass silage at 4 to 6 wk prepartum produced greater protein concentration than cows that were fed grazed grass ($P = 0.001$). Cows fed concentrates 4 to 6 wk prepartum produced lower protein concentration than cows that were not fed concentrates ($P < 0.001$). Colostrum

Table 3. Univariate analysis of physical variables associated with colostrum quality across farms in Northern Ireland

	Univariate analysis				*P*-value			
Variable	IgG (mg/mL)	Fat (%)	Protein (%)	Lactose (%)	IgG	Fat	Protein	Lactose
Farm	54.9	6.5	14.0	2.7	<0.001	<0.001	<0.001	<0.001
Herd size	52.4	6.7	13.5	2.8	0.63	0.70	0.70	0.64
Season of calving					0.002	<0.001	0.002	0.004
Autumn	52.1[a]	6.2[b]	13.4[a]	2.8[a]				
Spring	53.3[a]	7.1[a]	13.5[a]	2.8[a]				
Summer	52.3[ab]	5.9[b]	13.6[ab]	2.7[ab]				
Winter	58.9[b]	6.3[b]	14.4[b]	2.7[b]				
Parity					<0.001	0.003	<0.001	0.002
1	49.3[a]	7.3[b]	12.7[a]	2.8[b]				
2	50.1[a]	6.3[a]	13.0[a]	2.8[b]				
3	54.3[b]	6.5[a]	14.0[b]	2.7[b]				
4	55.5[b]	6.3[a]	14.3[b]	2.7[ab]				
5+	65.9[c]	6.3[a]	15.1[c]	2.6[a]				
Dry period (wk)					<0.001	<0.001	<0.001	0.005
<8	52.4[a]	5.6[a]	13.8[a]	2.8[a]				
8 to <12	57.2[b]	6.5[b]	14.0[a]	2.7[a]				
12 to <16	57.1[ab]	7.0[bc]	13.9[a]	2.7[a]				
≥16	61.2[b]	7.6[c]	15.2[b]	2.5[b]				
Calculated 305-d milk yield[1]	41.3	6.5	11.3	2.9	0.003	0.85	<0.001	0.09
First milk yield (kg)	51.3	6.5	13.4	2.8	0.24	0.39	0.33	0.79
Time to colostrum collection (h)					<0.001	0.23	<0.001	<0.001
<0.5	58.7[a]	7.0	14.8[a]	2.6[a]				
<1	56.4[a]	6.0	14.1[ab]	2.7[ab]				
<3	56.2[a]	6.6	14.1[ab]	2.7[ab]				
3–6	55.4[a]	6.5	14.0[ab]	2.7[ab]				
6–12	54.1[a]	6.9	13.8[b]	2.8[b]				
12–24	45.9[b]	6.6	12.5[c]	2.9[c]				

[a–c]Means within a column with different superscript letters differ ($P < 0.05$).

[1]Calculated previous 305-d milk yield.

Table 4. Summary of nutritional variables associated with colostrum quality across farms in Northern Ireland

		Univariate analysis				*P*-value[1]			
Variable	No. of samples	IgG (mg/mL)	Fat (%)	Protein (%)	Lactose (%)	IgG	Fat	Protein	Lactose
0–3 wk precalving									
Grass silage						0.12	0.39	0.60	0.49
Yes	1,189	54.7	6.6	13.7	2.7				
No	96	49.6	6.2	13.5	2.8				
Concentrates						0.39	0.02	0.22	0.27
Yes	796	53.5	6.8	13.6	2.8				
No	489	55.9	6.0	14.1	2.7				
Straw						0.37	0.06	0.49	0.59
Yes	690	55.1	6.8	13.6	2.7				
No	595	52.8	6.2	13.9	2.8				
4–6 wk precalving									
Grass silage						0.83	0.02	0.14	0.53
Yes	914	54.4	6.7	13.8	2.7				
No	371	53.9	6.1	13.4	2.8				
Concentrates						0.34	0.60	0.05	0.05
Yes	295	52.7	6.7	13.3	2.8				
No	990	54.9	6.5	13.9	2.7				
Straw						0.51	0.002	0.88	0.50
Yes	358	53.3	7.1	13.7	2.8				
No	927	54.8	6.2	13.7	2.7				
7–9 wk precalving									
Grass silage						0.95	0.007	0.49	0.25
Yes	761	54.2	6.9	13.8	2.7				
No	524	54.3	6.2	13.6	2.8				
Concentrates						0.96	0.13	0.61	0.23
Yes	222	54.1	6.9	13.5	2.8				
No	1,063	54.3	6.4	13.8	2.7				
Straw						0.39	0.001	0.22	0.37
Yes	273	52.7	7.3	13.4	2.8				
No	1,012	54.9	6.2	13.8	2.7				

[1]If *P*-value was <0.15, it was included in the multivariate analysis.

protein concentration was highest ($P = 0.02$) in the winter months compared with other seasons (Table 5). Colostral protein concentration was lower ($P = 0.001$) for samples collected later than 12 h after parturition. Cows that were not immunized against infectious bovine rhinotracheitis produced higher protein concentration ($P = 0.03$) than cows that were immunized (Table 5).

Fat. Cows in their first parity had a higher ($P = 0.03$) colostral fat concentration than higher-parity cows (Table 6). Cows with a dry period of 8 to 12 wk had higher fat concentration than cows with a dry period of less than 8 wk, but cows with a dry period of 16 wk or longer had a higher ($P < 0.001$) fat concentration than cows with a dry period of less than 12 wk. Colostrum fat concentration was higher ($P = 0.03$) in cows that had been immunized against leptospirosis (7.0%), compared with nonimmunized cows (6.1%). Dry cow nutrition showed a significant association with colostral fat concentration; cows fed grass silage had a higher ($P < 0.001$) fat concentration than cows fed grazed grass. Time from calving to colostrum collection had no effect ($P > 0.05$) on the colostral fat concentration produced at first milking after parturition (Table 6).

Lactose. Colostral lactose concentration decreased as parity increased; we observed the lowest lactose concentration in parity 5+ cows (Table 6). Cows with a dry period length of 16 wk or longer had superior ($P = 0.007$) lactose concentration compared to cows with a dry period length less than 16 wk. We observed the greatest lactose concentration in colostrum from cows that calved in the spring (Table 6). Lactose concentration was greater ($P < 0.001$) in samples collected later than 12 h after parturition.

Farm Management Practices

The mean parity of the cows involved in this survey was 3, ranging from 1 to 14. The mean BW of the cows during the precalving period was 609 kg (SD 70.1). The mean BCS of the cows was 2.9 ± 0.5 at calving (range 1.65–4.5). Almost 85% of colostrum samples obtained were from Holstein and Friesian cows, and the rest were

from Ayrshire and crossbreeds. The management of dry cows differed across farms in terms of calving season, immunization regimen, feeding, and housing. The mean birth weight of calves born from cows in this study was 40.9 ± 8.4 kg.

On-farm colostrum management practices, including volume, timing, and duration of feeding colostrum to calves are shown in Table 1. Almost 52% of calves were given their first feed of colostrum via esophageal tube, 28% were left to suckle the dam, 17% were bottle-fed, and the remaining 3% were fed using a combination of these methods. The majority of calves (80%) were fed >2 L of colostrum at their first feed [mean 2.9 L (SD 0.79)], and on average calves were fed 3.2 h (SD 4.36) after birth.

DISCUSSION

Studies conducted in the United States have shown large variability in colostrum IgG concentration between individual dairy cows and farms (Kehoe et al., 2007; Morrill et al., 2012). Currently, no data are avail-

Table 5. Factors associated with colostral IgG (mg/mL) and protein concentration (%) in multivariate analysis

		Multivariate analysis		
Factor	No. of samples	Composition (mg/mL, %)	SED[1]	*P*-value
IgG	1,215	50.8[a]	2.7	<0.001
Parity		52.0[a]		
1		55.3[a]		
2		55.3[a]		
3		68.0[b]		
4				
5+		59.0[b]	3.2	0.01
Time to colostrum collection (h)	1,172	60.2[b]		
<0.5		56.5[b]		
<1		55.9[b]		
<3		57.3[b]		
3–6		48.8[a]		
6–12				
12–24				
Protein				
Parity	1,198		0.3	<0.001
1		12.5[a]		
2		13.0[a]		
3		13.9[b]		
4		13.9[b]		
5+		15.0[c]		
Season of calving	1,222		0.4	0.02
Autumn		13.5[a]		
Spring		13.2[a]		
Summer		13.9[ab]		
Winter		14.1[b]		
Dam vaccinated against IBR[2]	1,222			
Yes		14.2[a]	0.4	0.03
No		13.1[b]		
Grass silage at 4 to 6 wk precalving	1,222		0.3	0.001
Yes		14.2[a]		
No		13.1[b]		
Concentrate 4 to 6 wk precalving	1,222		0.3	<0.001
Yes		13.0[a]		
No		14.4[b]		
Time to colostrum collection[3] (h)	1,157		0.4	0.001
<0.5		14.2[b]		
<1		14.0[b]		
<3		13.7[b]		
3 to 6		13.7[b]		
6 to 12		14.0[b]		
12 to 24		12.5[a]		

[a–c]Means within a column with different superscript letters differ ($P < 0.05$).

[1]SED = SE of the difference.

[2]IBR = infectious bovine rhinotracheitis.

[3]Time interval from birth to colostrum collection.

able to show the variation in colostrum and factors associated with colostrum quality for dairy herds in Northern Ireland, which are typically grassland-based systems. Although this study is specific to dairy farms in Northern Ireland, we expect that the findings will be relevant to grassland-based systems in other parts of the world. This paper provides data on the nutritional, immunological, and bacterial composition of colostrum, detailing how certain physical and managerial factors are associated with colostrum quality and outlining colostrum management practices in grassland-based dairy systems.

In the univariate model of this study, we found that individual farm had an effect on colostrum quality in terms of IgG, fat, protein, and lactose concentration. This finding indicated that different management practices on different farms had a significant effect on colostrum quality and confirmed that colostrum quality varies not only between cows but also between herds.

Colostrum IgG Concentration

The variation in colostral IgG concentration observed across all 21 farms (Figure 1) was similar to previous

Table 6. Factors associated with colostral fat and lactose concentration in multivariate analysis

		Multivariate analysis		
Factor	No. of samples	Composition (%)	SED[1]	*P*-value
Fat				
Parity	1,198		0.4	0.03
1		7.9[c]		
2		6.4[ab]		
3		6.1[ab]		
4		6.7[b]		
5+		5.7[a]		
Dry period (wk)	1,170		0.5	<0.001
<8		5.7[a]		
8 to <12		6.8[b]		
12 to <16		7.3[ab]		
≥16		7.2[bc]		
Vaccinated against leptospirosis	1,222		0.4	0.03
Yes		7.0[a]		
No		6.1[b]		
Grass silage fed 7 to 9 wk precalving	1,222		0.3	<0.001
Yes		7.1[a]		
No		6.0[b]		
Lactose				
Season of calving	1,222		0.06	0.01
Autumn		2.7[ab]		
Spring		2.8[b]		
Summer		2.6[a]		
Winter		2.6[a]		
Parity	1,198		0.05	0.002
1		2.7[b]		
2		2.7[b]		
3		2.7[b]		
4		2.7[ab]		
5+		2.6[a]		
Dry period (wk)	1,170		0.07	0.007
<8		2.8[b]		
8 to <12		2.7[b]		
12 to <16		2.7[b]		
≥16		2.5[a]		
Time to colostrum collection[2] (h)	1,157		0.06	<0.001
<0.5		2.5[a]		
<1		2.6[a]		
<3		2.6[a]		
3–6		2.7[a]		
6–12		2.7[a]		
12–24		2.8[b]		

[a–c]Means within a column with different superscript letters differ ($P < 0.05$).

[1]SED = SE of the difference.

[2]Time interval from birth until colostrum collection.

reports (Gulliksen et al., 2008; Morrill et al., 2012). Of colostrum samples in this current study, 44% contained <50 mg/mL IgG, and were therefore deemed unsatisfactory in terms of quality. Consequently, a sizable proportion of newborn calves from these herds were at increased risk of receiving colostrum of inadequate quality and experiencing failure of passive transfer (**FPT**). Taking into account the variations in IgG concentration, it may be relevant to consider how much colostrum a calf requires to achieve apparent passive transfer (**APT**). A recent study has suggested an intake of 150 to 200 g IgG (Chigerwe et al., 2012) to achieve APT. Using the equation described by Quigley (2001a), we can determine how much colostrum is required to meet the needs of the calf. This involves making assumptions in relation to BW (40 kg), apparent efficiency of absorption (26.4%), plasma volume (9% of BW), and plasma concentration (10 mg/mL). If calves were fed the historical recommendation of 2 L of colostrum, a colostral IgG concentration of 69 mg/mL would be required to achieve APT. In the current study, 61% of calves would have experienced FPT if fed 2 L of colostrum. On average, in the current study, calves were fed 2.9 L of colostrum for their first feed. Calves fed 2.9 L of colostrum containing at least 50 mg/mL IgG would have achieved APT, but 39% of calves would have experienced FPT if fed this volume at their first feed based on the colostrum IgG concentration. To manage this risk, feeding 4 L of colostrum would result in only 19% of calves experiencing FPT. A number of management practices can have a positive influence on the colostrum quality produced, but it is unlikely that calves from cows that produce colostrum with IgG below 20 to 29 mg/mL will achieve APT, independent of management practice.

As reported by others (Tyler et al., 1999; Morrill et al., 2012; Conneely et al., 2013), we found that increased parity positively influenced colostrum IgG concentration. However, on average, primiparous dams produced colostrum of adequate IgG concentration (50.8 mg/mL), and 44% of animals in their first and second parity produced high-quality colostrum (>50 mg/mL IgG), at an average yield of 5.4 L at the first milking postpartum. Consequently, 72% of the cows in their first and second parity produced an adequate IgG yield to provide the calf with a minimum of 150 g of IgG to achieve APT. This indicates that primiparous colostrum should not be automatically discarded and should be tested for IgG concentration. This study also showed that 73% of colostrum samples from cows in their fifth or greater parity were deemed high quality. Previous research has suggested that this is related to increased antigenic exposure in older cows, so that a greater array of antibodies are transferred from bovine serum to the colostrum (Donovan et al., 1986). In addition, the development of the mammary gland may have a role to play: younger cows may not be fully developed, and the transport of IgG into the mammary gland may be reduced (Devery-Pocius and Larson, 1983).

In agreement with others (Annen et al., 2004; Rastani et al., 2005; Mayasari et al., 2015), we found that a short dry period had a negative effect on IgG concentration in the univariate analysis. However, in the multivariate model, this association did not persist, in agreement with previous research (Watters et al., 2008; Shoshani et al., 2014). Overall, it is likely that dry period length does not have a major effect on IgG concentration unless the cow has insufficient time to allow for colostrogenesis, which occurs during the last few weeks of pregnancy.

Because the colostrogenesis process begins several weeks before parturition (Brandon et al., 1971; Godden, 2008), it was logical to presuppose that maternal nutrition during the dry period might have an effect on colostral Ig concentration. However, in agreement with others, we observed no relationship between dry cow nutrition and colostral IgG concentration (Blecha et al., 1981; Burton et al., 1984; Hough et al., 1990). A limitation of the current study was the restricted range of feed types offered to the cows, with the majority of dairy producers offering nonlactating cows either grass silage or grazed grass.

The interval from parturition to colostrum collection was negatively associated with colostrum IgG, in agreement with previous studies (Moore et al., 2005; Morin et al., 2010; Conneely et al., 2013). Therefore, reducing the time from calving to colostrum collection is a simple way for producers to positively influence the quality of colostrum fed to their calves and reduce the risk of FPT. Colostrum feeding method has been found to affect FPT; Besser et al. (1991) reported that the highest rate of FPT occurred when the calf was left to nurse the dam (61.4%), compared with bottle-feeding (19.3%) and using an esophageal tube (10.8%). In addition, Vasseur et al. (2010) found that 22% of Holstein calves 2 to 6 h old were unable to consume 2 L of colostrum from bottle-feeding. In this study, we observed that over 25% of calves were left to suckle the dam and 17% were bottle-fed; to increase APT in calves, it may be necessary for farmers to use esophageal tubes.

Previous research found that feeding calves colostrum that was high in bacteria reduced the apparent efficiency of absorption and resulted in calves achieving a lower serum IgG concentration at 24 h after birth (Elizondo-Salazar and Heinrichs, 2009b). In agreement with others (Fecteau et al., 2002; Swan et al., 2007), we found extremely high levels of bacterial contamination in the colostrum samples. It has been suggested

that the bacteriological quality of maternal colostrum is influenced by storage method and management practices (Stewart et al., 2005; Houser et al., 2008). We speculate that this may be the reason for the high bacterial contamination in this study. To avoid the risk of feeding pathogenic bacteria to naive calves best practice guidelines must be in place for producers to help prevent bacterial contamination of colostrum. One such practice is heat-treating, which has been shown by Elizondo-Salazar et al. (2010) to reduce bacteria levels: heating colostrum at 60°C for 30 or 60 min reduced the bacterial load.

Nutritional Components

Few studies have examined variation in the nutritional components of bovine colostrum (Kehoe et al., 2007; Morrill et al., 2012), and no data are available on dairy production systems in Northern Ireland. As suggested by Quigley et al. (2001b), calves fed colostrum that is low in protein may have a reduced ability to achieve glucogenesis during the first 24 h of life. This metabolic process is essential in neonatal calves to produce glucose (Hammon et al., 2013), which is necessary to provide a source of energy for the brain (Zierler, 1999). Similar to IgG concentration, colostral protein concentration improved as parity increased, but this was expected, because IgG is a protein (Parrish et al., 1950). Cows that calved in the winter produced 9 g/L more protein than spring-calving cows, but several factors tend to differ across seasons, including diet (Heck et al., 2009; Yasmin et al., 2012), housing, and climate (Nardone et al., 1997; Cabral et al., 2016). Dams immunized against infectious bovine rhinotracheitis before calving produced 11 g/L more protein than nonvaccinated cows. It is currently unknown why immunization is associated with the nutritional components of colostrum; this points to a need for further research.

We found that several management practices affected the level of fat produced in colostrum, including the fact that cows dry for longer than 16 wk produced 15 g/L more fat than cows dry for less than 8 wk. In comparison, Shoshani et al. (2014) reported that cows dry for 60 d had increased fat levels in their milk during the first month of lactation cows that were dry for only 40 d. In our study, heifers produced 22 g/L more fat than cows in parity 5+, in agreement with Morrill et al. (2012). Limited research has been conducted into the effect of dry cow nutrition on colostrum nutritional properties. In the current study, we found a relationship between colostral fat concentration and cow diet at 7 to 9 wk before parturition. Lerch et al. (2015) found that a high-energy/high-protein diet may result in the mobilization of body reserves and affect colostral nutritional composition.

Lactose is the primary carbohydrate present in colostrum and milk, and the major role of lactose is to regulate water and as a result osmotic content (Davies et al., 1983; Jenness, 1985). In this study, we found that colostrum lactose concentration was negatively correlated ($P < 0.001$) with IgG concentration ($R^2 = 0.34$). Thus, increased lactose concentration may have a dilution effect and may result in reduced IgG concentration. This was likely related to the increase in lactose synthesis that occurs with time after parturition and related to a water dilution effect lowering IgG concentration.

CONCLUSIONS

In the current study, colostrum quality in grassland-based dairy systems was highly variable in its nutritional, immunological, and bacterial composition. Colostrum IgG concentration averaged 55 mg/mL, with increased parity and sample collection earlier after parturition associated with the greatest IgG concentrations. Parity, prepartum vaccination, season of calving, and dry cow nutrition all affected the nutritional composition of colostrum. The results of this study also highlighted significant levels of bacterial contamination in colostrum, much greater than industry guidelines and an area for further investigation. Improvements should be made in colostrum feeding practices to reduce the number of calves left to suckle the dam and to feed a greater quantity of colostrum as soon as possible after birth. Because APT of immunity to the newborn is associated with the timing, volume, and quality of the colostrum offered to the calf, the findings from this study indicate the importance of measuring colostrum quality and highlight risk factors that dairy producers and advisers should consider when drawing up best practice management guidelines for colostrum management.

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