Factors associated with the concentration of immunoglobulin G in the colostrum of dairy cows

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Transfer of sufficient immunoglobulin G (IgG) to the neonatal calf via colostrum is vital to provide the calf with immunological protection and resistance against disease. The objective of the present study was to determine the factors associated with both colostral IgG concentration and colostral weight in Irish dairy cows. Fresh colostrum samples were collected from 704 dairy cows of varying breed and parity from four Irish research farms between January and December 2011; colostral weight was recorded and the IgG concentration was determined using an ELISA method. The mean IgG concentration in the colostrum was 112 g/l (s.d. = 51 g/l) and ranged from 13 to 256 g/l. In total, 96% of the samples in this study contained >50 g/l IgG, which is considered to be indicative of high-quality colostrum. Mean colostral weight was 6.7 kg (s.d. = 3.6 kg) with a range of 0.1 to 24 kg. Factors associated with both colostral IgG concentration and colostral weight were determined using a fixed effects multiple regression model. Parity, time interval from calving to next milking, month of calving, colostral weight and herd were all independently associated with IgG concentration. IgG concentration decreased (P < 0.01) by 1.7 (s.e. = 0.6) g/l per kg increase in the colostral weight. Older parity cows, cows that had a shorter time interval from calving to milking, and cows that calved earlier in spring or in the autumn produced colostrum with higher IgG concentration. Parity (P < 0.001), time interval from calving to milking (P < 0.01), weight of the calf at birth (P < 0.05), colostral IgG concentration (P < 0.01) and herd were all independently associated with colostral weight at the first milking. Younger parity cows, cows milked earlier post-calving, and cows with lighter calves produced less colostrum. In general, colostrum quality of cows in this study was higher than in many previous studies; possible reasons include use of a relatively low-yielding cow type that produces low weight of colostrum, short calving to colostrum collection interval and grass-based nutritional management. The results of this study indicate that colostral IgG concentration can be maximised by reducing the time interval between calving and collection of colostrum.

Keywords: colostrum, dairy, cow, milk, immunoglobulins

Implications

The objective of the present study was to determine the factors associated with both colostral quality and colostral weight in dairy cows in a pasture-based system. The results provide useful information to farmers to enable them to maximise the efficiency of their colostrum management programmes and improve calf health. Farmers should collect colostrum from cows as soon as possible after calving, be aware that if a large quantity of colostrum is produced it is likely to be of lower quality, and that cows calving late in spring may have reduced colostrum quality. In this study, there was no requirement to discard colostrum from heifers because of inferior quality.

Introduction

Colostrum is the first milk secreted after parturition (Park and Jacobson, 1993) and contains many substances that are important to the health of the neonate including immunoglobulins, cytokines, nutritional elements and growth factors (McGuirk and Collins, 2004). Immunoglobulins are plasma proteins, produced by lymphocytes in the mammalian bloodstream in response to foreign antigens, which play a crucial role in the immune mechanism to defend the body from pathogenic organisms and provide resistance to disease (Park and Jacobson, 1993). Five classes of immunoglobulins exist: IgM, IgG, IgA, IgD and IgE (Butler, 1969). Immunoglobulin G (IgG), which comprises 85% to 90% of the total immunoglobulins present in bovine colostrum (Larson et al., 1980), is transferred from the blood across the mammary epithelium,
accumulating in the mammary gland before parturition. Although colostrum contains a wide spectrum of other important components, the relationship between IgG concentrations and calf health is best understood; thus, the concentration of IgG in colostrum is considered the hallmark for evaluating colostrum quality (Godden, 2008). Good-quality bovine colostrum is defined as colostrum that has an IgG concentration of >50 g/l (McGuirk and Collins, 2004).

In 2011, the reported official national calf mortality rate in Ireland was 4.6% (calves dead in the first 12 months of life excluding stillbirths: AIM Statistics Report, 2011). This compares unfavourably with mortality rates reported for other European countries; Gulliksen et al. (2009) reported a lower mortality rate of 3.7% for calves in the same age group in Norway. Presently, there is a lack of published data on the colostrum quality of Irish dairy cows, and as such it is not known whether production of colostrum with a low IgG concentration may be a contributory factor to the high calf mortality rate in Ireland. Ensuring that the neonatal calf receives sufficient high-quality colostrum as soon as possible after birth is widely recognised as being crucial to the animal’s health and well-being. The many unfavourable consequences of insufficient absorption of IgG by the neonatal calf (e.g. increased risk of disease and death, slower growth rates and a reduction in long-term productivity) are well documented (Robison et al., 1988; DeNise et al., 1989). Inadequate absorption of immunoglobulins by the calf may occur for many reasons such as timing of the first feeding (Besser et al., 1985) and volume of the feeding (Stott et al., 1979). However, the factor of most critical importance is the concentration of IgG in colostrum (Pritchett et al., 1991).

Although much research has been conducted on the factors associated with colostrum quality in cows, including parity (Pritchett et al., 1991; Gulliksen et al., 2008; Kehoe et al., 2011), breed (Muller and Ellinger, 1981), length of the dry period (Pritchett et al., 1991), time interval from calving to milking (Lomba et al., 1978; Moore et al., 2005; Morin et al., 2010) and volume of colostrum produced (Kruse, 1970; Pritchett et al., 1991), few studies have examined the factors associated with the colostrum quality of cows in seasonal, grass-based systems such as those that exist in Ireland. Moreover, only a limited number of studies have attempted to quantify the relationship between colostral IgG concentration and colostral weight (Pritchett et al., 1991; Guy et al., 1994; Baumrucker et al., 2010).

The objective of this study was to determine the factors associated with colostral IgG concentration and colostral weight of the first milking post-calving in Irish dairy cows. Results from this study will provide valuable information to enable farmers to maximise the efficiency of their colostrum management programmes and ultimately improve calf health.

Material and methods

The study was conducted from 15 January to 7 December 2011 on four Teagasc research farms, namely Moorepark, Curtin’s, Kilworth and Ballydague, all located in County Cork, in southern Ireland (latitude 52°9’, longitude 8°16’).

Study population

Fresh colostrum samples (100 ml) were collected from 704 dairy cows, which calved between the months of January and April (n = 642), or between the months of September and December (n = 62). These animals consisted of 455 Holstein–Friesian, 50 Jersey, 81 Jersey × Holstein–Friesian crossbreeds, 28 Norwegian Red, 40 Norwegian Red × Holstein–Friesian crossbreeds and seven Montbéliarde, with the remaining 43 cows being a variety of Holstein cross-breeds. In total there were 205 first parity animals and 157, 139, 98 and 105 cows in their second, third, fourth and fifth or greater parity, respectively.

Cow management

Dry cow management. All spring-calving cows were managed similarly before and during colostrum sample collection. Cows were dried off when producing <8 kg milk daily or within 60 days of calving.

Spring-calving cows were housed in a cubic shed, where they remained until they were turned out to grass directly post-calving. The dry cow diet consisted of ad libitum silage (71% dry matter digestibility (DMD)), 2 kg of barley straw and 1 to 2 kg of dry cow concentrate per cow depending on cow body condition score (BCS) at drying off. Mineral supplementation commenced 2 months before calving using a powder mixed through the silage at a rate of 100 g/cow per day (Multitrace Pre-calver, Inform Nutrition Ireland).

All autumn-calving cows were retained at pasture during the dry period with the majority calving outdoors. Once calved, they joined the lactating herd but were maintained on a grazed pasture diet. The diet of the autumn-calving cows during the dry period consisted of grazed grass and they had access to a mineral lick to meet their pre-calving mineral requirements while at pasture.

The healthcare programme for all cows included prophylactic treatment for gastrointestinal roundworms and liver fluke, as well as routine vaccination against leptospirosis, bovine viral diarrhoea, salmonellosis and rotavirus.

Management at calving. Late-gestation spring-calving cows and heifers were housed in large group pens of ~20, while autumn-calving cows were retained at pasture in two groups (~30 per group) depending upon parturition date. When parturition became imminent, cows were moved into individual calving pens, where all calvings were attended and observed by competent and trained personnel. Calves were removed from the dam immediately (before they were standing) so that no suckling occurred.

Information recorded at calving included date and time of birth, sex of calf, weight and breed of calf, whether the calf was born alive or stillborn, presentation of the calf (normal, posterior, breech, leg–back, head–back, etc.) and degree of calving difficulty on a 1 to 5 scale (1 = no assistance, 5 = veterinary intervention). Other information available
included time interval from calving to subsequent milking, cow body weight measured up to 14 days post-calving and BCS (scale 1 to 5; Edmonson et al., 1989) measured within 14 days of calving, length of preceding dry period (pluriparae only), breed fraction, degree of heterosis and recombination and cow economic breeding index (EBI; Berry et al., 2007). The EBI is a single figure profit index aimed at identifying the most profitable animals for breeding dairy herd replacements, which comprises information on six sub-indexes related to profitable milk production: milk production, fertility, calving performance, beef carcass, maintenance and health.

Colostrum sampling and analysis
Cows were individually milked at the next scheduled herd milking time following calving (0830 or 1530 h) by machine into a steel churn and the weight of the colostrum was recorded. The entire quantity of colostrum obtained was agitated to ensure its constituents were evenly distributed; a 100 ml sample was taken into a 120 ml polypropylene bottle (SGR Scientific Ltd, Swords, Co. Dublin, Ireland) and was frozen immediately at −20°C. The frozen colostrum was thawed at room temperature, a subsample of the collected colostrum was centrifuged at 3500 g for 30 min, the surface fat was removed and the supernatant was collected and refrozen at −20°C until analysis.

The colostrum samples were thawed at room temperature the day before laboratory analysis. IgG concentration of the samples was determined by the ELISA method (Bovine IgG ELISA Kit Cat. No. 8010, Alpha Diagnostic International, San Antonio, TX, USA). Samples were assayed in duplicate, with an interassay CV of 0.15. The concentration of IgG in samples was calculated from a standard reference curve containing known concentrations of IgG. Any sample that resulted in an IgG concentration that fell outside the range of the standard reference curve was retested after further dilution according to the test recommendations.

Data editing
Cows were categorised according to the month of calving. One hundred and twenty three cows calved in January, 338 calved in February, 128 in March and 52 in April and 1 in May, 2 in August, 28 in September, 21 in October, 9 in November and 2 in December. For the purposes of the statistical analysis in this study, the one cow that calved in May was assumed to have calved in April, the two cows that calved in August were assumed to have calved in September and the two cows that calved in December were assumed to have calved in November.

The time of day of calving was categorised as: calved between the hours of 0600 and 1200 h (n = 181), 1200 and 1800 h (n = 155), 1800 and 0000 h (n = 184) and 0000 and 0600 h (n = 164); time of day of calving was unavailable for 20 animals and these were treated as a separate category. The time interval from calving to first milking was categorised as: milked within 3 h of calving (n = 173), between 3 and 6 h (n = 143), 6 and 9 h (n = 118), between 9 and 12 h (n = 111), between 12 and 15 h (n = 49), between 15 and 18 h (n = 55) and between 18 and 21 h post-calving (n = 21). Cows for which no record of time of calving was available (n = 34) were treated as a separate category. The length of the dry period was categorised as: <8 weeks (n = 41), 8 to 16 weeks (n = 384), 16 to 24 weeks (n = 41) and >24 weeks (n = 33); primiparae were treated as a separate category. The degree of calving difficulty was categorised as: (1) no assistance given to cow during calving (n = 621), (2) manual assistance given without use of a calving aid (n = 47), (3) manual assistance given with use of a calving aid (n = 22) and (4) calving time prolonged and/or veterinary assistance required (n = 14). Cows that gave birth to a calf of <20 kg (n = 9), 20 to 30 kg (n = 145), 31 to 40 kg (n = 338), 41 to 50 kg (n = 163) and >50 kg (n = 8) were treated as separate categories; records of weight of the calf at birth were unavailable for 41 cows and these were treated as a separate category. Cow BCS (scale 1 to 5), measured up to 14 days post-calving, was categorised as: ≤2.75 (n = 55), 3 (n = 135), 3.25 (n = 231) and >3.5 (n = 101). Cow BCS records were unavailable for 182 animals and these were treated as a separate category (i.e. ‘missing’). Cow body weight measured up to 14 days following calving was categorised as: ≤400 kg (n = 60), 401 to 450 kg (n = 111), 451 to 500 kg (n = 132), 501 to 550 kg (n = 101), 551 to 600 kg (n = 99) and >601 kg (n = 107). Cow body weight records were unavailable for 94 animals and these were treated as a separate category. Concentrate fed in the first 305 days of the previous lactation was categorised as: ≤400 kg (n = 46), 401 to 600 kg (n = 190), 601 to 800 kg (n = 210) and ≥800 kg (n = 52); records of concentrate fed in the first 305 days of the previous lactation were unavailable for 206 animals (including primiparae) and these were treated as a separate category. Milk production in the first 305 days of the previous lactation was categorised as: ≤3500 kg (n = 19), 3501 to 4000 kg (n = 28), 4001 to 4500 kg (n = 78), 4501 to 5000 kg (n = 73), 5001 to 5500 kg (n = 94), 5501 to 6000 kg (n = 99), 6001 to 6500 kg (n = 51) and >6500 kg of milk produced (n = 56); primiparae were treated as a separate category.

Statistical analysis
Both colostral IgG and colostral weight were normally distributed. Factors associated with colostral IgG concentration and weight were determined using a fixed effects multiple regression model in PROC GLM in SAS (Version 9.1, SAS Institute Inc., Cary, NC, USA).

A number of variables were first tested for association with IgG and colostral weight in a series of univariate analyses. Month of calving, time of day of calving, time interval from calving to milking, parity, dry period length, degree of calving difficulty, sex of the calf, whether the calf was born alive or stillborn, weight of the calf at birth, cow BCS measured up to 14 days following calving, cow body weight...
measured up to 14 days following calving, the quantity of concentrate fed in the first 305 days of the previous lactation, EBI of cow, milk production in first 305 days of previous lactation and herd were all considered as categorical variables. Heterosis and recombination loss coefficient as well as proportion of the breed Holstein, Jersey, Friesian, Montbéliarde, Norwegian Red or ‘other’, each treated as separate effects, were considered as continuous variables. Furthermore, IgG concentration of colostrum was included as an independent variable when the dependent variable was colostral weight. Weight of colostrum was included as an independent variable when the dependent variable was IgG concentration.

All variables associated \((P < 0.05)\) with the dependent variable in the univariate analyses were included in a multiple regression model. Non-significant variables \((P > 0.05)\) were sequentially removed using backward elimination. Once all remaining independent variables were associated \((P < 0.05)\) with the dependent variable, the removed variables were once again tested for significance with the significant variables forced into the multiple regression model. Interactions between all significant variables were examined; none were found to be significant. Least squares means were compared.

Genetic and residual variances were estimated for both IgG concentration and colostral weight using a linear mixed animal model in ASREML \((\text{Gilmour et al.}, 2009)\). Fixed effects included in the model were determined from the fixed effects model analysis with the exception of colostral weight, which was not considered for inclusion in the model. Animal was included as a random effect in the mixed model with the pedigree of each animal traced back at least four generations, where available.

**Results**

**Colostral IgG concentration**

The concentration of colostral IgG varied greatly among animals, with a mean of 112 g/l \((\text{s.d.} = 51 \text{ g/l})\) and a range of 13 g/l to 256 g/l (Figure 1); the coefficient of variation was 46%. In total, 96% of samples contained \(>50 \text{ g/l} \) of IgG, which is used as the threshold to define colostrum as being of high quality \((\text{McGuirk and Collins}, 2004)\).

Parity \((P < 0.001)\), time interval from calving to next milking \((P < 0.001)\), month of calving \((P < 0.05)\), colostral weight \((P < 0.01)\) and herd \((P < 0.05)\) were all independently associated with IgG concentration in the multiple regression model. There was a general trend for colostral IgG to increase with parity (Figure 2). First (97 g/l) and second (99 g/l) lactation cows produced colostrum with a lower IgG concentration than cows in their third and fifth lactation. Colostral IgG was negatively associated \((P < 0.001)\) with time interval from calving to milking. In general, colostrum harvested later than 9 h post-calving had a lower IgG concentration than colostrum harvested before this time (Figure 3). Colostrum with the greatest mean IgG concentration \((124 \text{ g/l})\) was produced by cows that were milked between 3 and 6 h post-calving, although there was no difference between colostrum harvested 3 to 6 h post-calving and colostrum harvested 3 h earlier or 3 h later. Cows milked between 18 and 21 h post-calving had the lowest IgG concentration \((93 \text{ g/l})\), although this was not different to that of colostrum harvested after 9 h.

Cows that calved in April produced colostrum with a lower IgG concentration \((87 \text{ g/l})\) than cows calving in the earlier spring.
months or in the autumn months (Figure 4). Concentration was negatively associated ($P < 0.01$) with colostral weight, decreasing linearly by 1.7 g/l (s.e. 0.6) per kg increase in colostral weight.

The heritability of IgG concentration was 0.10 (s.e. 0.07). The genetic standard deviation for IgG concentration was 16.0 g/l suggesting a coefficient of genetic variation of 14.3%.

Colostral weight
Mean colostral weight at the milking immediately post-calving was 6.7 kg (s.d. = 3.6 kg) with a range of 0.1 to 24 kg. Parity ($P < 0.001$), time interval from calving to milking ($P < 0.01$), weight of the calf at birth ($P < 0.05$), colostral IgG concentration ($P < 0.01$) and herd ($P < 0.001$) were all independently associated with colostral weight at the first milking in the multiple regression model.

Colostral weight at the first milking was positively associated ($P < 0.001$) with parity (Figure 5). First lactation animals produced the lowest yield of colostrum (5.3 kg). The highest yield, from third lactation cows (7.9 kg), while not different for cows entering their second or fourth lactation, was higher than that for cows entering their first and fifth lactation.

Colostral weight at first milking increased ($P < 0.001$) with time interval from calving to first milking (Figure 6). Cows milked 12 h post-calving and thereafter, yielded more colostrum than cows milked before this time. There was no difference among the least squares means of animals milked before 12 h; nor was there a difference among the least squares means of animals milked after 12 h. The highest yield of colostrum (8.2, s.e. = 0.7 kg) was from cows milked for the first time between 18 and 21 h post-calving, and the lowest yield (6.3, s.e. = 0.4 kg) was from cows milked between 3 and 6 h post-calving.

Colostral weight at the first milking was positively associated ($P < 0.05$) with weight of the calf at birth (Figure 7) with a difference of 2.1 kg colostral weight between the lightest (<20 kg) and heaviest (>50 kg) calves. The weight of colostrum at the first milking decreased linearly ($P < 0.01$) by 7 g (s.e. = 2 g) per g/l increase in IgG concentration.

The heritability of colostral weight was 0.21 (s.e. = 0.08). The genetic standard deviation of colostral weight was 1.49 kg indicating a coefficient of genetic variation of 22.3%.

**Discussion**
Ensuring that the neonatal calf ingests and absorbs a critical mass of IgG from colostrum is necessary for it to acquire immunity (McGuirk and Collins, 2004) and is established as being crucial to its future health and productivity (Kruse, 1970; Robison et al., 1988; DeNise et al., 1989). The bovine
placenta does not allow the transfer of immunoglobulins from the dam to the calf while in utero and so the newborn calf must absorb a critical mass of IgG from colostrum before cessation of intestinal transport occurs at 24 to 36 h of age to acquire immunity against the pathogenic organisms it will encounter as soon as it is born (Weaver et al., 2000).

As many studies evaluating colostral IgG concentration and weight have been undertaken within non-pasture-based systems of production (Morin et al., 2010; Kehoe et al., 2011), it is unknown whether low concentration of IgG in colostrum could be a factor contributing to the relatively high calf mortality rate in Ireland. The objective of this study, therefore, was to quantify the colostral IgG concentration and weight of Irish dairy cows in a pasture-based system and determine the associated factors.

**Colostral quality**

The colostrum of the cows in this study was, in general, of good quality. In total, almost 96% of the colostrum samples in this study contained > 50 g/l IgG, which is considered to be an indication of high-quality colostrum (McGuirk and Collins, 2004). Fifty-four percent of samples contained ≥100 g/l IgG. The existence of heritable genetic variation for IgG reported in this study, although lower than the heritability of 0.41 reported by Gilbert et al. (1988) in the colostrum of US Hereford, Angus and Simmental cows, nonetheless suggests that breeding for improved IgG levels in colostrum is indeed feasible.

The range of IgG concentration (13 to 256 g/l) was similar to the ranges reported in other studies; Baumrucker et al. (2010) reported values of 9 to 166 g/l in a US study of 214 cows while concentrations of 2 to 235 g/l were reported in a Norwegian study (Gulliksen et al., 2008). This wide range in colostral IgG concentration demonstrates the enormous variation that exists between individual cows. The mean IgG concentration of samples in the present study (112±51 g/l; mean±s.d.) was higher than that of some previous studies (Pritchett et al., 1991; Baumrucker et al., 2010; Morrill et al., 2012), but similar to that of others. Kehoe et al. (2011) reported a mean colostral IgG concentration of 96 g/l (s.d. = 38 g/l) in 540 Holstein cows in Pennsylvania, United States America, while Rivero et al. (2012) in a study of 157 Holstein–Friesians in Southern Chile also reported a high mean IgG concentration of 93 g/l (s.d. = 38 g/l). Bielmann et al. (2010) also reported a high mean concentration of 94 g/l in a study of 288 Holstein dairy cows in Ontario, Canada.

It is important to bear in mind that these studies have quantified colostral IgG using different laboratory analysis techniques; some have used radial immunodiffusion (Kehoe et al., 2011; Rivero et al., 2012) while others have used ELISA (Baumrucker et al., 2010; Nowak et al., 2012). Furthermore, differences in sample preparation between studies also exist. Baumrucker et al. (2010) removed the colostral fat before analysis but Morrill et al. (2012) did not. These differences in laboratory methods present difficulties when attempting to make true comparisons of colostral IgG concentrations across studies as variation in IgG concentrations measured may be partly attributable to the method used. While it has been established that removal of colostral fat before RID analysis can lead to an overestimation of IgG concentration (Fleenor and Stott, 1981), the authors of this paper have found that there is currently no clear consensus on whether fat should be removed before analysis by ELISA.

In order to further validate the ELISA results obtained in the present study, 20 colostrum samples were retested using the same kit in a different laboratory (Enfer Group, M7 Business Park, Newhall, Naas, Co. Kildare, Ireland). The results obtained were equally as high as those obtained in the initial analysis. Moreover, 20 colostrum samples were retested using a different ELISA kit (Bethyl Laboratories Inc., Montgomery, TX, USA); on this occasion the results obtained were higher than those obtained in the initial analysis. It is possible that the high mean IgG concentration of colostrum reported in this study may be a result of overestimation by the ELISA kit itself. Potential bias in the estimate of total mean IgG concentration does not affect the results of the fixed effects analysis.

Possible reasons for the relatively high mean IgG concentration of colostrum in the present study include a short calving to colostrum collection interval (Morin et al., 2010), good grass-based nutritional management, and the use of a relatively low-yielding cow type that produces low weight of colostrum. The average total lactation milk yield for the cows in the present study was 5256 kg, considerably lower than yields reported in previous studies; Pritchett et al. (1991) reported mean total lactation milk yield of 9079 kg. Short calving to colostrum collection interval was considered to be an important factor contributing to high colostrum quality in the study by Kehoe et al. (2011), in which colostrum was collected within 2 to 6 h of calving, and in the study by Rivero et al. (2012), in which colostrum was collected in the 1st hour after calving. In the present study, while there was a wide range in the time interval from calving to colostrum collection (shortest time interval from calving to milking was 1 h, the longest was 21 h), 61% of the samples were collected within 9 h of calving, which may have contributed to the high colostrum quality.

**Colostral weight**

The inverse relationships reported in the present study between colostral weight and IgG concentration corroborates previous studies (Pritchett et al., 1991; Guy et al., 1994) and is possibly due to a dilution effect. Guy et al. (1994) reported an increase in lactogenic activity that was concurrent with a decreased IgG concentration in colostral secretion, the timing and magnitude of which indicate that colostral IgG concentration is determined by the relative quantity of the non-IgG constituents of colostrum. IgG is actively transported from the serum of the dam across the mammary epithelial barrier by specific receptors to accumulate in the mammary gland before parturition (Larson et al., 1980). Increased secretion of lactose occurs and begins to incorporate more water, which increases colostrum volume and has a diluting effect on IgG concentration (Baumrucker et al., 2010).
In agreement with previous international studies (Lomba et al., 1978; Straub and Matthaeus, 1978; Moore et al., 2005; Morin et al., 2010), colostrum IgG concentration was negatively associated with the interval from calving to colostrum collection. Corroborating the results from Straub and Matthaeus (1978), the present study failed to identify a significant difference in IgG concentration for cows milked up to 9 h post-calving, although IgG decreased thereafter. Lomba et al. (1978) reported that immunoglobulin content was reduced to 80%, 70% and 40%, respectively by 6, 12 and 24 h postpartum, compared with immunoglobulin content in colostrum milked immediately postpartum. In the present study, IgG concentration of colostrum collected between 9 and 12 h postpartum was reduced to 86% compared with that of colostrum collected in the first 3 h postpartum, while IgG concentration of colostrum collected between 18 and 21 h postpartum was reduced to 77%. A more recent study (Morin et al., 2010) reported a decrease in colostral IgG concentration of 3.7% per hour post-calving. Furthermore, the ability of the neonatal calf to absorb IgG from colostrum declines progressively after 6 h of age (Besser et al., 1985) and thus colostrum should be collected from the dam and fed to the newborn calf as soon as possible after birth. This ensures colostrum of the highest possible IgG concentration is being fed, and also ensures maximum absorption of IgG by the neonate.

Cows that were milked later still produced colostrum with a lower concentration of IgG even after adjustment was made for weight of colostrum (i.e. the fact that a cow milked a long time post-calving had a low colostrum IgG concentration was not simply due to the fact that she was more likely to have had a higher colostral weight). As such, while post-parturient secretion by the mammary glands of a fluid with a much lower IgG concentration than that of colostrum contributes to lower colostral IgG with increased time from calving to milking (Morin et al., 2010), the present study does not support the view that dilution alone is responsible. Moore et al. (2005) also disputed the dilution hypothesis; reporting that while colostrum collected 6, 10 and 14 h after calving from 13 Holstein cows had significantly lower IgG concentrations than colostrum collected 2 h after calving, there was no significant increase in the weight of the colostrum produced at these times. For this reason they concluded that the observed decrease in colostral IgG concentration was not due to dilution effects and suggested that perhaps colostral immunoglobulins diffuse passively into the cow’s systemic circulation. Further research is required to elucidate the exact mechanism.

### Parity

The lower mean IgG concentration in younger cows is consistent with previous studies (Kruse, 1970; Muller and Ellinger, 1981; Pritchett et al., 1991). The immunoglobulins of bovine serum transferred into colostrum carry a wide array of antibody properties against a multitude of antigens to which the cow has been exposed (Larson et al., 1980); older cows are likely to be exposed to a greater number of pathogenic antigens in their lifetime, which is the likely explanation for the increase in colostral IgG with increasing parity. Increased milk yield of older cows is not a contributory factor here since milk yield was included in the multiple regression model. Selman et al. (1971) previously recommended discarding colostrum from first lactation heifers, but the results of this study do not support this. The mean IgG concentration of colostrum for heifers in this study was almost twice that considered to be the threshold for good-quality colostrum (50 g/l), and only 10% of the colostrum samples obtained from heifers were below that threshold. Therefore, on the basis of our findings, we would advise Irish farmers to disregard any previous recommendations to automatically discard colostrum from first lactation heifers, as it may be of high quality.

The lower colostral weight recorded in first lactation heifers in the present study is in contrast to some previous studies (Kehoe et al., 2011), which reported no significant association between parity and colostrum volumes produced. However, results from the present study are nonetheless consistent with others (Kruse, 1970). The lower quantity of colostrum produced by this group of animals is not surprising, given that the total milk yield of first lactation heifers throughout the entire lactation is less than that of cows in later lactations (Horan et al., 2005).

### Month of calving

Factors relating to cow health and nutrition may underlie the association observed in the present study between month of calving and colostral IgG concentration. Cows that calved in late spring in a seasonal calving herd were likely to have had reduced fertility, which prevented an early return to cyclicity and establishment of pregnancy early in the previous breeding season. Subclinical health issues may have been a contributory factor to both reduced fertility and lower colostral IgG concentrations in these cows; however, no health data were available to confirm or refute this. There is insufficient research at present examining the relationship between cow health status and IgG concentration of colostrum but this is an area that warrants further investigation.

In general, the cows that calved in April had a longer dry period than cows calved earlier. Forty-seven percent of the animals that calved in April (25 out of 47 for whom there are dry period records) had a dry period length <16 weeks, compared with 88% of cows calving in other months of the year. Cows with long dry periods are predisposed to becoming excessively fat (Morrow, 1976) and this appears to have been the case with the April calving cows; 44% had a BCS at calving above the target of 3.25 (Roche et al., 2009) compared with 17% of cows calving in the other months of the year. Over-conditioning of the dairy cow at calving has negative consequences for her immune system (Mulligan and Doherty, 2008); this may have been a factor in the lower colostral IgG concentrations in the April calving cows.
The diet during the dry period of the autumn-calving cows in this study consisted of grazed grass, which had higher CP (229 g/kg, s.d. = 33.2) and DMD (871 g/kg, s.d. = 15.3) than the grass silage diet of the spring-calving cows (140 g/kg, s.d. = 5.6, 716 g/kg, s.d. = 5.1; protein and DMD, respectively). The nutritional superiority of grazed grass relative to grass silage has been long established (Mayne and Laidlaw, 1995) and this may have contributed to the high quality of colostrum of these autumn calving cows in particular and of cows in this study in general. Similarly, Gulliksen et al. (2008) reported that cows calving during the months following the pasture season produced colostrum of higher quality compared with cows calving during other seasons. While some studies to date have shown that IgG concentration of colostrum is not affected by prepartum maternal nutrition, in terms of protein and energy requirements (Blecha et al., 1981; Hough et al., 1990; Nowak et al., 2012), further research is required to elucidate the complex relationship between nutrition and colostrum quality.

Calf birth weight

Larger cows are expected to have larger (i.e. heavier) calves because of the moderate heritability of animal size (Berry et al., 2004). Larger cows, on average, also have greater lactation yields (Berry et al., 2004), which also suggests greater colostrum yield. This is the likely reason for the greater colostrum yields in cows that had heavier calves at birth.

Conclusion

The results from this study show that in general the colostrum quality (112 g/l IgG) of cows from well-managed moderate-to-high quality (112 g/l IgG) of cows from well-managed moderate-bred Irish dairy herds of mixed breed is high. Older parity cows, cows that were milked earlier post-calving, cows that calved earlier in spring or in autumn produced colostrum with higher IgG concentration. Transfer of sufficient IgG to the neonatal calf via high-quality colostrum is of critical importance to optimise calf health. Reducing the time interval between calving and collection of colostrum is the most practical means by which the farmer can maximise colostral IgG concentration.

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References


