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An investigation into the factors associated with ewe colostrum production

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Highlights

- Colostrum volume is influenced by ewe breed and age
- Volume per kg ewe live weight mirrored colostrum volume
- Volume per kg lamb birth weight differed with ewe breed type
- IgG yield was influenced by ewe breed type and change in BCS during late gestation

Abstract

The majority of lamb mortality which occurs during the first 24 hours post-partum is preventable through providing the lamb with sufficient quantities of high quality colostrum during this time. Data from seven late gestation nutrition experiments carried out at this institute between 2002 and 2014 were collated into a single data set comprising of 415 twin bearing ewes. Analysis was carried out to investigate the key drivers of ewe colostrum production excluding nutrient intake, namely body reserve mobilisation, ewe breed type, ewe age, gestation length and lamb birth weight. The volume of colostrum produced at 1 and 18 hours post-partum was significantly lower than the volume recorded at 10 hour post-partum (P = 0.01). Multivariate regression analysis indicated that colostrum volume during the first 18 hours post-partum was influenced by lamb birth weight (P = 0.01), ewe age (P = 0.01), breed type (P = 0. 01) and gestation length (P = 0.06). Live weight change (P = 0.05) also had a significant influence on the volume of colostrum produced but BCS change did not affect colostrum production (P = 0.25). Further multivariate regression analysis indicated that IgG yield was influenced ewe breed type (P = 0.01), lamb birth weight (P = 0.02), gestation length (P = 0.05) and BCS change (P = 0.04). Live weight change (P = 0.12) and ewe age (P = 0.62) did not influence the quantity of IgG produced. Leicester ewes produced less colostrum per kg lamb birth weight at 1 hour post-partum compared to all other ewe breed types (P = 0.01) and less than Suffolk ewes at 10 hours post-partum (P = 0.01). The result of this analysis shows the key factors excluding ewe nutrition that drive colostrum production. Ewe breed type in particular appears to play an important role in the ability of the ewe to produce sufficient quantities of adequate quality colostrum. In conclusion the result of this analysis highlights the important factors associated with ewe colostrum volume and IgG yield excluding nutrition. In particular the overall structure of the flock such as breed type and ewe age is important when considering the ability of the flock to meet colostrum demands and hence reduce lamb mortality.

Key words: colostrum, sheep, live weight, Immunoglobulin G, ewe breed type, colostrum intake

1. Introduction

Globally, lamb morality accounts for 15-20% of all lambs born, most of these deaths occur in the first day post-partum (Nowak et al., 2000; Nowak and Poindron, 2006), with birth trauma, hypothermia, starvation and infectious disease (Dwyer et al., 2015) key causations. Much of this loss is preventable and primarily occurs due to a lack of sufficient quantities of adequate quality colostrum in the first 24 hours post-partum (Mellor and Murray, 1985; Kenyon et al., 2005). The amount of colostrum required by the lamb is largely dictated by its heat production requirements (Mellor and Murray, 1985; Dwyer et al., 2015). Colostrum requirements in early life range from 150 to 210 ml of colostrum per kg birth weight during the first 18 hours of life for a lamb born indoors (Mellor and Murray; 1986; Crosby et al., 2004; Boland et al., 2005; McGovern et al., 2015c)

Colostrum provides the new born lamb with energy to generate heat (Mellor and Murray, 1985), immunoglobulins (Ig) for passive immunity (Mellor, 1990) and acts as a laxative to aid in the passing of the meconium (Campbell, 1974). The composition of colostrum is critical to these functions and colostrum typically contains approximately 36-43% total solids, 10-13% fat, 2-3% lactose and 18-21% crude protein (O'Doherty and Crosby 1997; Crosby et al., 2005; Banchero et al., 2015 – calculated from Pattinson et al., 1995). Immunoglobulins, particularly immunoglobulin G (IgG), are a key component of colostrum providing the lamb with passive immunity. This passive immunity is essential as the lamb is born hypo-immunocompetent with Ig providing the lamb with protection against pathogens in early life (O'Doherty and Crosby, 1997; Boland et al., 2005b). Immunoglobulins present in colostrum are passed from the ewe's blood circulation into the mammary gland in a process called colostrogenesis (Barrington et al., 2001). Immunoglobulin yield declines rapidly during the first 24 hours post-partum (Hunter et al., 1977; Shubber et al., 1979) with declining yields at 1, 10 and 18 hours post-partum of approximately 45, 34 and 12 grams respectively reported (Boland et al., 2005a).

The lamb is capable of absorbing Ig through the intestinal wall, primarily in the lower ileum (Yvon et al., 1993), up to approximately 24 hours post-partum (Nowak and Poindron, 2006). Up to one quarter of ingested Ig is present in the lambs circulation at 24 hours post-partum (Boland et al., 2005a) but the lamb serum IgG concentration is sensitive to the pre-partum mineral nutrition of the ewe (Boland et al., 2005a, b; McGovern et al., 2015a). Intake of IgG required to prevent infection is not known (Mellor and Murray, 1985) but due to the intake capacity of the lamb a colostral IgG concentration of <50 g per litre within the first hour post-partum is considered inadequate (Dwyer et al., 2015). However, IgG yield and colostrum yield are positively related (O'Doherty et al., 1997) and the amount of colostrum required to meet the lambs energy requirement is greater than the amount required to prevent disease (Pattinson et al., 1995).

The structure and management of the flock has the potential to influence the volume and quality of colostrum produced by the ewe (Castro et al., 2011). Gestation length (Molina et al., 1995), dam age (Argüello et al., 2006) and dam breed (Ha et al., 1986) have been shown to be key factors influencing colostrum production in sheep, cattle and goats respectively. Body reserve mobilisation during late gestation also has the potential to influence colostrum quality as shown by Al-Sabbagh (2009) in sheep and Shearer et al. (1992) in dairy cows. However, findings relating specifically to sheep and in which all of these factors are considered together are limited making it difficult to determine what are the main factors of ewe colostrum production.

Colostrum production and quality has been a key focus of the late gestation nutrition research carried out at the University College Dublin Lyons Research Farm. Using data compiled from a selection of studies carried out since 2002 an analysis was conducted to investigate the main factors influencing ewe colostrum yield and IgG yield in twin bearing ewes.

2. Materials and Methods

Animal care and use approval was not required for this study as all data was collated from previous experiments carried out in this research institution. Experiments from which data was obtained, with the exception of McGovern et al. (2015b), were carried out under Irish

Department of Health experimental licences in accordance with the Cruelty to Animals Act 1876 (Cruelty to Animals Act. 1876; European Communities 1994). Data from McGovern et al. (2015b) was collected under Irish Medicines Board experimental licences in accordance with the European Union protection of animals used for scientific purposes regulations 2012 (S.I. No. 543 of 2012).

2.1. Data collation

Data from seven late gestation nutrition experiments carried out at the U.C.D. Lyons Research Farm between 2002 and 2014 was collated into a single data set comprising of 415 twin bearing ewes. Appendix 1 contains references to academic texts containing full descriptions and results of these studies. The materials and method descriptions that follow relate to the measurements taken that are relevant to this particular analysis.

2.2. Data collection

Ewes were mated using either natural service or laparoscopic artificial insemination as previously described (Boland et al., 2006; Campion et al., 2016). Categorical variables are listed in Table 1. All breeds included in the data set are crossbredswith the sire breed used to indicate the cross. Ewes classed as Terminal breed type ewes comprise of Charollais (20 ewes; 4.8% of all ewes), Texel (19 ewes; 4.6% of all ewes) and Vendeen (22 ewes; 5.3% of all ewes) type ewes.

Continuous variables are listed in Table 2. In each experiment ewes were offered a grass silage based diet with concentrate supplementation supplied during the final eight weeks of gestation. Grass silage was harvested as described by McGovern et al. (2015b). Commercially available concentrate supplements were used in all studies similar to that described by McGovern et al. (2015b) and linked to stage of gestation. Crude protein content of the concentrates used were between 140g/kg and 190g/kg dry matter (DM) with all studies reported using a 190g/kg crude protein (CP) ration for the final three weeks of gestation.

Live weight change (LWC) during late gestation was calculated by subtracting the live weight of the ewe recorded at 24 hours post-partum from the live weight of the ewe measured between six and eight weeks pre-partum (study dependent). Body condition score change (BCSC) was calculated by subtracting the BCS (zero to five scale; Jefferies, 1961) obtained at either day 141 of gestation or at 24 hours post-partum from the BCS collected between six and eight weeks pre-partum (study dependent). Across the studies BCS was measured by one of either two trained practitioners. One the practitioners was trained by the other technician to maintain consistency of the BCS measurements. Average lamb birth weight was the average weight of both lambs obtained within the first hour post-partum.

2.3. Colostrum production

Volume of colostrum produced at 1, 10 and 18 hours post-partum was measured from all 415 ewes by hand milking following intramuscular injection of oxytocin as described by Boland et al. (2004). Volume of colostrum per kg ewe live weight was calculated by dividing colostrum volume at each time point by ewe live weight obtained at 24 hours post-partum. Volume of colostrum per kg of lamb birth weight was obtained by dividing colostrum volume at each time point by twice the average lamb birth weight. Average lamb birth weight was multiplied by two as all ewes were twin bearing. Hourly colostrum production from 1 to 10 and 10 to 18 hours post-partum was calculated by dividing colostrum accumulation in the udder from 1 to 10 or 10 to 18 hours as appropriate by the number of hours over which the colostrum accumulated.

Immunoglobulin G yield data was available from 212 ewes, all of which were from studies in year group 1 (2002 – 2004). Terminal type ewes were removed from this analysis as their numbers were unbalanced in comparison to the other three breed types. Concentration of IgG was obtained as described by Crosby et al. (2004) according to the method of Fahey and McKelvey (1965) using single radial immunodiffusion kits (Betyl Laboratories, Montgomery, TX). Samples obtained at each time point from 212 ewes within the data set had IgG concentration figures available from which IgG yield was calculated as follows;

IgG yield = colostrum volume × (IgG concentration ÷ 1000)

2.4. Statistical analysis

Ewe was considered the experimental unit for all analysis and included as a random effect. Data was analysed to fit the assumptions of normality using the UNIVARIATE procedure in SAS (SAS, v9.4). A boxcox transformation was used where data did not fit the assumption of normality (Fahey et al., 2007). Regression coefficients were estimated using PROC MIXED (SAS, v9.4). The model for colostrum volume included the fixed effects of ewe, year group and time point (as the repeated measure), as well as the 2-way interaction of ewe breed type by time point. The same model was used for IgG yield data except year group was replaced by year as all data came from year group one.

Pearson's and Spearman's correlations were performed on variables to be used in the analysis to test for multicollinearity variables, however, in this study there was no multicollinearity. Variables with a P-value > 0.10 were removed from the final model. A p-value of ≤ 0.05 was used to denotes statistical significance, and 0.05 < P ≤ 0.10 was used to denote a statistical tendency. Colostrum volume, IgG yield, volume of colostrum produced per kg live weight at 24 hours post-partum and volume of colostrum produced per kg lamb birth weight were all treated as repeated measures. The repeated measures were fit using variance–covariance structures with Bayesian Information Criterion was used to select the most appropriate variance-covariance structure.

3. Results

Colostrum volume at 1, 10 and 18 hours post-partum for all ewes and disaggregated by breed type is presented in Table 3. The volume of colostrum produced at 1 and 18 hours post-partum was significantly lower than the volume recorded at 10 hour post-partum (P = 0.01).

Colostrum volume at 1 hour post-partum was lower in Leicester type ewes compared to all other breed types (P = 0.01), but only lower than Suffolk type ewes at 10 hours post-partum (P = 0.04). Terminal type ewes produced less colostrum at 18 hours post-partum than all other breed types (P = 0.01).

The pattern of colostrum production differed between breed types with no difference observed in colostrum production at 1 and 10 hours post-partum in Belclare and Terminal type ewes (P = 0.54) but colostrum volume was lower at 1 hour post-partum compared to 10 hours post-partum in Suffolk and Leicester type ewes (P = 0.01). Colostrum volume at 18 hours post-partum was lower than the volume recorded at 1 and 10 hours post-partum in Belclare and Terminal type ewes (P = 0.02). Leicester type ewes produced more colostrum at 18 hours post-partum than at 1 hour post-partum (P = 0.01). Suffolk type ewes produced less colostrum at 18 hours post-partum than at 10 hours post-partum but volume at 1 and 10 hours post-partum did not differ (P = 0.52).

Volume of colostrum produced per kg ewe live weight at1, 10 and 18 hours post-partum for all ewes and disaggregated by breed type is presented in Table 3. As with total colostrum produced the volume produced per kg live weight was highest at 10 hours post-partum (P = 0.01). Belclare ewes produced less colostrum per kg live weight at 18 hours post-partum than at 10 hours post-partum (P = 0.03). At 1 hour post-partum Leicester type ewes produced less colostrum per kg live weight than all other breed types (P = 0.01). Leicester type ewes tended to produced less colostrum per kg live weight at 10 hours post-partum than Suffolk type ewes (P = 0.09) who produced more colostrum than Belclare and Terminal ewes at this time (P = 0.02). Terminal type ewes produced less colostrum per kg live weight than all other breed types at 18 hours post-partum (P = 0.01) with Leicester type ewes also producing more than Belclare type ewes at this time point (P = 0.01) .

Colostrum volume per kg lamb birth weight is presented in Fig. 1. Leicester type ewes produced less colostrum per kg lamb birth weight at 1 hour post-partum compared to all other ewe breed types (P = 0.01) and less than Suffolk type ewes at 10 hours post-partum (P = 0.01). Suffolk type ewes produced more colostrum per kg lamb birth weight than Belclare and Terminal type ewes at 10 hours post-partum (P = 0.03). By 18 hours post-partum there was no difference in colostrum yield per kg lamb birth weight between Leicester type ewes and Belclare and Suffolk type ewes (P = 0.31). Terminal type ewes produced less colostrum per kg lamb birth weight compared to Belclare, Suffolk and Leicester type ewes at 18 hours post-partum (P = 0.01).

The hourly rate of colostrum production from 1 to 10 hours post-partum and from 10 to 18 hours post-partum is presented in Fig. 2. From 1 to 10 hours post-partum the hourly rate of colostrum production was higher in Suffolk and Belclare type ewes than Leicester type ewes (P = 0.04). Terminal type ewes had a lower hourly colostrum production rate than Belclare and Suffolk type ewes from 10 to 18 hours post-partum (P = 0.02) and tended to produce less colostrum during this time than Leicester type ewes (P = 0.08).

As presented in Table 4 total colostrum production to 18 hours post-partum was lower for Leicester type ewes than Belclare and Suffolk type ewes (P = 0.01) and tended to be lower than Terminal type ewes to 18 hours post-partum (P = 0.06). Total colostrum production to 18 hours post-partum was lower for Terminal type ewes than Suffolk type ewes (P = 0.05). Leicester type ewes produced less colostrum per kg ewe live weight to 18 hours post-partum than Suffolk type ewes (P = 0.04) and tended to produce less than Belclare type ewes (P = 0.09). Total volume per kg lamb birthweight was higher for Belclare and Suffolk type ewes in comparison to Leicester type ewes (P = 0.02) and was higher for Suffolk type ewes than Terminal type ewes (P = 0.03). Mean colostrum production per hour from 1 to 10 hours post-partum and 10 to 18 hours post-partum did not differ (P = 0.21).

As presented in Table 5 multivariate regression analysis indicated that colostrum volume during the first 18 hours post-partum was influenced by ewe age (P = 0.01) and breed type (P = 0. 01), lamb birth weight (P = 0.01), and tended towards being influenced by gestation length (P = 0.06). Live weight change (P = 0.05) also had a significant influence on the volume of colostrum produced but change in BCS did not affect colostrum production (P = 0.25). The estimation of colostrum volume increased with age, each year increase in ewe age increased colostrum volume by 37 ml (Fig. 3; P = 0.01). A 47 ml increase in the volume of colostrum produced by the ewe per kg increase in lamb birth weight (P = 0.01) was recorded. Ewes lambing at day 142 of gestation tended to produce more colostrum than those lambing at day 152 of gestation, with ewes producing 12 ml less colostrum per day increase in gestation length between day 142 and 151 of gestation (P = 0.06).

Mean IgG yield at 1, 10 and 18 hours post-partum is presented in Table 6. Yield of IgG decreased from 1 hour to 10 hours post-partum and from 10 hours to 18 hours post-partum (P = 0.01) and this was the same in all three breed types analysed (P = 0.04). Leicester type ewes had a lower IgG yield at 1 hour post-partum than Suffolk type ewes (P = 0.01) but had a higher IgG yield at 10 hours post-partum than Belclare type ewes (P = 0.01) and a higher IgG yield than Belclare and Suffolk type ewes at 18 hours post-partum (P = 0.04). The yield of IgG tended to be lower in Belclare type ewes at 1 hour post-partum compared to Suffolk type ewes (P = 0.06) and was lower in Belclare type ewes compared to Suffolk type ewes at 10 hours post-partum (P = 0.01).

As presented in Table 7 multivariate regression analysis indicated that IgG yield was influenced by breed type (P = 0.01), lamb birth weight (P = 0.02), gestation length (P = 0.05) year of study (P = 0.02) and change in BCS (P = 0.04). Live weight change (P = 0.12) and ewe age (P = 0.62) did not influence the quantity of IgG produced. A change in lamb birth weight (kg) from the mean led to 2.0 g change in IgG yield (P = 0.06). Ewes lambing at day

142 of gestation had a higher IgG yield than those lambing at day 151 of gestation, with ewes producing 0.67 g less IgG per day increase in gestation length between day 142 and 151 of gestation (P = 0.07). A breed type by time point interaction was observed for IgG yield (P = 0.01) with IgG yield decreasing across breed types from 1 to 10 hours post-partum.

4. Discussion

The results of this analysis indicates how some key flock structure and management factors excluding ewe nutrition can influence the ability of twin bearing ewes to produce sufficient quantities of adequate quality colostrum in the first 18 hours post-partum. Ewe breed type, ewe age, gestation length, lamb birth weight and late gestation live weight change are significant factors affecting the colostrum production ability of the ewe. Furthermore, ewe breed type, gestation length and lamb birth weight also affect the IgG yield of the ewe during this time. Previously published work has not investigated the effect of all of these factors collectively to identify what drivers of colostrum and IgG yield have the greatest influence as has been done in this analysis. Also there is a paucity of information relating to the effect on sheep colostrum and IgG production of some of the factors investigated here such as the effect of ewe breed on colostrum and IgG yield. The results discussed below provide important information for medium to long term flock planning.

Late gestation nutrition is a key regulator of the quantity and quality of colostrum produced by the ewe (Swanson et al., 2008). Although dry matter and crude protein intake data was included in this data set it was not used in the analysis as the studies from which the data was collated controlled daily feed allowance to meet requirements for maintenance and foetal growth. There was no variation in diet type either between the studies used; all ewes received a grass silage based diet supplemented with concentrates to meet energy and protein requirements. Furthermore, the effect of late gestation nutrition on ewe colostrum production and quality is well documented and discussed within the current literature (O'Doherty et al., 1997; Banchero et al., 2004a, b; Boland et al., 2006; Wallace et al., 2006; McGovern et al., 2015b; Campion et al., 2016).

Body reserve mobilisation is often used as an indicator of the nutritional status of the flock and its inclusion in this analysis helped account for any ewes that were over or under nourished during late gestation (O'Doherty et al., 1997; McGovern et al., 2015b; Campion et al., 2016). Colostrum volume increased for every kg reduction in live weight loss during late gestation, most likely attributable to increases in late gestation energy intake which would have reduced live weight loss. O'Doherty et al. (1997) and McGovern et al. (2015b) both reported higher colostrum yields from treatments with the highest energy intakes and lowest level of live weight loss during late gestation in comparison to the other treatment groups. This also offers a potential explanation as to why IgG yield increased as BCS change became increasingly positive. Similarly, Banchero et al. (2006) reported that ewes receiving 70% of their recommended ME allowance during late gestation lost more live weight than ewes receiving 110% of recommended ME allowance and produced less colostrum to 10 hours post-partum. The results of this analysis point to an important role of live weight change in colostrum production as it is a reflection of dry matter intake, particularly energy intake.

Sanson et al. (1993) previously stated that BCS is a better estimate of energy reserves than live weight. However, while live weight change did have a significant effect on colostrum volume, BCS change did not but did effect IgG yield. Live weight change and BCS change data from the records used in this analysis had a low correlation (19%) which could potentially be attributed to the different breed types used (Kenyon et al., 2014). This low correlation offers a potential explanation as to why BCS change did not have an impact on colostrum volume where live weight change did but did influence IgG yield. This result though is partly in agreement with Kenyon et al. (2014) who concluded that BCS appears to have little influence on ewe colostrum production. Al-Sabbagh et al. (1995) and Rozeboom et al. (2007) both reported that ewe BCS had no influence on the concentration of IgG within colostrum. Based on this paper and the authors previously mentioned it would appear as if the change in body reserve status as opposed to absolute live weight or BCS is what is important when discussing colostrum production.

However, Al-Sabbagh (2009) reported that ewes with a BCS of between 2.5 and 3.5 tended to produce more colostrum than ewes with a BCS less than 2.5. These authors gave no indication of nutritional management, but a BCS of less than 2.5 at parturition would be considered very low and point to potential undernourishment during late gestation which has been shown previously to negatively impact on ewe colostrum production (O'Doherty and Crosby, 1996). High BCS (>3.5) may also negatively impact ewe colostrum production by altering circulating progesterone concentrations and feed intake. The entire process of colostrogenesis is coordinated by hormones with progesterone and oestradiol controlling the onset of colostrogenesis (Castro et al., 2011). Higher levels of body reserves can reduce appetite and slow down progesterone withdrawal prior to parturition, both of which will negatively affect colostrum production (Oddy and Holst, 1991; Hamudikuwanda et al., 1996; Banchero et al., 2006). It could therefore be postulated that maintaining BCS change during late gestation to low levels will positively impact colostrum production and that extremely low (<2.5) and extremely high (>3.5) BCS will negatively influence colostrum production.

Colostrum volume increased with age, which is the same as parity number in the yearly lambing system operated on this research farm. This result is similar to the report of Wohlt et al. (1981) who reported that colostrum volume increased as ewe age increased from 1.5 - 2.0 years of age to 2.1 - 4.0 years and again to 4.1 - 8.0 years of age. However, unlike the previous authors this analysis gives a value for the change in colostrum volume per year increase in ewe age as opposed to using year groups. Higher milk yields as parity number increases have been reported in dairy cattle and goats previously (Carnicella et al., 2008; Wathes et al., 2007). A key factor in the increase in colostrum yield with ewe age could potentially be mammary gland development and how this differs as lactation number increases. The number of epithelial cells within the mammary gland appears to be incremental with age/parity as not all epithelium cells die at the end of lactation (Knight and Peaker, 1982; Peris et al., 1999) potentially impacting colostrum volume as ewe age increases.

Previous reports have discussed how changes in epithelial cell numbers during lactation are linked with increased and decreased milk production (Knight and Peaker, 1984; Capuco et al., 2001). Increasing epithelial cells within the udder leads to increases in udder size with Fernandez et al. (1995) reporting that milk yield and udder size were positively correlated. Additionally these authors reported that udder volume increases from primiparous to multiparous dairy ewes. It has also been reported that in goats as parity number increases udder volume declines more rapidly during lactation but that milk yield at the onset of lactation is higher (Peris et al., 1999). In sheep the majority of mammary gland development takes place during gestation (Swanson et al., 2008) allowing an accumulation of colostrum in the udder prior to parturition (Mellor and Murray, 1985). When this is considered with the evolution of the mammary gland with age as discussed it is reasonable to conclude that the increasing number of epithelium cells within the mammary gland contributes to an increase in ewe colostrum production with age.

Increasing gestation length had a negative impact on ewe colostrum production and IgG yield in this analysis. This is in contrast to the findings of Swanson et al. (2008) who reported that IgG concentration increased in primiparous ewes that lambed at either day 146.9 of gestation or day 150 of gestation. Likewise, Crosby et al. (2005) reported an increase in gestation length and higher colostrum yields at one hour post-partum from ewes receiving 100 mg progesterone supplementation from day 143 of gestation compared to control ewes. The latter attributed this increase in colostrum yield to longer gestation length of the unsupplemented ewes compared to the supplemented ewes, allowing more time for colostrum to accumulate in the mammary gland. It is difficult to explain the negative relationship between gestation length and colostrum volume and IgG yield observed in this analysis. At present literature would point to gestation length having the opposite effect to what was observed in this analysis. The data available for this analysis doesn't permit any deeper investigations that are merited based on this result but the results of this analysis do a point to a need for further investigation specifically into the effect of gestation length on ewe colostrum production.

Pattinson and Thomas (2004) reported that meat-type ewes produced less colostrum than milk-type ewes during the first 24 hours post-partum. These authors reported similar IgG concentrations between both milk-type and meat-type ewes though, suggesting that IgG yield differed between the two breed types. This is in agreement with the result recorded in this analysis where both colostrum volume and IgG yield were affected by breed type. Leicester ewes produced the lowest volume of colostrum and IgG at 1 hour post-partum, with colostrum production at this time point a measure of pre-partum colostrum accumulation (Mellor and Murray, 1986). Total colostrum volume produced to 18 hours post-partum was lower for Leicester type ewes as well suggesting that these ewes may not be genetically pre-dispositioned to produce high volumes of colostrum. The low volumes of colostrum from Leicester ewes in comparison to the other breed types may be a cause for concern in some outdoor lambing systems or extensive hill farming systems.

Thermoenergetic efficiency is influenced by lamb birth weight and litter size, with heavier lambs better able to cope with cold stress and maintain their body temperature (Kerslake et al., 2005; Kerslake et al., 2009). The amount of colostrum required by the lamb is dictated by a number of factors, but key amongst this is its requirements to maintain its body temperature

(Mellor and Murray, 1985; Dwyer et al., 2015). The volume of colostrum and yield of IgG a ewe produces is only as relevant as its ability to meet progeny requirements for energy and passive immunity in the first hours after birth. Numerous authors have reported different colostrum intake recommendations for new born lambs however; studies in this institute from where the data used was collated have always targeted a colostrum intake of 150 ml per kg birth weight during the first 18 hours of life (O'Doherty et al., 1997; Boland et al., 2004; Boland et al., 2006). These authors set a minimum threshold of 60 ml kg birth weight during the first 18 hours of life before intervening with substitute colostrum from another ewe.

Belclare, Suffolk and Terminal ewes all produced over 50 ml colostrum per kg lamb birthweight at 1, 10 and 18 hours post-partum, and produced sufficient colostrum to exceed the 150 ml per kg birth weight target at 18 hours post-partum. The lower colostrum volume produced by Leicester ewes was reflected in the colostrum produced per kg birth weight, and was below 50 ml kg birth weight at one hour post-partum. While the volume of colostrum was above 50ml per kg birth weight at 10 and 18 hours post-partum and exceeded the target 150ml per kg birth weight in total to 18 hours post-partum the initial production of colostrum is vital to the neonate lamb. Within ten minutes of birth the lambs' heat production increases (Dwyer and Morgan, 2006) and with that so does its energy requirements. In extreme cases where the lamb cannot respond to this increase in requirements and generate sufficient heat the resulting hypothermia will be irreversible (Dwyer et al., 2015).

Leicester cross ewes have been reported to be used in outdoor lambing systems (Alexander et al., 1990) where lamb colostrum intake requirements are high. Given the poor initial colostrum production of Leicester ewes during the first hour post-partum they may not be suitable for outdoor lambing or extensive hill farms where the lambs' energy requirements are high. However, Alexander et al. (1990) reported that Border Leicester ewes did not excel at caring for multiple lambs but when crossed with Merino sheep their mothering ability had a very favourable reputation amongst producers. The majority of the Leicester ewes in this study were crossed with Blackface Mountain sheep, a breed used for extensive hill farming systems (Dwyer and Lawrence, 2005).

When managed under similar management systems Blackface Mountain lambs tend to have lower mortality rates than breeds used for intensive farming systems (Dwyer and Lawrence, 2005). This potentially leads to the reason as to why Irish producers also speak favourably in terms of Leicester type ewes which are traditionally crossed with Blackface Mountain sheep. The reduced mortality rates associated with Blackface Mountain lambs discussed by Dwyer and Lawrence (2005) was linked to a higher colostrum fat composition in Blackface Mountain ewe colostrum and a better suckling ability in their lambs when compared to Suffolk sheep. Despite limitations in the colostrum and IgG production ability of the Leicester type ewes in this study they may be compensating for this through improved colostrum components such as fat and higher suckling ability in their lambs in comparison to other breed types. This also may explain their favourable reputation amongst sheep producers.

5. Conclusion

In conclusion the results of this analysis show that ewe breed type, age, gestation length and lamb birth weight all influence the yield of from the ewe to 18 hours post-partum. The yield of IgG from the ewe to 18 hours post-partum will also appear to be influenced by ewe breed type, gestation length and lamb birth weight. Body reserve change also has an influence over the colostrum yield and IgG yield of the ewe. Although most of these factors are outside of the immediate control of the producer they do provide information to be considered in medium to long term flock management decisions.

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Conflict of interest

Dear Editor,

The authors wish to declare that they have no known conflicts of interest to declare with this manuscript.

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References

Agricultural and Food Research Council (AFRC). 1993. Energy and protein requirements of ruminants. An advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients. CAB International, Oxford, UK

Al-Sabbagh, T. 2009. Colostral immunoglobulin as affected by nutritional status in Border Leicester Merino ewes deliver at Kuwait. Global Vet, 3, 281-285.

Al-Sabbagh, T. A., Swanson, L. V. & Thompson, J. M. 1995. The effect of ewe body condition at lambing on colostral immunoglobulin G concentration and lamb performance. Journal of Animal Science, 73, 2860-4.

Argüello, A., Castro, N., Alvarez, S. & Capote, J. 2006. Effects of the number of lactations and litter size on chemical composition and physical characteristics of goat colostrum. Small Ruminant Research, 64, 53-59.

Banchero, G. E., Clariget, R. P., Bencini, R., Lindsay, D. R., Milton, J. T. & Martin, G. B. 2006. Endocrine and metabolic factors involved in the effect of nutrition on the production of colostrum in female sheep. Reproduction Nutrition Development, 46, 447-460.

Banchero, G. E., Milton, J. T. B., Lindsay, D. R., Martin, G. B. & Quintans, G. 2015. Colostrum production in ewes: a review of regulation mechanisms and of energy supply. animal, 9, 831-837.

Banchero, G. E., Quintans, G., Martin, G. B., Lindsay, D. R. & Milton, J. T. B. 2004a. Nutrition and colostrum production in sheep. 1. Metabolic and hormonal responses to a high-energy supplement in the final stages of pregnancy. Reproduction, Fertility and Development, 16, 633-643.

Banchero, G. E., Quintans, G., Martin, G. B., Milton, J. T. B. & Lindsay, D. R. 2004b. Nutrition and colostrum production in sheep. 2. Metabolic and hormonal responses to different energy sources in the final stages of pregnancy. Reproduction, Fertility and Development, 16, 645-653.

Barrington, G. M., McFadden, T. B., Huyler, M. T. & Besser, T. E. 2001. Regulation of colostrogenesis in cattle. Livestock Production Science, 70, 95-104.

Boland, T. M., Brophy, P. O., Callan, J. J., Quinn, P. J., Nowakowski, P. & Crosby, T. F. 2004. The effects of mineral-block components when offered to ewes in late pregnancy on colostrum yield and immunoglobulin G absorption in their lambs. Animal science (Penicuik, Scotland), 79, 293-302.

Boland, T. M., Brophy, P. O., Callan, J. J., Quinn, P. J., Nowakowski, P. & Crosby, T. F. 2005a. The effects of mineral supplementation to ewes in late pregnancy on colostrum yield and immunoglobulin G absorption in their lambs. Livestock Production Science, 97, 141-150.

Boland, T. M., Callan, J. J., Brophy, P. O., Quinn, P. J. & Crosby, T. F. 2006. Lamb serum vitamin E and immunoglobulin G concentrations in response to various maternal mineral and iodine supplementation regimens. Animal Science, 82, 319-325.

Boland, T. M., Guinan, M., Brophy, P. O., Callan, J. J., Quinn, P. J., Nowakowski, P. & Crosby, T. F. 2005b. The effect of varying levels of mineral and iodine supplementation to ewes during late pregnancy on serum immunoglobulin G concentrations in their progeny. Animal Science, 80, 209-218.

Campion, F.P., McGovern, F.M., Lott, S., Fahey, A.G., Creighton, P. and Boland, T.M., 2016. Comparison of energy rationing systems for late gestation ewes: Impacts on ewe and lamb performance. Journal of Animal Science, 94(8), pp.3441-3456. Capuco, A., Wood, D., Baldwin, R., McLeod, K. & Paape, M. 2001. Mammary cell number, proliferation, and apoptosis during a bovine lactation: relation to milk production and effect of bST. Journal of Dairy Science, 84, 2177-2187.

Carnicella, D., Dario, M., Ayres, M. C. C., Laudadio, V. & Dario, C. 2008. The effect of diet, parity, year and number of kids on milk yield and milk composition in Maltese goat. Small Ruminant Research, 77, 71-74.

Castro, N., Capote, J., Bruckmaier, R. M. & Argüello, A. 2011. Management effects on colostrogenesis in small ruminants: a review. Journal of Applied Animal Research, 39, 85-93.

Crosby, T., Boland, T., Brophy, P., Quinn, P., Callan, J. & Joyce, D. 2004. effects of offering mineral blocks to ewes pre-mating and in late pregnancy on block intake, pregnant ewe performance and immunoglobulin status of the progeny. Animal science: an international journal of fundamental and applied research, 2004.

Crosby, T. F., O'Donnell, A., O'Doherty, J. V., Quinn, P. J. & Evans, A. C. O. 2005. Effects of exogenous progesterone on gestation length, foetal survival and colostrum yield in ewes. Theriogenology, 64, 1121-1129.

Cruelty to Animals Act. 1876. Accessed Nov. 19, 2012. http://www.irishstatutebook.ie/1876/en/act/pub/0077/print.html.

European Union (Protection of Animals used for Scientific Purposes) Regulations 2012. SI No 543/2012. Accessed Nov. 20, 2012. http://www.irishstatutebook.ie/2012/en/si/0543.html.

Dwyer, C., Conington, J., Corbiere, F., Holmøy, I., Muri, K., Nowak, R., Rooke, J., Vipond, J. & Gautier, J.-M. 2015. Invited review: Improving neonatal survival in small ruminants: science into practice. animal, 1-11.

Dwyer, C. & Morgan, C. 2006. Maintenance of body temperature in the neonatal lamb: Effects of breed, birth weight, and litter size. Journal of Animal Science, 84, 1093-1101.

Dwyer, C. M. & Lawrence, A. B. 2005. A review of the behavioural and physiological adaptations of hill and lowland breeds of sheep that favour lamb survival. Applied animal behaviour science, 92, 235-260.

Fahey, A. G., Marchant-Forde, R. M. & Cheng, H. W. 2007. Relationship Between Body Weight and Beak Characteristics in One-Day-Old White Leghorn Chicks: Its Implications for Beak Trimming. Poultry Science, 86, 1312-1315.

Fahey, J. L. & McKelvey, E. M. 1965. Quantitative determination of serum immunoglobulins in antibody-agar plates. The Journal of Immunology, 94, 84-90.

Fernández, G., Alvarez, P., San Primitivo, F. & de la Fuente, L. 1995. Factors affecting variation of udder traits of dairy ewes. Journal of Dairy Science, 78, 842-849.

Gulliksen, S., Lie, K., Sølverød, L. & Østerås, O. 2008. Risk factors associated with colostrum quality in Norwegian dairy cows. Journal of dairy science, 91, 704-712.

Ha, W., Lim, J. & Choi, C. 1986. A study on the immunoglobulin G concentration in milk and blood serum of Korean native goats, 1; changes of IgG concentration on the lactation period of Korean native goats. Korean Journal of Animal Sciences, 28.

Hamudikuwanda, H., Gallo, G., Block, E. & Downey, B. 1996. Adipose tissue progesterone concentrations in dairy cows during late pregnancy and early lactation. Animal Reproduction Science, 43, 15-23.

Hartmann, P. E., Trevethan, P. & Shelton, J. N. 1973. Progesterone and oestrogen and the initiation of lactation in ewes. Journal of Endocrinology, 59, 249-259.

Hunter, A., ReneaU, J. & Williams, J. 1977. Factors affecting IgG concentration in day-old lambs. Journal of animal science, 45, 1146-1151.

Jefferies, B. 1961. Body condition scoring and its use in management. Tasmanian journal of agriculture, 32, 19-21.

Kenyon, P., Stafford, K., Morel, P. & Morris, S. 2005. Does sward height grazed by ewes in mid-to late-pregnancy affect indices of colostrum intake by twin and triplet lambs? New Zealand veterinary journal, 53, 336-339.

Kenyon, P. R., Maloney, S. K. & Blache, D. 2014. Review of sheep body condition score in relation to production characteristics. New Zealand Journal of Agricultural Research, 1-27.

Kerslake, J., Kenyon, P., Stafford, K., Morris, S. & Morel, P. 2009. The effect of offering concentrate supplement to twin-and triplet-bearing ewes grazing a 60 mm herbage sward height on lamb birth weight, heat production and post-natal growth. The Journal of Agricultural Science, 147, 613-624.

Knight, C. & Peaker, M. 1982. Development of the mammary gland. Journal of Reproduction and Fertility, 65, 521-536.

McGovern, F., Magee, D., Browne, J., MacHugh, D. & Boland, T. 2015a. Iodine supplementation of the pregnant dam alters intestinal gene expression and immunoglobulin uptake in the newborn lamb. animal, 1-9.

McGovern, F. M., Campion, F. P., Lott, S. & Boland, T. M. 2015b. Altering ewe nutrition in late gestation: I. The impact on pre- and postpartum ewe performance. Journal of Animal Science, 93, 4860-4872.

McGovern, F. M., Campion, F. P., Sweeney, T., Fair, S., Lott, S. & Boland, T. M. 2015c. Altering ewe nutrition in late gestation: II. The impact on fetal development and offspring performance. Journal of Animal Science, 93, 4873-4882.

McNeill, D. M., Slepetis, R., Ehrhardt, R. A., Smith, D. M. & Bell, A. W. 1997. Protein requirements of sheep in late pregnancy: partitioning of nitrogen between gravid uterus and maternal tissues. J Anim Sci, 75, 809-16.

Mellor, D. & Murray, L. 1985. Effects of maternal nutrition on udder development during late pregnancy and on colostrum production in Scottish Blackface ewes with twin lambs. Research in veterinary science, 39, 230-234.

Mellor, D. & Murray, L. 1986. Making the most of colostrum at lambing. Veterinary Record, 118, 351-353.

Molina, P., Muelas, R., Fernandez, N., Torres, A., Caja, G. & Gallego, L. 1995. Change of colostrum composition and factors affecting the level of production and composition of colostrum from dairy ewes. Journal of Dairy Science, 78, 228.

Moore, M., Tyler, J. W., Chigerwe, M., Dawes, M. E. & Middleton, J. R. 2005. Effect of delayed colostrum collection on colostral IgG concentration in dairy cows. Journal of the American Veterinary Medical Association, 226, 1375-1377.

Nowak, R. & Poindron, P. 2006. From birth to colostrum: early steps leading to lamb survival. Reproduction Nutrition Development, 46, 431-446.

Nowak, R., Porter, R. H., LévY, F., Orgeur, P. & Schaal, B. 2000. Role of mother-young interactions in the survival of offspring in domestic mammals. Reviews of Reproduction, 5, 153-163.

O' Doherty, J. V. & Crosby, T. F. 1996. The effect of diet in late pregnancy on progesterone concentration and colostrum yield in ewes. Theriogenology, 46, 233-241.

O'Doherty, J. V. & Crosby, T. F. 1997. The effect of diet in late pregnancy on colostrum production and immunoglobulin absorption in sheep. Animal Science, 64, 87-96.

O'Doherty, J. V., Maher, P. F. & Crosby, T. F. 1997. The performance of pregnant ewes and their progeny when offered grass silage, maize silage or a maize silage/ensiled super pressed pulp mixture during late pregnancy. Livestock Production Science, 52, 11-19.

Oddy, V. & Holst, P. 1991. Maternal-foetal adaptation to mid pregnancy feed restriction in single-bearing ewes. Crop and Pasture Science, 42, 969-978.

Pattinson, S. & Thomas, E. 2004. The effect of sire breed on colostrum production of crossbred ewes. Livestock Production Science, 86, 47-53.

Pattinson, S., D. A. R. Davies, and A. C. Winter. "Colostrum production by prolific ewes." *Animal Prod* 52 (1991): 583.

Pattinson, S. E., Davies, D. A. R. & Winter, A. C. 1995. Changes in the secretion rate and production of colostrum by ewes over the first 24 h post partum. Animal Science, 61, 63-68.

Peris, S., Caja, G. & Such, X. 1999. Relationships between udder and milking traits in Murciano-Granadina dairy goats. Small Ruminant Research, 33, 171-179.

Rozeboom, K., Neale, B. & Darroch, C. Relationships among ewe body condition scores, lamb vigor, colostral quality, milk composition and reproductive performance. Journal of Animal Science, 2007. Amer Soc Animal Science 1111 North Dunlap Ave, Savoy, IL 61874 USA, 138-138.

Shearer, J., Mohammed, H., Brenneman, J. & Tran, T. 1992. Factors associated with concentrations of immunoglobulins in colostrum at the first milking post-calving. Preventive Veterinary Medicine, 14, 143-154.

Shubber, A., Doxey, D., Black, W. & Fitzsimons, J. 1979. Colostrum production by ewes and the amounts ingested by lambs. Research in veterinary science, 27, 280-282.

Swanson, T. J., Hammer, C. J., Luther, J. S., Carlson, D. B., Taylor, J. B., Redmer, D. A., Neville, T. L., Reed, J. J., Reynolds, L. P., Caton, J. S. & Vonnahme, K. A. 2008. Effects of gestational plane of nutrition and selenium supplementation on mammary development and colostrum quality in pregnant ewe lambs. Journal of Animal Science, 86, 2415-2423.

Wallace, J. M., Milne, J. S., Redmer, D. A. & Aitken, R. P. 2006. Effect of diet composition on pregnancy outcome in overnourished rapidly growing adolescent sheep. British journal of nutrition, 96, 1060-1068.

Wathes, D., Cheng, Z., Bourne, N., Taylor, V., Coffey, M. & Brotherstone, S. 2007. Differences between primiparous and multiparous dairy cows in the inter-relationships between metabolic traits, milk yield and body condition score in the periparturient period. Domestic animal endocrinology, 33, 203-225.

Wohlt, J. E., Kleyn, D. H., Vandernoot, G. W., Selfridge, D. J. & Novotney, C. A. 1981. Effect of Stage of Lactation, Age of Ewe, Sibling Status, and Sex of Lamb on Gross and Minor Constituents of Dorset Ewe Milk. Journal of Dairy Science, 64, 2175-2184.

Yvon, M., Levieux, D., Valluy, M.-C., Pélissier, J.-P. & Mirand, P. P. 1993. Colostrum protein digestion in newborn lambs. Journal of Nutrition-Baltimore And Springfield Then Bethesda-, 123, 586-586.

Appendix

Boland, T. M., Brophy, P. O., Callan, J. J., Quinn, P. J., Nowakowski, P. & Crosby, T. F. 2004. The effects of mineral-block components when offered to ewes in late pregnancy on colostrum yield and immunoglobulin G absorption in their lambs. Animal science (Penicuik, Scotland), 79, 293-302.

Boland, T. M., Brophy, P. O., Callan, J. J., Quinn, P. J., Nowakowski, P. & Crosby, T. F. 2005a. The effects of mineral supplementation to ewes in late pregnancy on colostrum yield and immunoglobulin G absorption in their lambs. Livestock Production Science, 97, 141-150.

Boland, T. M., Callan, J. J., Brophy, P. O., Quinn, P. J. & Crosby, T. F. 2006. Lamb serum vitamin E and immunoglobulin G concentrations in response to various maternal mineral and iodine supplementation regimens. Animal Science, 82, 319-325.

Boland, T. M., Guinan, M., Brophy, P. O., Callan, J. J., Quinn, P. J., Nowakowski, P. & Crosby, T. F. 2005b. The effect of varying levels of mineral and iodine supplementation to ewes during late pregnancy on serum immunoglobulin G concentrations in their progeny. Animal Science, 80, 209-218.

Campion, F.P., McGovern, F.M., Lott, S., Fahey, A.G., Creighton, P. and Boland, T.M., 2016. Comparison of energy rationing systems for late gestation ewes: Impacts on ewe and lamb performance. Journal of Animal Science, 94(8), pp.3441-3456.

McDermott, K. 2012. An evaluation of metabolisable and net energy systems during late gestation on ewe and lamb performance. Unpublished.

McGovern, F. M., Campion, F. P., Lott, S. & Boland, T. M. 2015. Altering ewe nutrition in late gestation: I. The impact on pre- and postpartum ewe performance. Journal of Animal Science, 93, 4860-4872.

McGovern, F.M., Sweeney, T., Ryan, M.T., Lott, S., Campion, F.P. and Boland, T.M., 2017. An investigation into the effects of maternal supplementation with excess iodine on the mechanisms and impacts of reduced IgG absorption in the lamb postpartum. British Journal of Nutrition, 117(7), pp.951-963.

Figure 1 *Colostrum yield per kg lamb birth weight by breed at 1, 10 and 18 hours post-partum.*

Terminal breed category contains ewes classified as Charollais (20 ewes; 4.9% of all ewes), Texel (19 ewes; 4.7% of all ewes) and Vendeen (22 ewes; 5.4% of all ewes).

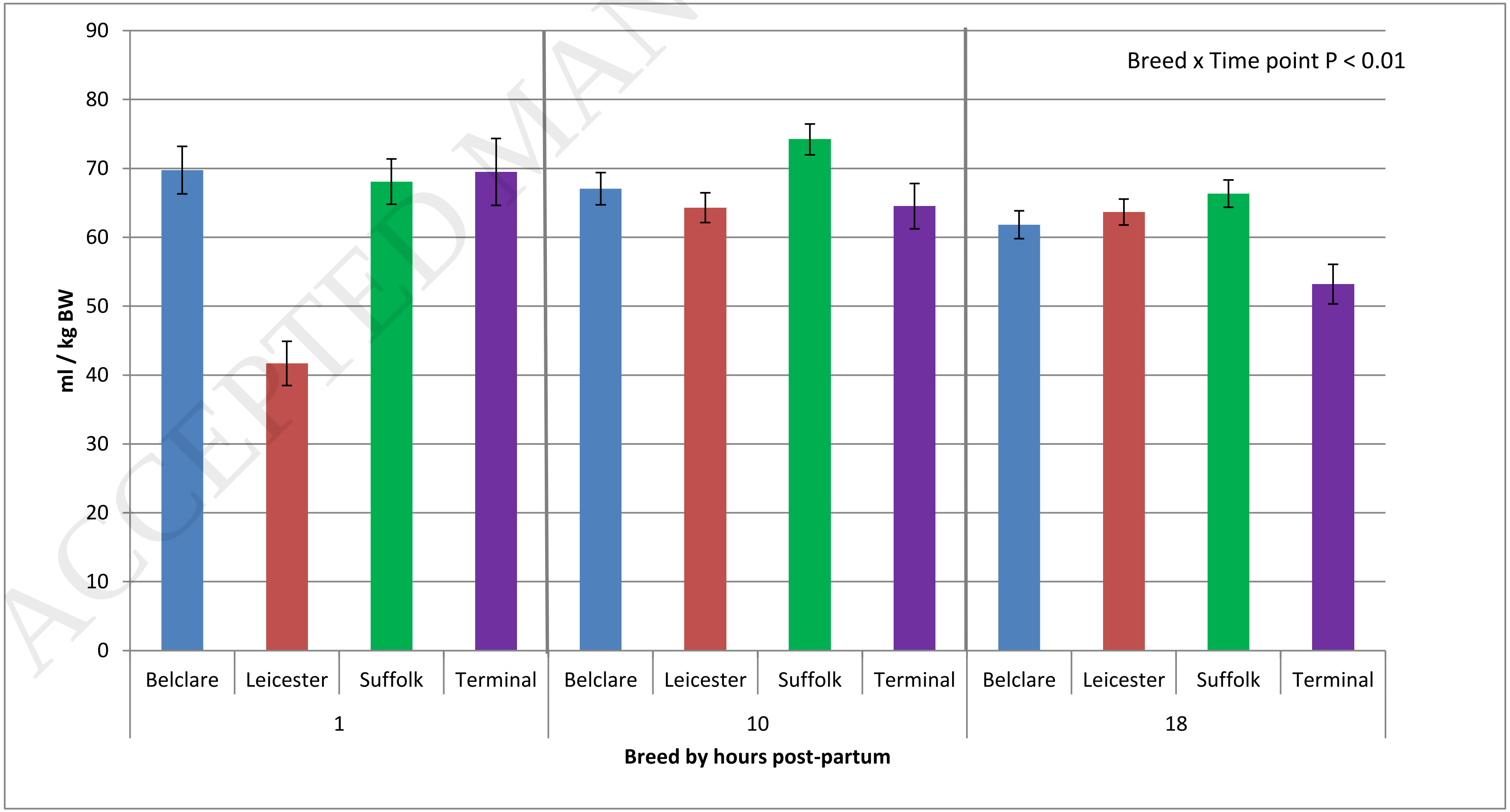
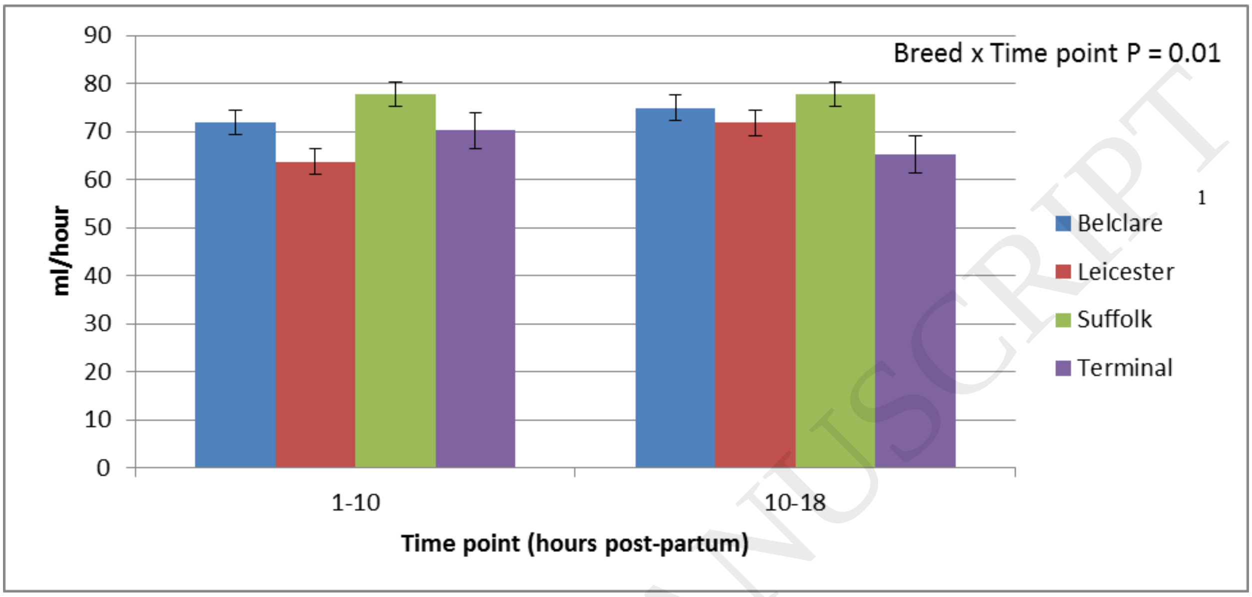


Figure 2 *Colostrum yield per hour from 1 to 10 and 10 to 18 hours post-partum (ml).*

[1]Terminal breed category contains ewes classified as Charollais (20 ewes; 4.9% of all ewes), Texel (19 ewes; 4.7% of all ewes) and Vendeen (22 ewes; 5.4% of all ewes).



Tables

Table 1 *Descriptive values of independent categorical variables studied in 415 ewes*

Factor	Categories	Ewes (%) per categories
Breed type		
	Belclare	98 (24%)
	Leicester cross	122 (29%)
	Suffolk	134 (32%)
	Terminal[1]	61 (15%)
Year Group	1 (2002 – 2004)	262 (63%)
	2 (2012 – 2014)	153 (37%)
Age	1	74 (18%)
	2	80 (19%)
	3	86 (21%)
	4	95 (23%)
	5	80 (19%)

[1]Terminal breed category contains ewes classified as Charollais (20 ewes; 4.9% of all ewes), Texel (19 ewes; 4.7% of all ewes) and Vendeen (22 ewes; 5.4% of all ewes).

Table 2 *Descriptive values of independent continuous variables and dependent variables in 415 ewes*

Variables	No. of Records	Mean	St Dev.	95% CI	Minimum	Maximum
Gestation (days)	413	147	1.8	147.1 to 147.3	142	151
Birth weight (kg)	369	4.8	0.76	4.76 to 4.85	2.65	7.4
Live weight change (kg)	415	-4.2	4.38	-4.48 to -3.99	-20	10
BCS change	352	-0.3	0.35	-0.33 to -0.29	-1.3	0.8
Colostrum						
Volume (ml)	1231	587	253.6	572.4 to 600.7	20	1500
1 hour post-partum	405	544	311.2	513.6 to 574.4	20	1450
10 hours post-partum	413	634	229.8	611.5 to 656.0	60	1500
18 hours post-partum	413	581	200.4	561.7 to 600.4	90	1370
Volume/kg ewe live weight (ml)	1233	8.6	3.65	8.44 to 8.85	0.4	26.4
1 hour post-partum	407	8.0	4.58	7.60 to 8.49	0.4	26.4
10 hours post-partum	413	9.3	3.24	9.01 to 9.64	1.1	20.6
18 hours post-partum	413	8.6	2.78	8.29 to 8.83	1.4	16.6
Volume/kg birth weight (ml)	1233	63.6	27.81	62.01 to 65.30	2.2	182.0

1 hour post-partum	363	60.7	35.75	56.96 to 64.34	2.2	182.0
10 hours post-partum	367	67.9	24.45	65.39 to 70.41	4.7	164.7
18 hours post-partum	367	62.4	20.63	60.29 to 64.52	10.5	138.2
IgG Yield (g)	760	28.5	19.07	27.20 to 29.91	1.7	120.1
1 hour post-partum	256	38.9	21.11	36.33 to 41.53	1.8	120.1
10 hours post-partum	258	32.3	15.40	30.40 to 34.17	4.5	82.8
18 hours post-partum	246	13.8	8.35	12.79 to 14.89	1.7	37.1
Volume per hour (ml)	826	71.5	25.3	69.80 to 73.25	6.67	171.25
1 – 10 hours post-partum	413	70.4	25.54	67.95 to 72.89	6.67	166.67
10 – 18 hours post-partum	413	72.6	25.01	70.21 to 75.06	11.25	171.25

Table 3 *Colostrum volume and volume/kg ewe live weight at 1, 10 and 18 hours post-partum for all ewes and broken down by breed type (Least Square Means ± SEM)*

Variables	1 Hour	10 Hours	18 Hours	SEM	P-value
Volume (ml)					
All ewes	576^{a}	640^{b}	581^{a}	13.0	0.01
Belclare ewes	642^{abd}	639^{ad}	592^{bd}	24.2	0.02
Leicester ewes	383^{ae}	597^{bd}	594^{bd}	22.3	0.01
Suffolk ewes	624^{ad}	706^{be}	631^{ad}	23.2	0.01
Terminal ewes[1]	653^{ad}	617^{ad}	508^{be}	34.0	0.01
SEM	33.4	23.2	20.3	.	.
P-value	0.01	0.04	0.01	.	.
Volume/kg ewe live weight (ml)					
All ewes	8.5^{a}	9.4^{b}	8.5^{a}	0.19	0.01

Belclare ewes	9.4^{ad}	9.1^{abde}	8.5^{bd}	0.35	0.03
Leicester ewes	6.1^{ae}	9.4^{bd}	9.4^{bd}	0.32	0.01
Suffolk ewes	9.1^{ad}	10.1^{be}	9.0^{ad}	0.33	0.01
Terminal ewes[1]	9.5^{ad}	8.5^{ade}	7.3^{be}	0.49	0.01
SEM	0.51	0.33	0.28	.	.
P-value	0.01	0.03	0.04	.	.

[a,b] Means within a row with common superscripts do not differ (*P > 0.05*)

[d,e] Means within a column with common superscripts do not differ (*P > 0.05*)

[1]Terminal breed category contains ewes classified as Charollais (20 ewes; 4.9% of all ewes), Texel (19 ewes; 4.7% of all ewes) and Vendeen (22 ewes; 5.4% of all ewes).

Table 4 *Total colostrum volume, total volume/kg ewe live weight and total volume/kg lamb birth weight to 18 hours post-partum by ewe breed type and hourly colostrum production from 1 to 10 and 10 to 18 hours post-partum for all breeds (Least Square Means ± SEM)*

Variables	**Belclare**	**Leicester**	**Suffolk**	**Terminal[1]**	**SEM**	**P-value**
Volume (ml)	1873^{acxy}	1587^{bx}	1991^{axy}	1779^{cy}	63.4	0.06
Volume/kg ewe live weight (ml)	26.4^{x}	24.6^{ay}	26.6^{bxy}	26.4^{abxy}	0.82	0.09
Volume/kg lamb birth weight (ml)	196^{ac}	170^{b}	209^{a}	184^{bc}	6.9	0.03
	1-10 hours post-partum		**1-18 hours post-partum**		**SEM**	**P-value**
Volume per hour (ml)	70.9		72.4		1.32	0.21

^{a,b} Means within a row with common superscripts do not differ (*P > 0.05*)

^{x,y} Means within a row with common superscripts do not differ (*P > 0.10*)

[1]Terminal breed category contains ewes classified as Charollais (20 ewes; 4.9% of all ewes), Texel (19 ewes; 4.7% of all ewes) and Vendeen (22 ewes; 5.4% of all ewes).

20 **Table 5** *Estimates of the effects of factors studied on colostrum volume measured at 1, 10 and 18 h post-partum from 415 ewes*

Effect	Estimate	SEM	P-value	Lower	Upper
Intercept	1890	790.5	0.01	335.8	3444.9
Belclare	84	32.9	0.01	19.2	148.3
Leicester	85	32.0	0.01	17.6	142.0
Suffolk	123	33.6	0.01	56.6	188.6
Terminal[1]	0	.	.	.	.
Age[2] (1 year)	-154	35.1	0.01	-223.3	-85.7
Age (2 years)	-84	31.5	0.01	-145.7	-21.9
Age (3 years)	-76	30.5	0.02	-135.9	-16.2
Age (4 years)	-19	30.1	0.65	-77.9	40.4
Age (5 years +)	0	.	.	.	.
Gestation (days)	-10	5.5	0.06	-21.0	0.5
Live weight Change (kg)	4	2.1	0.05	0.2	8.2
Birth weight (kg)	45	13.6	0.01	18.0	71.4
1 hour post-partum	145	40.9	0.01	64.5	225.1
10 hours post-partum	109	26.3	0.01	57.3	160.5

18 hours post-partum	0	.	.	.	.

[1]Terminal breed category contains ewes classified as Charollais (20 ewes; 4.9% of all ewes), Texel (19 ewes; 4.7% of all ewes) and Vendeen (22 ewes; 5.4% of all ewes).

[2] Age at parturition

Table 6 *IgG yield at 1, 10 and 18 hours post-partum for all ewes and broken down by maternal and terminal breed types from 212 ewes (Least Square Means ± SEM)*

Variables	1 Hour	10 Hours	18 Hours	SEM	P-value
All ewes	39.9[a]	30.2[b]	13.3[c]	1.43	0.01
Belclare ewes	39.0[ade]	21.2[bd]	10.2[cd]	3.53	0.01
Leicester ewes	32.6[ad]	36.1[be]	16.7[ce]	1.71	0.04
Suffolk ewes	47.9[ae]	33.3[be]	12.9[cd]	1.77	0.01
SEM	2.29	2.29	2.42	.	.
P-value	0.01	0.01	0.01	.	.

[a,b] Means within a row with common superscripts do not differ (*P > 0.05*)

[d,e] Means within a column with common superscripts do not differ (*P > 0.05*)

Table 7 *Estimates of the effects of factors studied on colostrum IgG yield measured at 1, 10 and 18 h post-partum from 212 ewes*

Effect	Estimate	SEM	P-value	Lower	Upper
Intercept	107.0	57.57	0.01	-6.59	220.57
Belclare	-2.7	4.13	0.28	-10.79	5.46
Leicester	3.9	2.51	0.01	-1.07	8.79
Suffolk	0	.	.	.	.
Year of study (2002)	-6.2	2.21	0.01	-10.56	-1.88
Year of study (2003)	-4.5	1.80	0.02	-8.05	-0.97
Year of study (2004)	0	.	.	.	.
Gestation (days)	-0.7	0.40	0.05	-1.45	0.11
BCS change	4.7	2.15	0.04	0.47	8.92
Birth weight (kg)	2.0	1.07	0.02	-0.11	4.09
1 hour post-partum	35.0	2.45	0.01	30.23	39.87
10 hours post-partum	20.4	2.46	0.01	15.58	25.25
18 hours post-partum	0	.	.	.	.