The association between immunoglobulin G in sow colostrum and piglet plasma

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ABSTRACT: Colostrum provides newborn piglets with energy and passive immunity and is essential for survival of the piglets. The plasma concentration of immunoglobulin G (IgG) in piglets is dependent on several factors, most importantly the concentration of IgG in sow colostrum (colostrum IgG). The main aims of this study were to investigate the variation in concentration of colostrum IgG between herds and the individual sows within herd and to investigate factors associated with plasma IgG concentrations in piglets (piglet IgG). From 4 herds (A to D), 876 piglets from 62 sows were included in the study. Colostrum was sampled from sows immediately after expulsion of the first piglet and before the first suckling (t1), mid-way through farrowing (just after the sixth piglet was born; t2), and after the last piglet was born (t3). At d 1, 0.5 mL blood from piglets was collected in tubes containing EDTA, and IgG concentrations were analyzed. Mean colostrum IgG concentration across all herds was 53.9 g/L. Herd A had mean colostrum IgG of 38.3 g/L, whereas the other 3 herds (B, C, and D) had mean colostrum IgG of 47.4, 60.4, and 67.8 g/L, respectively. Colostrum IgG at t1, t2, and t3 across all herds was 56.2, 53.7, and 42.5 g/L, respectively. Mean concentration of piglet IgG across all samplings was 21.7 g/L. Multilevel linear regression analysis was performed with piglet IgG (g/L) as outcome. In this model, the herd effect accounted for 9% of the total variance and 34% of the variance resided at sow level. Piglet IgG was associated with herd, birth order (n), body mass index (BMI) > 17 (kg/m²), and colostrum IgG at t1 (g/L) with an overall P-value < 0.01. Herd D had the highest predicted mean level of piglet IgG. The main model predicted that piglet IgG decreased linearly by 0.4 g/L with each piglet born (P < 0.01). The model also predicted an increase by 0.1 g/L for each gram per liter extra colostrum IgG in colostrum (P = 0.03). Piglets with a BMI above 17 kg/m² had a greater piglet IgG (+4.5 g/L) than those with a BMI at 17 kg/m² or below (P < 0.01). Concentrations of colostrum IgG varied largely between herds and between sows. The largest variation of piglet IgG was mainly on the piglet level, supporting the complex nature of IgG production and uptake. However, the strong association between colostrum IgG and piglet IgG shows that increased IgG level in colostrum will improve the levels of IgG in piglets and potentially increase survival of the piglets.

Key words: body mass index, colostrum, immunoglobulin G, piglet, plasma, sow, swine


INTRODUCTION

Colostrum provides newborn piglets with energy for growth and heat production (Le Dividich, and Noblet, 1984; Herpin et al., 1994), provides passive immunity, and is essential for health and survival (Sangild, 2003). In swine, the epitheliocorial nature of the placenta prevents passive immunity transfer to the fetus. Immunoglobulin G (IgG) is the most clinically important globulin during the first weeks of life.
and IgG from colostrum is absorbed over the gastrointestinal tract during the first 24 to 48 h postpartum (Sjaastad et al., 2012). However, absorption of IgG in piglets is dependent on the timing of gut closure (Rooke and Bland, 2002). Genotype, parity, age, vaccination status, and endocrine status of the sow; fat composition of feed; and herd management are reported to influence colostrum yield and composition (Devillers et al., 2007; Farmer and Quesnel, 2008; Eastwood et al., 2014). Colostrum IgG varies greatly between sows. The concentration of IgG in sow colostrum is reported to range from 48.0 to 95.6 g/L in single herds (Klobasa and Butler, 1987; Tuchscherer et al., 2002; Svendsen et al., 2005; Couret et al., 2009; Foisnet et al., 2010; Bovey et al., 2014). In addition to animal factors, herd management is an important factor influencing piglet IgG. In a review by Kirkden et al. (2013), they suggest management solutions that will improve both colostrum IgG and piglet IgG concentrations. Providing extra attentions to small piglets in nonhomogenized litters may be necessary to ensure absorption of enough IgG in piglets (Muns et al., 2014). Uptake of IgG can be indirectly measured by recording piglet’s IgG in serum after birth (Svendsen et al., 2005). The aims of this study were to investigate the variation in concentration of colostrum IgG between herds and the individual sows within herd and to investigate factors associated with plasma IgG concentrations in piglets (piglet IgG).

**MATERIAL AND METHODS**

The experimental protocol for this study did not require approval by the Norwegian Animal Research Authority due to an exception for such procedures in the Norwegian regulations for animal testing (FOR 1996-01-15 no. 23, Regulation of animal testing, §2: Scope).
Management

Detailed housing and management characteristics are presented in Table 1. All herds used the same vaccination regime, for example, vaccination against *Escherichia coli*, porcine parvovirus, and *Erysipelothrix rhusiopathiae*. In each herd, gilts and sows were individually kept in loose-housed standard farrowing pens with a piglet creep area. The size of pens varied, but all pens were of equal size within each herd (details in Table 1). The sows were fed a commercial lactation diet, including small amounts of hay before farrowing (Table 1). All sows had ad libitum access to water. Farrowing was attended and allowed to start naturally. The automatic temperature regulation of the gestation rooms were set in all herds at 18 to 19°C. Manual intervention during farrowing was performed by the farmer if the birth interval between 2 piglets exceeded 90 min. In herd D, the first 6 to 8 firstborn piglets were dried and placed under a heat lamp until the second colostrum sample (midway through farrowing [just after the sixth piglet was born; t2]) was taken; see more details in the paper by Rootwelt et al. (2012b). Thereafter, the remaining piglets were placed at the udder. All herds had a mean weaning age of 33.0 d (±1.7).

Recorded Variables

Variables recorded at the herd level were introduction to farrowing pen, size of farrowing pen, and type of breed used when inseminating. Sow level variables recorded at each farrowing were parity, farrowing length, birth interval, litter size, and colostrum IgG.

Colostrum was sampled from sows immediately after expulsion of the first piglet and before the first suckling (t1), at t2, and after the last piglet was born (t3). The definition of last piglet born was when the contractions had stopped and after the expulsion of the placenta. Colostrum was collected from 3 random teats located in the anterior, middle, and posterior part of the udder. Colostrum from these 3 teats was pooled to 5 to 10 mL at each time point (t1, t2, and t3). The samples were frozen at −40°C and later analyzed for concentration of colostrum IgG with an in-house single radial immunodiffusion test kit (VMRD Inc., Pullman, WA). All of the laboratory analyses included 2 duplicates from the same sample. The mean of the duplicates is the final value used and compared with the other values obtained from the rest of the samples.

Time elapsed from expulsion of the first piglet until the birth of each subsequent piglet was recorded (birth time) as well as sex. All live piglets were weighed at birth (birth weight [BiW]; n = 805). In addition, we also obtained the weight in 566 piglets the next day (weight on d 1 [WD1]). The time from birth to second weighing was registered. Body length was measured within 24 h postpartum from the os occipitale to the root of the tail. Body mass index (BMI) was calculated using BW (kg) and the square of body length (m²) at birth: BMI = BiW (kg)/the square of body length (m²).

At d 1, 0.5 mL whole blood was evacuated from the vena jugularis externa/interna/communis of the piglets and collected in tubes containing EDTA as an anticoagulant (n = 692). Time from birth to blood sampling was recorded. The blood samples were subsequently stored at room temperature until they were centrifuged at 3,000 × g for 10 min at 20°C the next working day. Plasma was then frozen at −40°C until analysis of IgG with an in-house single radial immunodiffusion test kit (VMRD Inc.). Values below the lower detection limit of 3.8 g/L were defined as 0.

Colostrum yield was estimated by recording and adding the weight gain for each piglet from birth to d 1 (Couret et al., 2009). Estimated measures of colostrum intake per piglet were calculated using a formula designed by Theil et al. (2014): colostrum intake (g) = −106 + (2.26 × WG1) + (200 × BiW) + (0.111 × TS) − (1,414 × WG1)/TS + (0.0182 × WG1)/BiW. Time suckling (TS) was calculated from the time of birth until time of second weighing. Weight gain (WG1) was the difference between BiW and WD1.

Finally, regarding the regression analysis with piglet IgG concentration as the outcome, only 644 piglets of the 692 originally blood sampled animals were used. Four sows were excluded from the regression analysis due to missing values of colostrum IgG at t1, and their piglets were, therefore, also excluded. In litters with few piglets (<8), colostrum sampling was performed only at t1 and t2, and this led to several missing values at t3. Additionally, in herd D, no samples were collected at t3 due to the protocol in this herd. We also had missing WD1 values; however, this variable was not used in the regression analysis and did not influence the number of animals in the regression analysis.

Statistical Analyses

Descriptive statistics were performed using JMP (SAS Inst. Inc., Cary, NC) and STATA (Stata SE/10 for Windows; Stata Corp., College Station, TX). This was performed on the herd, sow, and piglet level. Box plots were used to explore and describe the development of IgG concentrations in colostrum throughout the farrowing in relation to factors at the sow level.

The outcome variable chosen for the regression analysis was piglet plasma IgG (g/L) on d 1. Predictor variables used in the analysis at sow level were parity, farrowing length, litter size, average birth intervals, and colostrum IgG at t1. Predictor variables at piglet
level were sex, birth order, birth time, and BMI at birth. Linearity between the continuous and dichotomous variables was investigated with graphs using a logit function in STATA, creating a scatterplot smoothing (lowess) line between the 2 variables. Plots, best linear fit, and $R^2$ were used to explore how different predictors explained the variation in colostrum IgG and piglet IgG.

As one of the aims was to explore the level of variation on each hierarchical level, the multilevel mixed effects linear regression model (xtmixed in STATA) was built by including herds and sows as random effects. However, as the 4 herds were individually selected and not randomly included in the study, the final model included herd as fixed effect ($\beta_1$) and sow as random effect. Therefore, none of the predictor variables at herd level could be included in the statistical model due to collinearity. This final model was used to estimate predictors associated with 644 piglet IgG samples.

In the model-building process, each variable was separately tested without any random effects included, and variables with a $P$-value < 0.20 within this univariable analysis were considered for inclusion in the final model.

When building the final model, a forward stepwise technique was used, starting with the variables with the lowest $P$-values from the separate variable analysis (Kielland et al., 2010). Therefore, any distortion and confounding could be observed as each variable was included. Confounding variables were tested by running the model with and without that variable. Running the model with and without extreme values of predictors was also performed. When exploring influencing values, no values were deleted from the analysis due to high influence. The variables giving a model with the best fit were chosen. If variables were highly correlated with each other (|$\rho$| > 0.8; Dohoo et al., 2009), only 1 of these variables was included.

In all analyses, statistical significance was considered with a $P$-value < 0.05. Goodness of fit for each model was evaluated and the best model was chosen. Normality plots of standardized residuals were evaluated and potential outliers and observations with large influence were explored. The model was tested with and without possible influencing points.

## RESULTS

### Sow and Litter Characteristics

Total mean parity was 2.7, ranging from 1 to 8, of which 28% were primiparous, 25% were parity 2, 24% were parity 3, and 23% were parity 4 to 8. Average litter size was 14.1 piglets, and the average farrowing length was 4 h, ranging from 1 to 12 h. Average birth interval between piglets was 18.3 min, ranging from 0 min to 8 h. One piglet had an interval of 8 h after the previous piglet, and this piglet was born dead and as the last one in that litter. After excluding that 1 piglet from the descriptive analysis, the range in birth interval was 0 min to 3 h. Number of piglets that were dead at birth was, on average, 1.27 per litter, ranging from 0 to 7 piglets. Average colostrum yield per sow at d 1, estimated from piglet’s individual weight gain, was 1.4 kg, ranging from 0.33 to 2.69 kg. Estimated colostrum yield was not significantly associated with litter size ($P = 0.69$).

Mean colostrum IgG across all samples was 53.9 g/L. Herds A and B had a mean colostrum IgG of 38.3 and 47.4 g/L, respectively, whereas herds C and D had a mean colostrum IgG of 60.4 and 67.8 g/L. Mean colostrum IgG at t1, t2, and t3 for all herds decreased throughout farrowing: 56.2, 46.8, and 42.5 g/L, respectively (Fig. 1; Table 2). Mean values at t2 and t3 do not include herd D. No significant difference in colostrum IgG concentrations across parity was found ($P > 0.05$).

### Piglet Characteristics

The average BiW was 1.46 kg, ranging from 0.48 to 2.53 kg. At d 1, the weight was, on average, 1.59 kg, ranging from 0.48 to 2.92 kg. Average weight difference on d 1 was 0.12 kg, ranging from –0.43 to 1.06 kg. This average weight gain was influenced by a reduction in BW from birth to d 1 in 4% of the piglets. When these piglets were excluded from the descriptive analysis, the average weight gain was 138 g. Male piglets ($n = 456$) weighed significantly more (60 g) at birth than females ($n = 366, P = 0.03$), with 1.48 and 1.42 kg, respectively.
Mean concentration of piglet IgG at d 1 was 21.7 g/L, ranging from 0 to 58 g/L. Estimated measure of colostrum intake, using the formula by Theil et al. (2014), was 353 g per piglet, ranging from 123 to 595 g, with only 3% of the piglets below 200 g. Estimated colostrum intake for each piglet was significantly associated with litter size ($P < 0.01$), with an estimate of 11 g lower intake with each additional piglet born. Mean BMI was 20.1 kg/m$^2$, ranging from 12.7 to 36.5 kg/m$^2$.

When exploring the association between the outcome (piglet IgG) and the predictor variables, the relationship between piglet IgG and BMI was significant but not a straight line (Fig. 2). Therefore, during the model-building process, we found a cut off at 17 kg/m$^2$. When the BMI was above 17.0 kg/m$^2$, it was no longer significantly associated with piglet IgG. With that as background, the BMI variable was categorized into 2 groups. One group was from 12.7 to 17 kg/m$^2$ ($n = 71$; baseline), and another was from 17.1 to 36.5 kg/m$^2$ ($n = 805$). This categorization significantly improved the model.

### Associations between Colostrum Immunoglobulin G and Plasma Immunoglobulin G

Explorative graphs of the total data set indicate a clear correlation between colostrum IgG at t1 and piglet IgG at d 1 (Fig. 3) and a distinct herd difference (Fig. 4). The lowess curve in Fig. 3 indicates that the piglet IgG level in plasma flattens out when colostrum IgG is above 60 g/L.

Multilevel linear regression analysis was performed with piglet IgG (g/L) as outcome and details are shown in Table 3. Because of strong herd effects, herd was included as fixed effect. Piglet IgG was associated with herd, birth order ($n$), BMI > 17 (kg/m$^2$), and colostrum IgG at t1 (g/L). Herd D had the highest

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### Table 2. Mean concentrations of colostrum immunoglobulin G (IgG) in the 4 herds at 3 time points (t1, t2, and t3) during farrowing and concentrations of IgG in piglet plasma (piglet IgG) at d 12

<table>
<thead>
<tr>
<th>Item</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colostrum IgG at t1</td>
<td>40.5</td>
<td>53.5</td>
<td>69.6**</td>
<td>64.2**</td>
</tr>
<tr>
<td>Colostrum IgG at t2</td>
<td>37.3</td>
<td>46.7</td>
<td>58.5**</td>
<td>69.9***</td>
</tr>
<tr>
<td>Colostrum IgG at t3</td>
<td>34.8</td>
<td>41.1</td>
<td>54.6***</td>
<td></td>
</tr>
<tr>
<td>Piglet IgG at d 1</td>
<td>18.2</td>
<td>19.7</td>
<td>22.2</td>
<td>26.3</td>
</tr>
</tbody>
</table>

1Colostrum was sampled from sows immediately after expulsion of the first piglet and before the first suckling (t1), midway through farrowing (just after the sixth piglet was born; t2), and after the last piglet was born (t3).

2Values marked with * differ from values in herd A (baseline): *$P < 0.05$; **$P < 0.01$; ***$P < 0.005$.

3No piglets suckled between t1 and t2 in herd D.

4In herd D, no samples at t3 were collected due to the protocol in this herd.

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**Figure 2.** Scatter plot of body mass index by piglet immunoglobulin G concentration in plasma on d 1, with a locally weighted smoothing (lowess) line (solid) between the 2 variables and a fitted regression line (broken line).

**Figure 3.** Scatter plot between piglet immunoglobulin G (IgG) and colostrum IgG concentrations. Colostrum was sampled immediately after expulsion of the first piglet and before the first suckling (t1) and before first suckling. Piglet plasma IgG concentrations were sampled at d 1. Solid line illustrates a locally weighted smoothing (lowess) line and the broken line is a fitted linear line with 95% confidence interval (CI) bands.
predicted mean level of piglet IgG. Piglet plasma IgG concentrations decreased linearly by 0.4 g/L with each piglet born and increased by 0.1 g/L with each gram per liter that the colostrum IgG increased. Piglets with a BMI above 17 kg/m² had a 4.5 g/L greater piglet IgG than those with a BMI at 17 kg/m² or below.

From this model, one could compare predicted piglet IgG of 2 average piglets in 2 different herds. Predicted piglet IgG concentrations of a piglet born as number 7, with a BMI above 17 kg/m², which suckled a sow with colostrum IgG of 56 g/L at t₁, and was born in herd D would have an estimated piglet IgG of 25.0 g/L. A piglet with identical characteristics in herd A would have an estimated IgG of 17.3 g/L. The difference between these 2 piglets is mainly due to the herd level difference (Table 3).

When including sow as a random effect in the model, 36% of the unexplained variance of plasma IgG between piglets resided at sow the level and 64% of the unexplained variation remains at the piglet level. This indicates that there is a large similarity between each piglet within each litter. When running the model with both herd and sow as random effects, the model calculates the level of unexplained variance on each of the 3 hierarchical levels. The variance at the sow level stays constant at 34%. Nine percent of the variance at the piglet level resides at the herd level and 57% at the piglet level.

**DISCUSSION**

Concentrations of plasma IgG in piglets is said to be dependent on the amount of available colostrum (Devillers et al., 2011), amount of colostrum ingestion, IgG absorption in the piglet’s gut (Jensen et al., 2001), and gut closure (Rooke and Bland, 2002). According to Jensen et al. (2001), 22.6% of colostrum IgG is absorbed by a piglet’s gut and the average piglet IgG has been found to be 35 g/L (Svendsen et al., 2005). Present findings on piglet IgG were lower than those found by others (Svendsen et al., 2005). However, Svendsen et al. (2005) used only 6 sows from 1 herd in a split study design and these sows had a high average mean concentration of colostrum IgG at almost 80 g/L. Our study indicates a strong association between the concentration of colostrum IgG and piglet IgG and that there are large variations between both sow and herd. The high level of colostrum IgG in the study by Svendsen et al. (2005) may, therefore, explain why they found such large mean piglet IgG concentration 27 h after birth.

The concentration of piglet IgG decreased with each piglet born. As litter size was not significantly associated with piglet IgG, this indicates that the time of birth relative to farrowing start is essential. Hence, being born late has a negative effect on the level of piglet IgG at d 1. This is in agreement with another study that concluded that the duration of farrowing is likely to affect the level of passive immunity acquired by piglets born late in the birth order (Bourne, 1969). Our results indicate that although being born late is not beneficial for acquiring passive immunity, the level of colostrum IgG counteracts that negative effect. Other studies have found that increased litter size is associated with increased neonatal death rate (Baxter et al., 2013; Rutherford et al., 2013). This is not only because of the increased litter size itself but rather because of prolonged farrowing. As the IgG in colostrum declines rapidly the first 24 h postpartum (Rooke and Bland, 2002), being born late means less available colostrum IgG, which may be one of the causes of increased preweaning mortality.

The positive association between colostrum IgG and piglet IgG supports the importance of high IgG levels in colostrum. In a recent review by Theil et al. (2014) on how to improve the quality and increase the concentration of colostrum IgG, one of the important nutrient factors is stated to be supplementation of fatty acids during late gestation, and another study points out that supplementation with long-chain n-6 and n-3 PUFA is especially important (Mitre et al., 2005). Others have found that vitamin supplementations given to sows could improve the IgG absorption in piglets (Rooke and Bland, 2002).

Body mass index was significantly associated with piglet IgG at d 1, and the degree of association flattened after the piglet reached a BMI of 17 kg/m². This indicates that piglets with BMI of 17 kg/m² and below may be too weak to acquire sufficient amounts of piglet IgG, as in the group above 17 kg/m². Interestingly, this is the
case regardless of all the other factors accounted for in the model, such as herd, parity, birth order, and colostrum IgG. One explanation for why a BMI below 17 kg/m² is negatively associated with piglet IgG may be that piglets with a BMI below 17 kg/m² might have experienced some level of intrauterine growth restriction (IUGR; Baxter et al., 2013; Hales et al., 2013). Body mass index may, therefore, give an indication of both the level of body lipid content and the level of adipose tissue present in newborns (Baxter et al; 2013). The results of Hales et al. (2013) indicate that body conformation is associated with postnatal survival risks and not BiW alone. The same study reports differences in morphology between piglets that had experienced IUGR and those that had not. Intrauterine growth restriction piglets have previously been found to have a lower BMI than those categorized as normal (Attig et al., 2008). Intrauterine growth restriction status was not identified in the present study; however, IUGR is a practical measure to identify low viability piglets.

Because of the decreased relative body surface area as BMI increases, piglets with a high BMI have reduced loss of body heat and body fluids compared with piglets with lower BMI, both of which are essential during the critical newborn period. In litters of unequal body sizes in particular, attending to less vital piglets may be necessary to ensure absorption of sufficient concentrations of IgG (Muns et al., 2014). Identification of these piglets at risk, therefore, is critical to ensure oral supplementation with the aim of increasing neonatal survival (Amdi et al., 2013). Oral supplementation has been found to deliver comparable IgG in the neonatal piglet (Campbell et al., 2012). The association between colostrum IgG and piglet IgG concentration differed among herds. One difference was that in herd D, each piglet was dried and placed under a heating lamp after birth. This management characteristic in herd D may explain why it had both the highest descriptive and the highest predicted mean levels of piglet IgG. Human support of weak piglets is reported to increase their ability to acquire immunity (Kirkden et al., 2013), and when piglets were either placed under the heat lamp or both dried and placed under the heat lamp, the mortality at weaning was reduced (Andersen et al., 2009). Another distinct herd difference was the time of sow introduction to the farrowing pen. A long adjustment period is assumed to be the best practice and may reduce stress. Stress can reduce the level of IgG in colostrum, as stress has an impact on the immune system (Couret et al., 2009). Our descriptive statistics indicate a difference between herds A and B and herds C and D regarding the colostrum IgG concentrations.

**Table 3.** Results from a mixed effects linear regression model with the concentration of piglet plasma immunoglobulin G (IgG) at d 1 as the outcome and multiple predictor variables

<table>
<thead>
<tr>
<th>Predictor variables</th>
<th>No. of piglets</th>
<th>β</th>
<th>SE</th>
<th>95% CI 1</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Herd</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>184</td>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>176</td>
<td>–7.7</td>
<td>2.3</td>
<td>–12.1</td>
<td>–3.2</td>
</tr>
<tr>
<td>B</td>
<td>170</td>
<td>–5.9</td>
<td>1.9</td>
<td>–9.6</td>
<td>–2.3</td>
</tr>
<tr>
<td>C</td>
<td>114</td>
<td>–4.7</td>
<td>2.2</td>
<td>–8.9</td>
<td>–0.4</td>
</tr>
<tr>
<td><strong>Parity</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>186</td>
<td>Baseline</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>173</td>
<td>1.1</td>
<td>1.9</td>
<td>–2.6</td>
<td>4.7</td>
</tr>
<tr>
<td>3</td>
<td>139</td>
<td>2.8</td>
<td>2.4</td>
<td>–1.9</td>
<td>7.4</td>
</tr>
<tr>
<td>4–8</td>
<td>146</td>
<td>3.6</td>
<td>2.3</td>
<td>–0.9</td>
<td>8.2</td>
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<tr>
<td>Birth order</td>
<td>644</td>
<td>–0.4</td>
<td>0.1</td>
<td>–0.5</td>
<td>–0.3</td>
</tr>
<tr>
<td>Colostrum IgG at t1, 3 g/L</td>
<td>644</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
</tr>
<tr>
<td>BMI ≤ 17 kg/m²</td>
<td>51</td>
<td>Baseline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI &gt; 17 kg/m²</td>
<td>593</td>
<td>4.6</td>
<td>1.0</td>
<td>2.7</td>
<td>6.5</td>
</tr>
<tr>
<td>Intercept 5</td>
<td>644</td>
<td>19.1</td>
<td>2.7</td>
<td>13.8</td>
<td>24.4</td>
</tr>
</tbody>
</table>

1CI = confidence interval.
258 sows were used in the analysis.
3t1 = immediately after expulsion of the first piglet and before the first suckling.
4BMI = body mass index.
5Random effect on sow level, accounting for dependency between each piglet in the same litter.

Immunoglobulin G acquisition in piglets is a passive absorption through the basolateral membrane of the enterocyte. The main impact of keeping piglets warm is a reduction of heat loss and improved thermoregulation ability; therefore, more body energy is available for sucking and competing for a teat. Therefore, keeping piglets warm might improve absorption of IgG in the intestine, but its main contribution is by enhancing vitality and

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capacity to suckle. The statistical model shows that the majority of the variance resides at the piglet level, meaning that when born, in whichever state, management and herd factors can account for only a certain proportion of the variation in IgG level in piglets. Therefore, it is important to explore factors of improvement at the piglet level, such as breeding for better vitality and an even piglet size in the litter. It is tempting to speculate whether prenatal maturity, as approximated by BMI, also influences the development of the intestine. One study has found that the intestinal mucosa is very sensitive to dietary stimuli in the time just after birth (Jensen et al., 2001). In addition, the motility of the intestines decreases with low body temperatures (Mallet, 2002). As a consequence, one may assume that keeping piglets warm gives an overall positive effect on absorption of IgG.

Mean concentration of IgG in sow colostrum is reported to be 61.8 mg/mL (Halliwell and Gorman, 1989). As in accordance with other studies (Quesnel, 2011; Rolinc et al., 2012), we found that colostrum IgG decreased during farrowing. This was expected as most colostrum is produced before farrowing (Theil et al., 2014). In a review by Roome and Bland (2002), they state that the level of colostrum IgG also changed greatly during the first 24 h after farrowing. Location of udder sampling (front vs. back teats) is also reported to effect the concentration of colostrum IgG of the sample (Inoue et al., 1980). We sampled from 3 locations and pooled the samples, thereby avoiding this difference.

Parity has been found to have an effect on colostrum quality (Devillers et al., 2007). Multiparous sows usually have increased colostrum yield; primiparous and old sows usually have a reduced colostrum yield. Colostrum is found to be of better quality in multiparous sows, providing better passive immunity than that in primiparous sows (Carney-Hinkle et al., 2013). The parity effect on colostrum IgG was explored in our study, but no significant difference was found. Studies have found that the vaccination status of the sow and immune difference between sows influence the level of colostrum IgG (Bourne et al., 1975). All 4 study herds used the same vaccination regime; nevertheless, we found a large variation in colostrum IgG levels between sows. One explanation may be the normal variation of the immunoreaction of each sow (Gudding, 2010). In the sow, maternal glucocorticoid levels influence lactogenesis (Farmer and Quesnel, 2008). In this study, no physiological or behavioral measures of stress in the farms were recorded. We therefore cannot conclude that farms A and B were operating under greater stress levels than farms C and D. One may, however, speculate whether factors affecting stress of the sow explain the differences in colostrum quality between the farms found in our study. One stress factor could be the short introduction period to the farrowing pen as previously mentioned. Another stress factor may be group housing during gestation. However, another study reported no difference between colostrum IgG in sows housed in different systems (Zhao et al., 2013).

The study went over a 2.5 y period, including seasonal changes and some variability of stockpersons. The feeding formulas remained the same throughout. In a field study involving different sow operations, there will always be some factors that must be adjusted for by accounting for the unexplained variance at the herd level. We feel confident that the aforementioned factors did not vary between herds to an extent that would alter our results and conclusions. However, the study must be interpreted within the limits of a larger field study.

Colostrum yield per sow varies between 0.85 and 5.6 L/per day (Foisnet et al., 2010; Quesnel, 2011). In the present study, colostrum yield was measured indirectly by recording and adding the weight gain for each piglet from birth to d 1 (Couret et al., 2009). One can argue that this estimate depends on the litter size and the piglets’ capability to suckle. Colostrum intake is influenced by piglet vitality, birth order, and total number of piglets born alive (Quesnel et al., 2012). However, a significant association between estimated colostrum intake by each individual piglet and litter size was found, as piglets in large litters received less colostrum. This indicates that litter size does affect intake of colostrum (Devillers et al., 2007) but not the concentration of piglet IgG in plasma, although this seems contradictory. Therefore, litter size was included in the model, but no signs of confounding effect were discovered. One explanation of this contradictory finding could be that the level of piglet IgG in plasma flattens out above a certain level of colostrum IgG. Our descriptive statistics indicate that such a level exists.

Several previous studies on colostrum IgG have been performed in single herds. In single herd studies, there are limitations in terms of low external validity. External validity is largest in epidemiological studies, when statistical analysis are used, and where the model accounts for both several predictors and for the unexplained variation on all hierarchical levels. With a mixed model, the distribution of the unexplained variation across the levels can be calculated. The present study shows how results regarding external validity are not necessarily robust, and extrapolation from the results should be done with care.

Interestingly, even when including herd as a fixed effect and indirectly accounting for various herd and management practices, 9% of the variation was on the herd level. This could mean that there are factors in a hierarchical level above herd, climate, breed, etc. that influence the piglet IgG concentrations. This un-
explained variation may be due to genetic difference of either sow or boar, which is in accordance with the review written by Farmer and Quesnel (2008). They found literature referring to breeding line differences in both colostrum composition and colostrum yield (Farmer and Quesnel, 2008).

Conclusion

Concentrations of colostrum IgG varied largely between herds and between sows. The largest variation of piglet IgG was mainly on the piglet level, supporting the complex nature of IgG production in sows and uptake in piglets. However, the strong association between colostrum IgG and piglet IgG shows that increased IgG levels in colostrum will improve the levels of IgG in piglets and potentially increase the survival of piglets as well.

LITERATURE CITED


