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Sow and piglet factors determining variation of colostrum intake between and within litters

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Colostrum intake has a short- and long-term beneficial impact on piglet performance and mortality. Sows' colostrum production and piglets' colostrum intake are limited and highly variable. The present study investigated sow and piglet factors explaining the variation of colostrum intake between and within litters. The CV for colostrum intake and birth weight (BW_b) of all piglets within a litter was calculated to evaluate the variation of colostrum intake and BW_b within a litter (colostrum and litter BW_b heterogeneity, respectively). A total of 1937 live-born piglets from 135 litters from 10 commercial herds were included. Colostrum intake per piglet averaged 371 ± 144 g and was affected by breed ($P = 0.02$). It was lower when oxytocin was administered to the sow during parturition ($P = 0.001$) and with increased litter size ($P < 0.001$). It was higher when the interval between birth and first suckling decreased (t_{FS}, $P < 0.001$). Colostrum intake was positively influenced by BW_b ($P < 0.001$) and this association was more pronounced in piglets from Topigs ($P = 0.03$) and Hypor ($P = 0.03$) sows compared with piglets from Danbred sow breeds. The positive relationship between colostrum intake and BW_b was more pronounced when t_{FS} lasted longer ($P = 0.009$). Heterogeneity in colostrum intake averaged 31 ± 11%, it increased when oxytocin was applied during farrowing ($P = 0.004$) and when stillbirth occurred ($P = 0.006$). Colostrum heterogeneity was positively associated with litter size ($P < 0.001$) and litter BW_b heterogeneity ($P = 0.01$). The positive relationship between colostrum and litter BW_b heterogeneity was more pronounced when oxytocin was applied during farrowing ($P = 0.04$). The present study demonstrated that oxytocin should be used cautiously in sows during farrowing. Farrowing and colostrum management should prevent or counteract the adverse influences of stillbirth, large and heterogeneous litters on colostrum intake and colostrum heterogeneity. The study also confirmed the expected association between BW_b and colostrum intake and indicated that the impact of BW_b on colostrum intake was different among breeds (Hypor v. *Danbred) and dependent on piglets' latency to first suckling. Hence, colostrum management should focus on low birth weight piglets, especially in some breeds, and low colostrum intake in low birth weight piglets can be counteracted by shortening the t_{FS}.*

Keywords: colostrum, heterogeneity, intake, piglets, variation

Implications

Piglets' colostrum intake is crucial regarding short- and long-term survival and performance. However, sows' colostrum production is limited and piglets' colostrum intake is highly variable between and within litters. Therefore, knowledge about factors determining colostrum intake variation within and between litters will enable pig producers to optimize colostrum management and ultimately maximize piglets' lifetime production potential.

Introduction

The crucial role of colostrum on piglet pre-weaning mortality and performance has been reported by several studies (e.g. Devillers *et al.*, 2007; Decaluwé *et al.*, 2014b). A longer-term impact on mortality and performance was suggested (Devillers *et al.*, 2011; Quesnel *et al.*, 2012) and has been recently demonstrated (Declerck *et al.*, 2016b). Hence, colostrum management is a promising tool to limit economic losses, health and welfare concerns in commercial pig herds. The supply of energy (Herpin *et al.*, 2005; Le Dividich *et al.*, 2005), immunity (Rooke and Bland, 2002) and bio-active compounds (Xu *et al.*, 2000) by colostrum may explain its positive short- and long-term effects. Total colostrum yield is reported to be independent from litter size (e.g. Devillers *et al.*, 2007; Foisnet *et al.*, 2010), compromising the individual piglet intake of sufficient colostrum in large litters of high-prolific sows. Moreover, piglets' colostrum intake is not only limited and highly variable across piglets between litters (Farmer and Quesnel, 2009), but also within litters

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(Le Dividich *et al*., 2005; Devillers *et al*., 2011). By understanding this variation, farrowing management can be adjusted to optimize the use of available colostrum between and within litters. Studies regarding colostrum intake in high-prolific commercial swine herds are needed to unravel the factors explaining the variation in piglets' colostrum intake. As colostrum intake depends on both the sow's ability to produce colostrum and the piglets' ability to extract, suckle and ingest the colostrum (Devillers *et al*., 2011), the present study aimed to unravel which sow and piglet factors determine the variation of colostrum intake between and within litters at commercial pig herds.

Material and methods

Study population and animal handling

In total, 135 litters comprising 1937 live-born piglets from 10 different commercial pig herds in Belgium were enrolled in the study. A detailed description of the study population can be found in Declerck *et al*. (2016a and 2016b). Studies were approved by the Ethical Committee of the Faculty of Veterinary Medicine, Ghent University, Belgium (no. 2013/98 and no. 2011/85). The herds were selected on the basis of willingness of the farmer to cooperate. In total, five different sow breeding lines were included: one of own crossbred Landrace and four commercial crossbred sows (PIC, Topigs, Hypor and Danbred). In each farm, only one sow breeding line was present. All sows were inseminated with semen from Piétrain boars. Table 1 represents the main herd characteristics, the number of studied sows per herd and the outcome and predictor variables per herd. Farrowing induction was not applied during the study period. Continuous farrowing supervision 24 h a day was performed and sows starting parturition during supervision were enrolled in the study. No restriction on parity or on gestation length was imposed. However, it was taken into account that parity and gestation length were randomly distributed across the different herds and breeds. The periparturient management routines of the herds were maintained as much as possible. The administration of oxytocin or manual birth assistance performed by the farrowing staff was registered. Immediately after birth, piglets were dried with a paper towel and weighed. The birth order was marked on their back and piglets were individually ear tagged and placed back on the place from where they were taken. Furthermore, time of birth and time of first suckling (teat in mouth) were registered. Piglets were weighed individually 24 h after birth of the first littermate. Cross-fostering was not allowed before the 2nd day of life.

Colostrum intake

Colostrum intake was estimated using the model described by Theil *et al*. (2014). This mechanistic model quantifies colostrum intake by sow-reared piglets with normal suckling pattern and normal physical activity compared with bottle-fed piglets. The model is based on 24-h weight gain (WG; g), birth weight (BW_b; kg) and duration of colostrum intake (D; min). Colostrum intake was only calculated from 1582 piglets as colostrum intake from piglets that died during the first 24 h was not calculated. Duration of colostrum intake was defined as the time between the first and the second weighing and is shown in the following equation: $-106 + 2.26\ \text{WG} + 200\ \text{BW}_b + 0.111\ \text{D} – 1414\ \text{WG/D} + 0.0182\ \text{WG/BW}_b$. To evaluate the variation of colostrum intake within a litter, the CV (%) for colostrum intake of all piglets within the litter was calculated by dividing the standard deviation of colostrum intake between littermates by the mean colostrum intake of a litter. This CV will further be referred to as colostrum heterogeneity.

Definitions and data handling

The outcome variables (piglets' colostrum intake and colostrum heterogeneity) were analyzed as continuous variables. The predictor variables at sow level were breed, parity, gestation length, duration of farrowing, use of oxytocin during parturition, manual birth assistance, stillbirth, litter size and litter BW_b heterogeneity. Sows belonged to five different breeding lines: crossbred Landrace, PIC, Topigs, Hypor or Danbred. In the present study, parity ranged from 1 to 11 and was categorized in three groups, namely: parity 1 (young sows), parity 2 to 4 (intermediate sows), parity 5 or higher parity (old sows). Gestation was assumed to start at the day of first insemination (day 0) and day of parturition was assumed to be the last day of gestation. Gestation length varied from 111 to 116 days and was categorized in three groups, namely 111 to 113 days (early parturition), 114 to 115 days (normal parturition) and 116 days (late parturition). The duration of farrowing was calculated as the time interval between the birth of the first and last live-born piglet. A stillborn piglet was defined as a piglet without signs of decay and found dead behind the sow. The use of oxytocin, manual birth assistance and the occurrence of stillbirth were considered as binary variables. Litter size was defined as the number of live-born piglets. To evaluate the birth weight variation within a litter, the CV for birth weight of all piglets within the litter was calculated and will be further referred to as litter BW_b heterogeneity. Litter size and litter BW_b heterogeneity were considered as continuous variables. The predictor variables at piglet level were the interval between birth and first suckling (t_{FS}), birth weight, birth rank, birth interval and gender. The interval between birth and first suckling was calculated on the basis of time of birth and the time of first suckling. All piglet factors were considered as continuous on behalf of the binary variable gender.

Statistical analysis

Basic descriptive statistics were used to explore the outcome variables (piglets' colostrum intake and colostrum heterogeneity) and predictor variables at sow level (breed, parity, gestation length, duration of farrowing, use of oxytocin during parturition, manual birth assistance, stillbirth, litter size and litter BW_b heterogeneity) and predictor variables at piglet level (t_{FS}, birth weight, birth rank, birth interval and gender). Colostrum intake, colostrum heterogeneity, farrowing duration, litter size, litter heterogeneity and

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birth weight were normally distributed, whereas parity, gestation length, t_{FS} and birth interval were not normally distributed. Results are reported as mean ± SD or median (IQR) when variables are normally or not normally distributed, respectively.

To model possible associations between the outcome and predictor variables, two linear mixed models were fitted. A random herd effect was included to correct for clustering of sows in a herd and to correct for confounding factors at herd level. Similarly, a nested random sow effect was included to correct for clustering of piglets within litters and to correct for confounding factors at the sow level. Initially, univariable linear mixed regression models between the outcome variables and each predictor variable were examined. Statistical significance in this step was assessed at $P < 0.20$. Furthermore, for continuous predictor variables, the assumption of linearity was examined by the Loess curves between each individual predictor variable and the outcome variables and by the scaled residuals of the univariable models. If necessary, transformation of the predictor variables or inclusion of higher order effects was considered. Regarding t_{FS} and birth interval, a log transformation was performed to obtain a linear association with the outcome variables. Second, Pearson's or Spearman's rank correlation coefficients, for either normally or not normally distributed independent variables, respectively, were calculated among the significant independent variables to avoid multicollinearity in the next steps. None correlation between two selected independent variables was higher than 0.60 and therefore, multicollinearity could be never assumed. Then, the independent variables were used to build a multivariable linear regression model by a manual stepwise backward model building procedure. Statistical significance in this step was assessed at $P < 0.05$. The estimates of the significant predictor variables are presented with their corresponding 95% confidence interval. Finally, all two-way interactions were tested and removed when non-significant ($P > 0.05$). To check whether the assumptions of normality and homogeneity of variance had been fulfilled normal probability plots of residuals and plots of residuals *v.* predicted values were generated. Influence of outliers was tested through Cook's distance, DFFITS (the change in the predicted value for a point, obtained when that point is left out of the regression), and DFBETAS (the standardized difference in the parameter estimate due to deleting the observation). No influential cases were found. Statistical analysis was performed in SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Descriptive results

Factors at sow and piglet level determining the variation of colostrum intake of 1582 piglets were recorded. Colostrum intake per piglet averaged 371 ± 144 g. Colostrum heterogeneity averaged 31 ± 11%. Sows had a median parity of 3 [2; 5] and a median gestation length of 115 [114; 116] days. Farrowing lasted on average 221 ± 99 min. Oxytocin was administered to 49 (36%) sows and manual birth assistance was offered to 27 (20%) sows. Stillbirth occurred in 74 (55%) litters. Litter size averaged 14 ± 3 live-born piglets. Litter heterogeneity was 20 ± 6%. The median interval between birth and first suckling lasted 37 [20; 67] min. Piglets' birth weight averaged 1.28 ± 0.32 kg. The median birth interval was 9 [3; 18] min. The number of male live-born piglets was 952 (49%). At the herd level, descriptive data of the outcome and predictor variables are summarized in Table 1.

Colostrum intake

Parity, gestation length, manual birth assistance, stillbirth and birth rank did not affect piglets' colostrum intake regarding univariable analysis ($P > 0.20$). Breed, the use of oxytocin during farrowing, litter size, birth weight and t_{FS} were retained in the final multivariable model. No multicollinearity was assumed between the remaining variables. In the final multivariable mixed model (Table 2), two significant interaction terms (birth weight × breed and birth weight × t_{FS}) were included. In order to interpret the interacted parameters (birth weight, breed and t_{FS}) in a more comprehensive way, the variable birth weight was centred by subtracting the mean birth weight (1.28 kg). Hence, interaction terms become 0 when the model considered piglets with the mean birth weight. The intercept represents a Danbred piglet with a mean birth weight which dam was not injected with oxytocin during farrowing. The intercept is associated with a mean colostrum intake of 570 g (95% CI 472 to 667).

Colostrum intake per piglet varied significantly with breed ($P = 0.02$). Considering piglets with an average birth weight (1.28 kg), Hypor piglets consumed 50 g (95% CI 14 to 87) more colostrum compared with Danbred piglets ($P = 0.007$). Colostrum intake per piglet decreased on average 37 g (95% CI 15 to 59) when oxytocin was applied to the dam ($P = 0.001$). Colostrum intake was negatively associated with litter size as piglets' colostrum intake decreased on average 9 g (95% CI 6 to 13) for each additional live-born piglet ($P < 0.001$). A positive association between colostrum intake and birth weight was observed ($P < 0.001$), for example, colostrum intake by Danbred piglets with a t_{FS} of 1 min increased on average 152 g (95% CI 62 to 242) with each increase of 1 kg in birth weight. Furthermore, the strength of this positive association between colostrum intake and birth weight varied across breeds (Figure 1). Regarding piglets with a t_{FS} of 1 min, a higher birth weight of an additional kilogram resulted in a significantly steeper increase of colostrum intake in Topigs (215 g, 95% CI 134 to 297) compared with Danbred piglets (152 g, 95% 62 to 242) ($P = 0.03$), and in Hypor (211 g, 95% CI 132 to 290) compared with Danbred piglets (152 g, 95% 62 to 242) ($P = 0.03$). A positive association between colostrum intake and t_{FS} was observed. Considering piglets weighing the mean birth weight (1.28 kg), piglets' colostrum intake decreased on average 15 g (95% CI 8 to 22) with each unit

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Table 1 *Herd characteristics, the number of studied sows per herd and the herd averages ± SD with regard to the outcome and predictor variables from 1582 piglets originating from 135 litters on 10 commercial pig herds*

	Herd number									
	1	2	3	4	5	6	7	8	9	10
Breed of sows	Crossbred Landrace	PIC	Topigs	Topigs	Topigs	Hypor	PIC	Danbred	Danbred	Hypor
Number of sows	300	1700	450	520	450	600	700	750	300	600
Batch-production system (weeks)	3	2	5	5	4	4	3	2	4	4
Lactation period (weeks)	4	3	3	3	3	3	4	3	3	3
Piglets weaned/sow per year	25	27	30	25	26	27	26	28	30	27
Number of studied sows	10	35	10	10	10	20	10	10	10	10
Colostrum intake (g)	380 ± 139	367 ± 151	389 ± 124	353 ± 117	345 ± 140	426 ± 145	387 ± 154	290 ± 108	324 ± 115	432 ± 159
Colostrum heterogeneity[1] (%)	33 ± 16	33 ± 11	30 ± 8	24 ± 8	36 ± 11	30 ± 9	33 ± 12	31 ± 10	34 ± 7	30 ± 13
Sow factors										
Parity	3.8 ± 3.2	3.9 ± 2.0	3.2 ± 1.6	2.7 ± 2.3	4.5 ± 2.6	4.7 ± 2.8	3.9 ± 1.7	3.9 ± 1.0	3.5 ± 1.0	3.6 ± 2.0
1 (*n*)	3	2	0	3	1	2	1	1	1	2
2 to 4 (*n*)	4	20	9	5	6	9	5	6	8	4
5 to 11 (*n*)	3	13	1	2	3	9	4	3	1	4
Gestation length (days)	114.5 ± 0.5	114.0 ± 1.4	113.7 ± 0.5	114.1 ± 0.3	114.3 ± 0.5	115.5 ± 0.7	115.0 ± 0.4	114.9 ± 0.5	115.5 ± 0.7	114.3 ± 0.4
111 to 113 (*n*)	0	14	3	0	0	2	0	1	0	0
114 to 115 (*n*)	10	15	7	10	10	6	9	9	4	10
116 (*n*)	0	6	0	0	0	12	1	0	6	0
Parturition duration (min)	204 ± 48	205 ± 61	258 ± 109	203 ± 61	243 ± 74	193 ± 98	226 ± 122	172 ± 35	349 ± 135	213 ± 91
Presence of stillbirths (*n*)	4	24	5	5	8	19	4	3	6	5
Use of oxytocin (*n*)	3	5	3	3	8	15	2	4	5	1
Manual palpation (*n*)	4	9	2	1	0	3	3	1	2	2
Litter size (*n*)	13.3	14.5	15.8	14.8	14.9	14.1	12.7	17.1	18.1	14.9
Litter heterogeneity[2] (%)	20.0 ± 5.7	23.8 ± 6.5	20.9 ± 5.0	17.4 ± 6.1	17.6 ± 7.1	20.9 ± 6.6	22.5 ± 3.7	20.4 ± 4.8	18.2 ± 3.2	19.4 ± 5.5
Piglet factors										
t_{FS}[3] (min)	39 ± 35	37 ± 46	35 ± 27	52 ± 45	41 ± 22	51 ± 43	56 ± 39	62 ± 49	79 ± 56	48 ± 48
Birth weight (kg)	1.37 ± 0.30	1.17 ± 0.34	1.20 ± 0.31	1.17 ± 0.30	1.23 ± 0.30	1.33 ± 0.35	1.30 ± 0.35	1.19 ± 0.30	1.26 ± 0.28	1.39 ± 0.29
Birth rank										
Birth interval	20 ± 27	15 ± 20	17 ± 23	16 ± 21	15 ± 17	15 ± 30	20 ± 26	10 ± 13	21 ± 34	13 ± 20
Gender (%)										
Male	54	48	50	44	46	55	47	46	50	55
Female	46	52	50	56	54	45	53	54	50	45

[1]Colostrum heterogeneity = the CV for colostrum intake of all piglets within a litter (%).
[2]Litter heterogeneity = the CV for birth weight of all piglets within a litter (%).
[3]t_{FS} = the interval between birth and first suckling (min).

Table 2 *Parameter estimates of the multivariable linear mixed model with colostrum intake (g) as the outcome variable*

Predictor variables	Estimate	*F*-value (df)	*P*-value
Breed		3.03 (4, 1380)	0.017
Own crossbred Landrace	−14		0.57
PIC	22		0.28
Topigs	26		0.15
Hypor	50		0.007
Danbred	Ref.		
Use of oxytocin during farrowing			
Yes	−37	10.83 (1, 1380)	0.001
No	Ref.		
Litter size (*n*)	−9	24.42 (1, 1380)	<0.001
Log t_{FS}[1] (min)	−15	17.80 (1, 1380)	<0.001
Birth weight (kg) (centred)	152	19.83 (1, 1380)	<0.001
Birth weight (centred) × breed		17.80 (1, 1380)	<0.001
Own crossbred Landrace	−15		0.68
PIC	−14		0.64
Topigs	63		0.03
Hypor	59		0.03
Danbred	Ref.		
Birth weight (centred) × log t_{FS}	26	6.90 (1, 1380)	0.009

[1]t_{FS} = the interval between birth and first suckling (min).

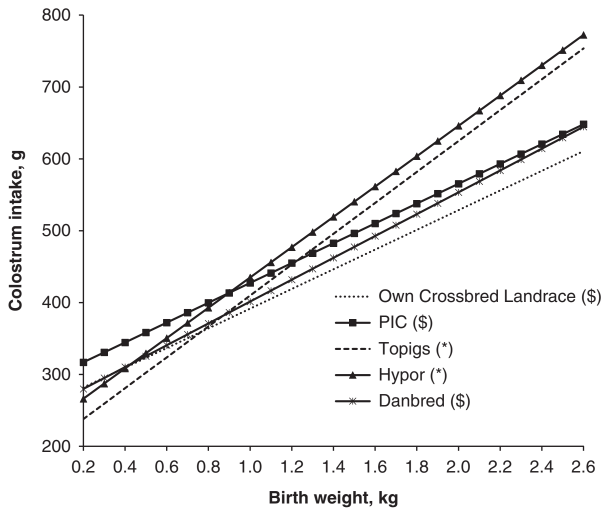

Figure 1 To illustrate the interaction between birth weight and breed on colostrum intake, hypothetical groups of piglets of different breeds with birth weights varying between the minimum (0.2 kg) and maximum (2.6 kg) observed birth weight, with an interval between birth and first suckling of 1 min and originating from litters with 14 live-born piglets which dam was not injected with oxytocin were generated. For all breeds, a positive association between colostrum intake and birth weight was observed. However, this association was more pronounced (steeper slope) for Topigs and Hypor piglets (symbol '*') compared with the other breeds (symbol '$').

increase of log t_{FS}. The strength of this positive association between colostrum intake and birth weight was more pronounced for longer t_{FS} (Figure 2). Regarding Danbred piglets, a higher birth weight of an additional kilogram resulted in a significantly steeper increase of colostrum intake if t_{FS} lasted longer (P = 0.009).

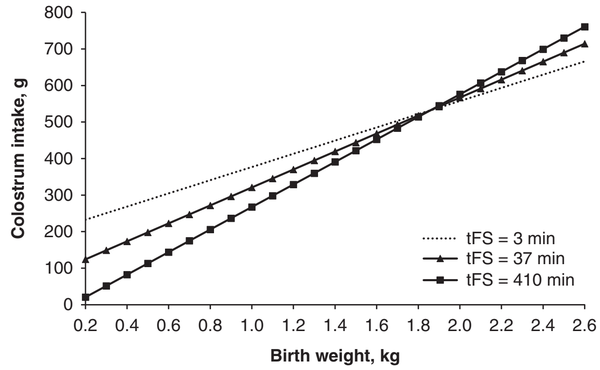

Figure 2 To illustrate the interaction between birth weight and the interval between birth and first suckling (t_{FS}) on colostrum intake, hypothetical groups of Danbred piglets with birth weights varying between the minimum (0.2 kg) and maximum (2.6 kg) observed birth weight, with t_{FS} lasting 3 min (minimum), 37 min (median) and 410 min (maximum), and originating from litters with 14 live-born piglets which dam was not injected with oxytocin were generated. For all t_{FS}, a positive association between colostrum intake and birth weight was observed. However, this association was more pronounced (steeper slope) for longer t_{FS}.

Colostrum heterogeneity

Breed and gestation length were excluded by univariable analysis (P > 0.20). Stillbirth, the use of oxytocin during farrowing, litter size, litter BW_b heterogeneity were retained in the final multivariable model. No multicollinearity was assumed between the remaining variables. In the final multivariable mixed model (Table 3), a significant interaction term (the use of oxytocin × litter BW_b heterogeneity) was included. In order to interpret the interacted parameters (the use of oxytocin during parturition and litter heterogeneity) in a more comprehensive way, the variable litter BW_b heterogeneity was centred by subtracting the mean litter BW_b heterogeneity (20%). Hence, the interaction term became 0 when the model considered litters with the mean litter BW_b heterogeneity (20%).

In litters with the mean litter BW_b heterogeneity (20%), the colostrum heterogeneity increased on average 5.03% (95% CI 1.64 to 8.42) when oxytocin was administered to the dam (P = 0.004; Figure 3). In litters with stillbirth, colostrum heterogeneity was 4.58% (95% CI 1.38 to 7.78) higher compared with litters without stillbirth (P = 0.006). For every extra live-born piglet, colostrum heterogeneity increased 0.99% (95% CI 0.42 to 1.57) (P < 0.001). A positive association between colostrum heterogeneity and litter BW_b heterogeneity was observed. Furthermore, the strength of this positive association between colostrum heterogeneity and litter BW_b heterogeneity was more pronounced when oxytocin was applied during farrowing (Figure 3). When oxytocin was not applied during farrowing, colostrum heterogeneity increased 0.40% (95% CI 0.09 to 0.72) with each 1% increase in the litter BW_b heterogeneity (P = 0.01). When oxytocin was applied, colostrum heterogeneity increased 0.95% (95% CI 0.50 to 1.42) with each 1% increase in the litter BW_b heterogeneity (P = 0.04).

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Table 3 *Parameter estimates of the multivariable linear mixed model with colostrum heterogeneity[1] (%) as the outcome variable*

Predictor variable	Estimate	*F*-value (df)	*P*-value
Use of oxytocin during farrowing			
Yes	5.03	8.63 (1, 119)	0.004
No	Ref.		
Stillbirth			
Yes	4.58	8.01 (1, 119)	0.006
No	Ref.		
Litter size (*n*)	0.99	11.61 (1, 119)	<0.001
Litter heterogeneity[2] (%) (centred)	0.40	22.07 (1, 119)	0.01
Use of oxytocin × litter heterogeneity (centred)			
Yes	0.55	4.23 (1, 119)	0.04
No	Ref.		

[1]Colostrum heterogeneity = the CV for colostrum intake of all piglets within a litter (%).
[2]Litter heterogeneity = the CV for birth weight of all piglets within a litter (%).

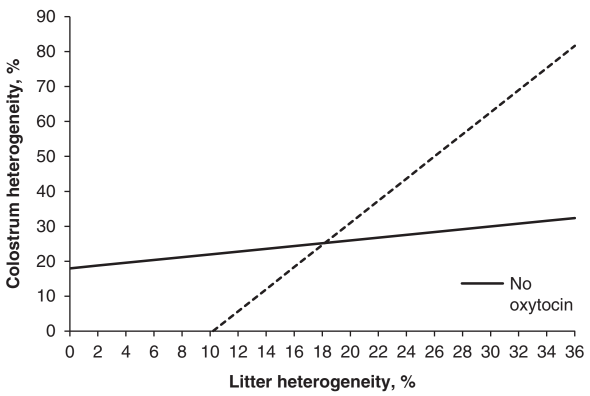

Figure 3 To illustrate the interaction between the use of oxytocin and litter heterogeneity on colostrum heterogeneity, hypothetical litters with 14 live-born and no stillborn piglets and with a litter heterogeneity varying between the minimum (0%) and maximum (36%) observed litter heterogeneity were generated. Regardless whether oxytocin was used during farrowing or not, a positive association between colostrum heterogeneity and litter heterogeneity was observed. However, this association was more pronounced (steeper slope) when oxytocin was used.

Discussion

Most previous studies estimated colostrum intake by the regression equation of Devillers et al. (Devillers *et al.*, 2004 and 2007; Quesnel, 2011; Decaluwé *et al.*, 2014b), whereas colostrum intake in this study was estimated by the mechanistic model of Theil *et al.* (2014). As Devillers' equation was obtained from bottle-fed piglets, colostrum intake of sow-reared piglets is underestimated (mainly) because of the lower amount of energy needed to obtain colostrum in bottle-fed *v.* sow-reared piglets. The equation by Theil *et al.* (2014) is believed to quantify the colostrum intake of sow-reared piglets more accurately and therefore better suited for this study with sow-reared piglets. As the study was conducted across different commercial herds, the present results have a high external validity and practical relevance.

Breed

In the present study, piglets' colostrum intake was affected by breed. To our knowledge, previous studies did not observe any relationship between colostrum intake and breed, as most of them included only one breed (e.g. Devillers *et al.*, 2007; Decaluwé *et al.*, 2014a and 2014b). Several hypotheses could explain this association. First, colostrum production and hence, colostrum intake might be different among breeds. However, in previous work, we showed that colostrum yield did not differ significantly between breeds (Declerck *et al.*, 2015). Therefore, the explanation of the association between breed and colostrum intake is more likely related to the significant differences between breeds regarding litter size, birth weight and t_{FS} (data not shown). Also other breed factors, such as udder morphology or teat access (Vasdal and Larsen, 2012; Ocepek *et al.*, 2016) might influence the different colostrum intake between breeds.

Oxytocin

When oxytocin was administered during farrowing to the sow, colostrum intake decreased, colostrum heterogeneity increased and the strength of the positive association between colostrum and litter BW_b heterogeneity was more pronounced. These observations seem to be contradictory regarding the role of oxytocin in milk ejection, *postpartum* mammary growth and mobilization of body reserves (Kent *et al.*, 2003; Valros *et al.*, 2004). However, some hypotheses can explain the observed negative impact of oxytocin administration on colostrum intake and colostrum heterogeneity. First, the lower colostrum intake could be due to the underlying indication of oxytocin administration. Oxytocin might be indicated to shorten farrowing duration or speeding up placenta expulsion (Alonso-Spilsbury *et al.*, 2004; Peltoniemi *et al.*, 2016). The hormones involved in the parturition process are also involved in milk production and milk ejection. Hence, hormonal imbalances resulting in prolonged farrowing and leading to the use of oxytocin may be the underlying mechanism of a lower colostrum production resulting in a lower piglets' colostrum intake. Second, the lower colostrum intake and the higher colostrum heterogeneity could be related with the consequences of oxytocin (mis)use such as a higher risk of dystocia and *intrapartum* asphyxia (Alonso-Spilsbury *et al.*, 2004; Mota-Rojas *et al.*, 2005). *Intrapartum* asphyxia impairs the vitality in piglets and hence, compromises their colostrum intake (Mota-Rojas *et al.*, 2005). The use of oxytocin increased the influence of litter BW_b heterogeneity on colostrum heterogeneity as the risk of asphyxia and impaired vitality by oxytocin (misuse) (Mota-Rojas *et al.*, 2005) might be higher in heterogeneous litters with more low birth weight piglets (Milligan *et al.*, 2001) as low birth weights are more susceptible to *intrapartum* asphyxia compared with normal birth weight littermates (Herpin *et al.*, 1996; Pedersen *et al.*, 2011). Finally, the injection itself and the myometrial contractions induced by oxytocin might also be stressful and harmful to sows and hence, compromise suckling behaviour and milk letdown by the sows. Further research is needed

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to elucidate how oxytocin should be used with regard to colostrum management.

Stillbirth
Colostrum heterogeneity was higher in litters with stillbirth. Quesnel *et al.* (2012) reported that colostrum yield was negatively associated with the number of stillborn piglets and hence, the lower amount of colostrum in litters with stillbirth could result in more competition among littermates leading to higher colostrum heterogeneity. However, stillbirth was not related with colostrum yield in a previous study (Declerck *et al*., 2015). The current observation of higher colostrum heterogeneity in litters with stillbirth might be associated with the fact that in litters with stillbirth, the liveborn littermates might also be weakened by temporary hypoxia (Herpin *et al*., 1996).

Litter size
When litter size increased, colostrum intake decreased and colostrum heterogeneity increased. As colostrum production is independent from litter size (e.g. Le Dividich *et al*., 2005; Foisnet *et al*., 2010; Quesnel *et al*., 2012; Declerck *et al*., 2015), colostrum intake is especially limited in large litters. Large litters are associated with more competition and teat fights (Milligan *et al*., 2001) and hence, colostrum ejection might be disturbed (Andersen *et al*., 2011). Moreover, in large litters, litter heterogeneity is increased by the higher proportion of low birth weight piglets (Milligan *et al*., 2001; Quiniou *et al*., 2002), implying a higher colostrum heterogeneity with increased litter size. In large litters, it is of utmost importance to use the available amount of colostrum optimally among littermates by proper management practices (Vasdal *et al*., 2011; Muns *et al*., 2015 and 2016).

Litter birth weight heterogeneity
In the present study, colostrum intake by small piglets was negatively correlated with litter heterogeneity (data not shown). Therefore, the observed positive relationship between colostrum and litter BW_b heterogeneity can be linked to the fact that low birth weight piglets are disadvantaged in heterogeneous litters.

Birth weight
On the basis of equation to estimate colostrum intake, birth weight largely determines colostrum intake. However, the multivariable model revealed a higher impact of birth weight on colostrum intake than calculated from the equation itself, which is in agreement with the findings of Devillers *et al.* (2007). The observed positive association between birth weight and colostrum intake is in accordance with previous studies (Tuscherer *et al*., 2000; Le Dividich *et al*., 2005; Devillers *et al*., 2007). It might be linked to a higher vitality, competitive advantage at the udder and a higher ability to suckle colostrum from teats (Le Dividich *et al*., 2005; Devillers *et al*., 2007) in heavier *v.* lighter piglets. Colostrum management should focus on low birth weight piglets, especially in Topigs and Hypor sows because of the interaction between birth weight and breed on colostrum intake.

The interval between birth and first suckling
The present study observed a higher colostrum intake in piglets with short latency to first suckling, which agrees with the role of t_{FS} as a vitality parameter in newborn piglets (Tuchscherer *et al*., 2000; Baxter *et al*., 2008). Vitality immediately after delivery is the first factor influencing the acquisition of colostrum by piglets (Devillers *et al*., 2007; Quesnel *et al*., 2012). Piglets suckling colostrum fast *v*. slow after delivery were reported to have higher weaning weights and pre-weaning survival rates (Quesnel *et al*., 2012; Decaluwé *et al*., 2014b; Declerck *et al*., 2016b). The observed negative association between colostrum intake and t_{FS} agrees with the observation that measures helping piglets get to the udder are beneficial for survival (Vasdal *et al*., 2011). The interaction between t_{FS} and birth weight on colostrum intake confirms that both are important vitality parameters (Devillers *et al*., 2007; Baxter *et al*., 2008; Foisnet *et al*., 2010) and may compensate each other. Hence, facilitating the smallest piglets to access the udder might be promising to optimize colostrum intake in low birth weight piglets.

Conclusion

Colostrum intake and heterogeneity are affected by different factors at sow and piglet level. Oxytocin during delivery should be used cautiously as it was negatively related with colostrum intake and increased the heterogeneity in colostrum intake. Furthermore, management measures are needed to prevent or counteract the adverse influences of stillbirth (e.g. parturition supervision), large and heterogeneous litters (e.g. supplementation with colostrum) on colostrum intake and heterogeneity. Colostrum management should focus on low birth weight piglets. The positive association between birth weight and colostrum intake was different among breeds and hence, especially in Topigs and Hypor breeds, efforts should be made to increase birth weight and to favour colostrum intake of low birth weight piglets. Farmers can anticipate the adverse influence of low birth weight on colostrum intake by shortening t_{FS} (e.g. drying and placing the piglets at the udder). Colostrum management should be tailored to specific farm observations in order to optimize colostrum intake across piglets between and within litters and ultimately to maximize piglets' lifetime production.

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