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Changes in back fat thickness during late gestation predict colostrum yield in sows

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Directing protein and energy sources towards lactation is crucial to optimise milk production in sows but how this influences colostrum yield (CY) remains unknown. The aim of this study was to identify associations between CY and the sow's use of nutrient resources. We included 37 sows in the study that were all housed, fed and managed similarly. Parity, back fat change (ΔBF), CY and performance parameters were measured. We obtained sow serum samples 3 to 4 days before farrowing and at D1 of lactation following overnight fasting. These were analysed for non-esterified fatty acids (NEFA), urea, creatinine, (iso) butyrylcarnitine (C4) and immunoglobulins G (IgG) and A (IgA). The colostrum samples collected 3, 6 and 24 h after the birth of the first piglet were analysed for their nutrient and immunoglobulins content. The technical parameters associated with CY were parity group (a; parities 1 to 3 = value 0 v. parities 4 to 7 = value 1) and ΔBF D85-D109 of gestation (mm) (b): CY (g) = 4290–842a–113b. ($R^2 = 0.41$, $P < 0.001$). The gestation length ($P < 0.001$) and the ΔBF between D109 and D1 of lactation ($P = 0.050$) were identified as possible underlying factors of the parity group. The metabolic parameters associated with CY were C4 at 3 to 4 days before farrowing (a), and 10logC4 (b) and 10logNEFA (c) at D1 of lactation: CY (g) = 3582–1604a + 1007b − 922c ($R^2 = 0.39$, $P = 0.001$). The colostrum composition was independent of CY. The negative association between CY and ΔBF D85-D109 of gestation could not be further explained based on our data. Sows that were catabolic 1 week prior to farrowing seemed unable to produce colostrum to their full potential. This was especially the case for sows with parities 4 to 7, although they had a similar feed intake, litter birth weight and colostrum composition compared with parities 1 to 3 sows. In conclusion, this study showed that parity and the use of body fat and protein reserves during late gestation were associated with CY, indicating that proper management of the sow's body condition during late gestation could optimise the intrinsic capacity of the sow's CY.

Keywords: colostrum, sow, condition, parity

Implications

Pre-weaning piglet mortality is mainly due to an energy deficit. As colostrum is the piglets' main source of energy, improving colostrum yield (CY) has economical and ethical benefits. Throughout gestation, changes in body's reserves have to be closely monitored, because of their association with nutrient partitioning in the sow and CY. As CY is vital to sustain piglet performance, evaluating the management measures in order to modulate back fat changes in late gestating sows is therefore recommended.

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Introduction

The two principal functions of colostrum are delivering energy and passive maternal immunity to the piglet (Rooke and Bland, 2002; Le Dividich *et al.*, 2005). The piglets' energy reserves at birth can provide about 420 kJ/kg birth weight (BW_B): this hardly exceeds half of the amount of energy a newborn piglet needs under thermoneutral conditions (Noblet *et al.*, 1997; Le Dividich *et al.*, 2005). The additional energy needed to maintain a constant body temperature and for weight gain must be supplied through colostrum intake (CI). Furthermore, the piglets depend entirely on colostrum in order to obtain passive maternal immunity because the epitheliochorial type of placenta disables its prenatal delivery

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(Rooke and Bland, 2002; Salmon *et al.*, 2009). Le Dividich *et al.* (2005) stated that the piglet needs to consume at least 160 g colostrum/kg BW_B.

Pre-weaning mortality ranges between 10% and 13% in the main pig-breeding countries (Edwards, 2002) and piglets usually die during the first 3 days after birth (Le Dividich *et al.*, 2005). Inadequate CI by the piglet is a major direct and subjacent cause of mortality during the first days after birth mainly due to hypothermia and hypoglycaemia (Le Dividich *et al.*, 2005). In addition, insufficient intake of maternally derived immunoglobulins will have a negative effect on the piglets' health status, thus weight gain and survival, at later stages in life (Rooke and Bland, 2002; Le Dividich *et al.*, 2005).

Previous studies have shown that the total colostrum yield (CY) per sow is 3.4 kg on average, but varies largely among sows (Devillers *et al.*, 2007; Foisnet *et al.*, 2010). This variation can be attributed to environmental-related factors, the piglet's and the sow's characteristics (Devillers *et al.*, 2007; Farmer and Quesnel, 2009; Quesnel, 2011). The litter size was not correlated with total CY (Devillers *et al.*, 2007) and the CI with bottle-fed piglets rendered twice as much CI compared with sow-reared piglets (Le Dividich *et al.*, 1997), which indicates that the total CY is the major limiting factor for the CI. In general, there is insufficient information available to thoroughly understand how CY can be increased in sows. It is well established that the optimal availability of energy and protein is central in maximising the intrinsic capacity of the sow's milk production (Boyd *et al.*, 1995). Foisnet *et al.* (2010) suggested that sow's peripartal hormonal changes, its insulin sensitivity and the availability of glucose might play an important role in the total CY.

According to our knowledge, studies investigating the partitioning of nutrients in relation to CY are scarce and the association with the sow's body condition has never been described. Therefore, the aim of this study is to identify associations between the changes in energy stores and the nutrient metabolism in late gestating sows and CY.

Material and methods

Description of study population

The experiment was performed during the months of April and May 2011 at a commercial farm in Flanders with 1700 PIC (Pig Improvement Company) sows in a 2-week batch system. Thirty-seven sows of different parities (1 to 7), equally divided over 2-week groups, were observed from D85 of gestation until D3 of lactation. The day of first insemination was defined as D0 of gestation, and the day of parturition as the last day of gestation and D0 of lactation.

From D29 until D107 of gestation, the sows were housed in a group housing system with 15 animals per pen. On D108 of gestation, the sows were moved to the farrowing unit where they were housed individually in conventional farrowing crates until weaning. Floor heating and an IR lamp were used to create a microclimate for the piglets.

Between D85 and D107 of gestation, the gestation diet (pellets) was provided by two feeders per pen that dropped a small amount of feed at regular intervals throughout the day at an average level of 2.2 kg/sow per day. In the farrowing unit, the sows were manually fed a transition diet (meal) once a day, until D1 or 2 after farrowing. When a sow had not finished the meal of the previous day, the trough was emptied and a smaller amount of fresh feed was given. Starting from D2 or 3 of lactation, the sows received a lactation diet (meal) four times a day. Average ± s.e.m. feed intake (kg) 6, 5, 4, 3, 2, 1 days before parturition, at day of parturition and 1, 2, 3 days after parturition was 2.0 ± 0.0, 1.9 ± 0.1, 1.8 ± 0.01, 1.8 ± 0.01, 1.9 ± 0.01, 1.9 ± 0.01, 1.7 ± 0.1, 1.8 ± 0.1, 3.7 ± 0.3, 4.9 ± 0.2, respectively. During the entire experiment, the sows had free access to fresh drinking water (drinking nipple – flow 1.5 to 2 l/min).

The induction of parturition was not applied, and farrowing intervention was kept to a minimum. When the birth interval between two piglets exceeded one hour, manual extraction was performed. Oxytocin was not administered during parturition, as this interferes with mammary secretion (Ellendorf *et al.*, 1982). No additional help or care was given to the piglets unless there was a risk of them getting crushed.

On D2 of lactation, the litters were standardised to 11 ± 1 piglet by cross-fostering within the observed group of sows or to non-observed sows when too many piglets were present.

Measurements

All the measurements of back fat thickness (BF) were performed by the same person on standing sows at the P2-position (Maes *et al.*, 2004) after hair removal using a digital BF indicator (Renco Lean Meter, S.E.C. Repro Inc., Ange-Gardien-de-Rouville, Québec, Canada) at D85, D109 and D111 of gestation, and at D1 of lactation. The BF was always measured at the same, marked spot on both sides of the sow. Values from the two measurements were averaged to obtain a single BF measurement. Devillers *et al.* (2006) described that the secretory activity of the mammary gland starts at D85 of gestation. In this study, D109 of gestation was the first whole day that sows were housed in the farrowing unit. Therefore, we calculated the change in BF between D85 and D109 of gestation (ΔBF D85-D109, mm) as BF D109 minus BF D85, and the change in back fat between D109 of gestation and D1 of lactation (ΔBF D109-D1, mm) as BF D1 minus BF D109. The change in back fat should be interpreted as follows: a negative value represents back fat loss or back fat mobilisation; a positive value represents back fat gain or back fat deposition.

The rectal body temperature (digital thermometer, accuracy 0.1°C) was recorded between 04.30 and 05.00am the day before, of and the day after farrowing to monitor health status. Parity, gestation length, number of liveborn and stillborn piglets, and parturition length were recorded for every sow. Feed intake was recorded daily from D111 of gestation until D3 of lactation for every sow. The sow's CY was calculated as the sum of the CI by each piglet within a litter.

The piglets' CI (g) was estimated by a regression equation as described by Devillers *et al.* (2004), based on BW_B, weight at 17 to 24 h of age (further referred to as weight at 24 h of

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age, BW_{24}), duration of CI (t with 17 h $\leq t \leq$ 25 h), and time between birth and first suckling (t_{FS}). The equation is the following:

$$CI = -217.4 + 0.217 \times t + 1861019 \times BW_{24}/t + BW_B \times (54.80 - 1861019/t) \times (0.9985 - 3.7 \times 10^{-4} \times t_{FS} + 6.1 \times 10^{-7} \times t_{FS}^2$$

The detailed handling of piglets at birth was as follows: when a piglet was born, the back of the piglet was dried with a paper towel, a number was written on the back with a marker and the piglet was ear-tagged allowing identification. The umbilical cord was shortened when it was longer than ~15 cm. After weighing, they were placed against the sow's vulva again with their nose. The accuracy of the scale was 0.02 kg and the birth interval was recorded for every piglet.

Samples

Feed samples were taken from the silos at the end of the study.

Serum (8 ml, serum cloth activator tubes) of the sows was collected by punction of the *vena jugularis* while they were restrained by a snare. The sampling was done before the morning meal after an overnight fasting period of 20 h. As colostrum is mainly produced the week prior to farrowing (Devillers *et al.*, 2006), we collected serum each other day during that week. In this way, we obtained serum from every sow 3 to 4 days before farrowing and only these were further analysed. We also collected and analysed serum samples of the sows at D1 of lactation. The blood samples were stored in iced water, subsequently centrifuged at 671 × **g** for 10 min and serum was stored frozen at −20°C until further analysis. The serum was analysed for urea, creatinine, non-esterified fatty acids (NEFA), (iso)butyrylcarnitine (C4), immunoglobulin G (IgG) and immunoglobulin A (IgA).

The colostrum (35 ml) was collected at 3, 6 and 24 h after birth of the first piglet, equally divided from all teats on one side of the udder. Except for the sample at 3 h, 2 ml of oxytocin (10 IU/ml) was administered intramuscularly 5 min before sampling. At the time of the sample collection at 6 h, six sows did not complete the farrowing and they were also given an injection of 2 ml of oxytocin. The samples were subdivided and frozen immediately at −20°C and stored until further analysis. Each colostrum sample was analysed for its chemical composition, IgG and IgA.

Analyses of samples

Feed. The nutritional composition of the diets were analysed according to the Association of Official Analytical Chemists methods (Thiex, 2002) (ISO 5983-1, 2005; ISO 1443, 1973; ISO 5498, 1981). The gestation diet contained 90.6% dry matter (DM), 3.9% of crude fat (CF), 13.5% of CP, 4.7% of crude ash (CA) and 9.6% of crude fibre (CFib). The transition diet contained 88.7% DM, 3.5% CF, 13.6% CP, 6.2% CA and 8.5% CFib. The lactation diet contained 89.7% DM, 5.2% CF, 18.2% CP, 5.3% CA and 4.3% CFib.

Serum. Creatinine, urea and NEFA were measured spectrophotometrically (Ultrospec IIE, LKB, Biochrom, Cambridge, England) using a commercial colorimetric diagnostic kit (Randox Laboratories, Crumlin, UK). A quantitative electrospray tandem mass spectrometry was used to determine C4 as described by Vreken *et al.* (1999). (Iso)butyrylcarnitine is a catabolite of amino acids that can be metabolised to oxaloacetate, which is needed to react with acetyl CoA when entering the citric acid cycle (Michal, 1999a and 1999b). As serum samples were obtained after an overnight fasting of 20 h, we can assume that C4 mainly reflects a catabolism of body protein. Immunoglobulins G and A were analysed by a porcine quantitative sandwich enzyme immunoassay technique (Bethyl Laboratories Inc., Montgomery, USA). All samples were analysed in duplicate.

Colostrum. The DM, fat, protein and lactose content were analysed by Lactoscope FTIR Advanced type FTA-3.0 (Delta Instruments, Drachten, the Netherlands). The samples were diluted 1 : 2 with distilled water and calibrated curves were verified with Gerber and Kjeldahl analysis. These analyses were not done in duplicate because of the high amount of sample needed for one analysis.

Immunoglobulins G and A were analysed by a porcine quantitative sandwich enzyme immunoassay technique (Bethyl Laboratories Inc., Montgomery, Texas, USA) in duplicate and in the same array, in order to avoid inter-array variation.

Statistics. The data is reported as LSMean ± standard deviation or median ± interquartile range when variables were normally or not normally distributed, unless mentioned otherwise. The Kolmogorov–Smirnov test was used to analyse whether variables were normally distributed. The correlation analysis was performed using Pearson or Spearman Rank correlation analysis when variables were distributed normal or not normal. Sows were divided into two groups based on parity: parities 1 to 3 ($n = 18$) and parities 4 to 7 ($n = 19$). In order to analyse whether the variables differed between groups, we used an independent samples t-test or a Kruskall–Wallis analysis when variables were hence normally or not normally distributed.

In order to analyse which variables were associated with CY, multivariable regression analysis was performed using forward modelling. The statistical model is

$$Y = \beta_0 + \left(\sum_{i=1}^{n} \beta_i X_i \right) + \varepsilon_i$$

with Y as the dependent variable, β_0 as a constant value, β_i as slope coefficients, X_i as the independent variable and ε_i as the random error term. The dependent variable was CY for each model. The independent variables and their slope coefficients are shown in the regression equations. For each regression model, the normality and homogeneity of variance, outliers and their influence and multicollinearity were tested through residual analysis, leverage, studentised deleted residuals, Cook's distance, DFFITS, DFBETAS,

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variance inflation factor and tolerance. When needed, variables were transformed and reported as such.

The overtime change of the colostrum composition was analysed by repeated measures ANOVA for normally distributed data and by Friedmann's two-way ANOVA for not normally distributed data.

All statistical analyses were performed using SPSS 19.0 (IBM Company Headquarters, Chicago, Illinois, USA), considering statistical significance when $P < 0.05$.

Results

Production parameters

The range is marked between brackets. The parity was 3.8 ± 2.1 (1 to 7), the gestation length was 114.6 ± 1.7 days (112 to 117), the farrowing duration was 234 ± 117 min (53 to 591) and the litter size was 14.6 ± 2.4 (10 to 20). The number of liveborn piglets was 13.5 ± 2.2 (10 to 18), the number of stillborn piglets was 1.0 ± 2.0 (0 to 5), with a total litter BW_B of 19.0 ± 2.8 kg (13.3 to 24.3). The day before farrowing the sow's rectal body temperature was 38.1 ± 0.4°C (37.3 to 39.0), on the day of farrowing it was 38.2 ± 0.5°C (37.1 to 39.0) and the day after farrowing it was 38.9 ± 0.4°C (38.0 to 39.7). For the individual piglets, the birth interval was 8.0 ± 14.0 min (0 to 108) and t_{FS} was 20.0 ± 31.0 min (4 to 207), the BW_B was 1305 ± 338 g (400 to 2380), their BW_{24} was 1393 ± 348 g (480 to 2420), their weight gain during the first 24 h was 60 ± 100 g (−230 to 300). The BW_B of the liveborn piglets ($P = 0.204$) and t_{FS} ($P = 0.441$) did not differ between piglets born before D114 of gestation or the ones born after.

Feed intake and back fat of the sows

Data considering feed intake, BF and ΔBF are shown in Table 1. Colostrum yield was not correlated to the feed intake between D111 of gestation and farrowing ($r = -0.07$, $P = 0.666$), and during the first 3 days of lactation ($r = -0.03$, $P = 0.874$). We observed a back fat loss in 30 sows between D85-D109 and in 27 sows between D109-D1. Changes in BF during both periods did not correlate with the BF level at the beginning of the respective period ($-0.02 < r < 0.3$, $P > 0.05$).

Colostrum yield

The total CY was 3243 ± 132 g (1568 to 5017) per sow. The CI per piglet was 245 ± 154 g with a maximum of 635 g and the average CI per kg BW_B of the piglets was 196 ± 108 g with a maximum of 394 g (Table 1). Thirty-seven percent of the sows were not producing and 31% of the piglets did not consume 160 g colostrum per kg liveborn piglet, the threshold value as proposed by Le Dividich *et al.* (2005).

Multivariable regression analysis, performed with all variables presented in Table 2, revealed two factors that were associated with CY: parity group and ΔBF D85-D109. The obtained regression equation ($R^2 = 0.41$, $P < 0.001$) was: CY = 4290 − 842 (parity group) − 113 (ΔBF D85-D109, mm). The details are shown in Table 3. Both variables were negatively associated with CY. The sows with a parity of 4 to 7 produced 840 g less colostrum compared with sows with a parity of 1 to 3 and within a parity group, an extra loss of 1 mm BF between D85 and D109 of gestation was associated with an increase in CY of 113 g. Raw data of these variables are presented in Table 2 and Figure 1.

As parity *per se* did not provide further insights into how CY might be affected, we tried to identify factors underlying parity. Therefore, we first compared characteristics regarding feed intake, BF, the farrowing process and the litter performance between the two parity groups (Table 2). We could only identify a difference for the BF characteristics and gestation length. Older sows had a lower BF at all times ($P < 0.004$), tended to lose more BF between D109 of

Table 1 *CY, feed intake, BF of sows (n = 37) and colostrum intake by piglets (n = 551)*

Level	Variable	Mean/median	s.d./I.R.	Minimum	Maximum
Sows	CY (g)	3243	804	1568	5017
	Average CI per liveborn piglet (g)	246	74	98	421
	Average CI per kg liveborn piglet (g)	187	53	78	295
	Daily feed intake D111-D1 (kg)*	2.0	0.3	0.9	2.0
	Feed intake D1-D3 (kg)	10.4	2.5	4.5	14.6
	BF at day *x* of gestation (mm)				
	D85	18.5	5.7	9.0	34.0
	D109	16.5	5.7	8.5	31.5
	D111	16.5	5.7	8.5	31.5
	BF D1 of lactation (mm)	15.7	5.9	8.0	32.5
	ΔBF D85-D109 (mm)	−2.0	2.3	−6.0	4.5
	ΔBF D109-D1 (mm)	−0.8	1.2	−3.5	2.0
Piglets	CI (g)*	245	154	0	635
	CI/kg birth weight (g)*	196	108	0	394

CY = colostrum yield; CI = colostrum intake; BF = back fat thickness; I.R. = interquartile range; ΔBF D85-D109 = change in BF between day 85 and day 109 of gestation; ΔBF D109-D1 = change in BF between day 109 of gestation and day 1 of lactation.
Mean ± s.d. or median ± I.R. are given for variables with a normal or non-normal distribution (indicated by *).
Colostrum intake/yield was determined as described by Devillers *et al.* (2004).

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Table 2 *Comparison of colostrum, feed intake, back fat, farrowing and litter characteristics, between sows of different parity groups*

	Parity group			
Variable	1 to 3	4 to 7	s.e.m./I.R.	*P*-value
Number of sows	18	19		
Colostrum characteristics				
CY (g)	3688	2821	132	<0.001
CY/kg liveborn piglet (g)	210	165	9	0.008
Feed characteristics				
Daily feed intake D111-D1 (kg)	2.0	2.0	0.04	0.599
Feed intake D1-D3 (kg)	10.5	10.4	0.4	0.925
BF characteristics				
BF D85 (mm)	21.3	15.9	0.9	0.002
BF D109 (mm)	19.2	14.0	0.9	0.003
BF D111 (mm)	19.2	14.0	0.9	0.004
BF D1 (mm)	18.8	12.8	1.0	0.001
ΔBF D85-D109 (mm)	−2.1	−1.9	0.4	0.782
ΔBF D109-D1 (mm)	−0.4	−1.2	0.2	0.050
Farrowing characteristics				
Gestation length (days)	115.6	113.6	0.3	<0.001
Farrowing duration (min)	208	256	19	0.205
Litter size	14.1	15.1	0.4	0.247
Liveborn piglets	13.4	13.7	0.4	0.685
Stillborn piglets*	0.5	1.0	2	0.210
Litter characteristics				
Litter BW_B (kg)	18.7	19.3	0.5	0.470
Litter BW_B liveborn piglets (kg)	17.8	17.7	0.4	0.916
Average piglet BW_B (kg)	1.3	1.3	0.03	0.556
Average BW_B liveborn piglets (kg)	1.4	1.3	0.03	0.558
Average t_{FS}* (min)	27	27	16	0.443

I.R. = interquartile range; CY = colostrum yield; BF = back fat thickness; BW_B = birth weight; t_{FS} = time between birth and first suckle.
Normally distributed variables were analysed with an independent samples *t*-test and mean ± s.e.m. is given.
Not normally distributed variables (indicated with *) were analysed with a Kruskal–Wallis analysis and median ± I.R. is given.
CY (determined as described by Devillers *et al.*, 2004); D111-D1 = day 111 of gestation until day 1 of lactation; D1-D3 = day 1 of lactation until day 3 of lactation; ΔBF D85-D109 = change in BF between day 85 and day 109 of gestation; ΔBF D109-D1 = change in BF between day 109 of gestation until day 1 of lactation.

Table 3 *Multivariable regression analysis when we used technical parameters (technical model) or metabolic parameters (metabolic model) as predictors*

Model	Predictor	Slope	s.d.	CI for slope	*P*-value
Technical model	Constant	4291	351	[3579; 5005]	<0.001
	Parity group	−842	210	[−1269; −415]	<0.001
	ΔBF D85-D109 (mm)	−113	46	[−206; −20]	0.018
Metabolic model	Constant	3582	460	[2645; 4520]	<0.001
	C4 3 to 4 days before farrowing (μmol/l)	−1604	631	[−2889; −318]	0.016
	10 log C4 D1 of lactation (μmol/l)	1077	412	[238; 1915]	0.013
	10 log NEFA D1 of lactation (mmol/l)	−922	367	[−1670; −174]	0.017

CI = confidence interval; ΔBF D85–D109 = change in BF between D85 and D109 of gestation; NEFA = non-esterified fatty acid; C4 = (iso)butyrylcarnitine.
The dependent variable is the colostrum yield (g) per sow. For the technical model, the sows were divided in two parity groups: parities 1 to 3 and parities 4 to 7. In the regression equation, the *x*-value of parities 1 to 3 sows is 0 and the *x*-value of parities 4 to 7 sows is 1.

gestation and D1 of lactation ($P = 0.050$) and had a shorter gestation length ($P < 0.001$). Then, we investigated possible associations between these characteristics and CY. Only ΔBF D109-D1 ($r = 0.39$, $P = 0.017$), BF D85 ($r = 0.39$, $P = 0.017$) and the gestation length ($r = 0.39$, $P = 0.017$) were correlated to CY, the latter two being mutually highly correlated ($r = 0.680$, $P < 0.001$).

Using forward linear modelling techniques, we were able to see the R^2 with each new variable added to the model. The first factor entered in the model was the ΔBF D85-D109 and this explained 13% (R^2) of the observed variability in CY. When the factor 'parity group' was added to the model, an extra 28% of the variability in CY was explained, making a total of 41%. We rebuilt the model without the factor

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'parity group' but with the three factors that were identified as possibly underlying the parity group effect. Again, in a first step, the ΔBF D85-D109 explained 13% (R^2) of the observed variability in CY. When we added the three factors, an extra 21% of the variability in CY was explained with BF D85 removed from the model due to confounding issues. This indicates that in this study, the ΔBF D109-D1 and gestation length are factors underlying to the factor parity group, without explaining all variation in CY explained by parity group. Raw data of ΔBF D109-D1 and gestation length are plotted against CY in Figure 2 and Supplementary Figure S1.

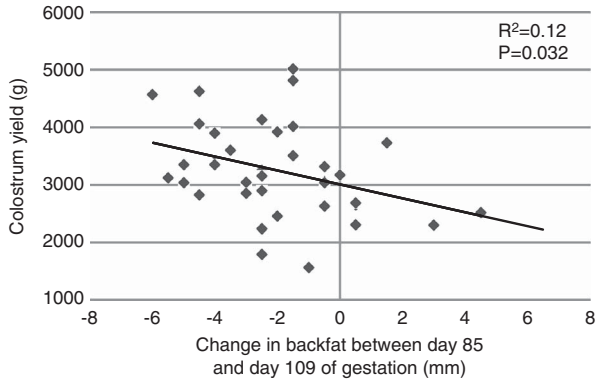


Figure 1 The association between colostrum yield and the back fat change between D85 and D109 of gestation is shown.

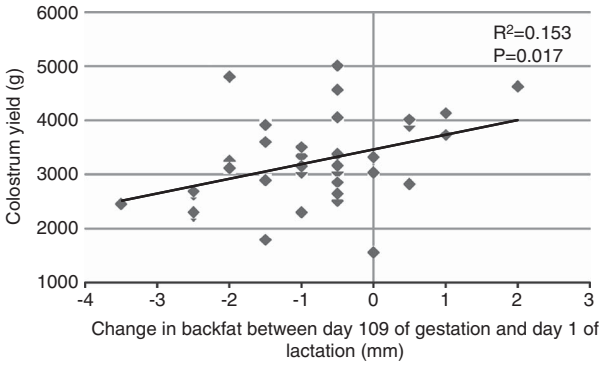


Figure 2 The association between colostrum yield and the back fat change between D109 of gestation and D1 is shown.

Colostrum composition

The nutritional composition (%) and concentration of IgG and IgA (mg/ml) in the colostrum are shown in Table 4. The concentration of fat and lactose had increased, whereas all other parameters had decreased over time ($P < 0.001$). The colostrum composition was not correlated to CY (r between −0.3 and 0.3, $P > 0.05$). The total output of nutrients (fat, protein, lactose) through colostrum did correlate with CY ($0.64 < r < 0.94$, $P < 0.001$).

Serum analysis

The concentration of the parameters measured in the serum are shown in Table 5. The concentration of C4 3 to 4 days before farrowing was higher in parities 4 to 7 sows compared with parities 1 to 3 sows, whereas at D1 of lactation, the concentration of C4 tended to be lower in the parities 4 to 7 sows.

The serum concentration of C4 3 to 4 days before farrowing was negatively associated with CY and at D1 of lactation, the logarithmic transformation of NEFA was negatively associated with CY and the logarithmic transformation of C4 was positively associated with CY ($R^2 = 0.39$, $P = 0.001$). The obtained regression equation was: CY = 3582 − 1603 C4 (μmol/l) + 1077 10 log C4(μmol/l) − 922 10 log NEFA (mmol/l). Details of the regression equation are shown in Table 3 and raw data of these variables are plotted against CY in supplementary Figures S2, S3 and S4.

Discussion

The negative association between CY and ΔBF D85-D109 we observed, has never been described before. As we did not collect more data between D85 and D109 of gestation, we can only propose some hypotheses that might explain this association. The period between D85 and D109 of gestation is considered to be important for mammogenesis (Kensinger *et al.*, 1982; Ji *et al.*, 2006), which was suppressed by keeping sows in an anabolic state during this period (Weldon *et al.*, 1991). Our study population was mainly catabolic between D85 and D109 of gestation and there is no information available to date whether this benefits gestational mammogenesis. The negative association between CY and

Table 4 *Mean composition based on fresh samples (%) and mean concentrations of immunoglobulin G and A in colostrum 3, 6 and 24 h after birth of the first piglet*

Variable	3 h	6 h	24 h	*P*-value
% fat	8.9 (0.6)	9.9 (0.5)	14.2 (0.6)	<0.001
% protein	25.2 (0.6)	21.9 (0.5)	11.6 (0.4)	<0.001
% lactose	3.1 (0.1)	3.7 (0.1)	5.5 (0.4)*	<0.001
% dry matter	37.2 (0.7)	35.5 (0.1)	31.2 (0.7)	<0.001
IgG (mg/ml)	92 (40)*	85 (35)*	18.3 (2.8)	<0.001
IgA (mg/ml)	11 (8)*	8.1 (0.8)	2.8 (2.5)*	<0.001

IgG = immunoglobulin G; IgA = imunoglobulin A.
Statistical analysis of the time effect was performed.
Mean ± s.d. or median ± I.R. are given for variables with a normal or non-normal distribution (indicated by *).

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Table 5 *Comparison of serum metabolites between sows of different parity groups*

	Parity group			
Variable	1 to 3	4 to 7	s.e.m./I.R.	*P*-value
Number of sows	18	19		
Urea (mg/dl) 3 to 4 days before farrowing	32.7	30.7	0.8	0.241
Creatinine (mg/dl) 3 to 4 days before farrowing	2.7	2.9	0.06	0.153
NEFA (mmol/l) 3 to 4 days before farrowing	0.7	0.8	0.07	0.431
C4 (μmol/l) 3 to 4 days before farrowing	0.4	0.5	0.03	0.047
Urea (mg/dl) at D1 of lactation	32.0	34.5	1.4	0.383
Creatinine (mg/dl) at D1 of lactation	2.8	3.0	0.06	0.160
NEFA (mmol/l) at D1 of lactation	0.2	0.2	0.26	0.641
C4 (μmol/l) at D1 of lactation	0.7	0.6	0.5	0.053
IgG (mg/ml) at D111 of gestation	14.1	16.4	0.8	0.138
IgA (mg/ml) at D111 of gestation	1.8	2.3	0.2	0.149
IgG (mg/ml) at D1 of lactation	13.0	14.5	0.7	0.305
IgA (mg/ml) at D1 of lactation	1.6	2.1	1.8	0.164

I.R. = interquartile range; NEFA = non-esterified fatty acid; C4 = (iso)butyrylcarnitine; IgG = immunoglobulin G; IgA = immunoglobulin A.
Normally distributed variables were analysed with an independent samples *t*-test and mean ± s.e.m. is given.
Not normally distributed variables (indicated with *) were analysed with a Kruskal–Wallis analysis and median ± I.R. is given.

ΔBF D85-D109 could also be the result of a higher energy demand of sows with a higher mammary development. Aside from the possible association with mammogenesis, BF and changes in BF could also alter the sow's level of insulin sensitivity and thus its lactogenesis. A decreased insulin sensitivity is needed to a certain extent in order to direct glucose to the mammary gland (Père and Etienne, 2007) where it is used for lactose synthesis (Shennan and Peaker, 2000). Père *et al.* (2000) state that all sows develop an insulin resistance starting from D85 of gestation and this is more apparent in fat sows. A positive energy balance increases the concentration of leptin (Barb *et al.*, 2001), which leads to a lower insulin sensitivity (Franks *et al.*, 2007; Papadopoulos *et al.*, 2009). It might be worthwhile looking further into the relations between the change of body condition during late gestation, gestational mammogenesis, colostrogenesis and colostrum yield.

The higher CY in sows with parities 1 to 3 corresponds to the findings of Devillers *et al.* (2007) who reported that second and third parity sows tended to produce more colostrum than primiparous and older sows. The observed association between parity group and CY cannot be explained by parity as such, but because other factors differ between parity groups. As thoroughly described in the results section, we identified ΔBF D109-D1 and gestation length as the two factors differing between parity groups and being correlated to CY, thus proving to be candidates to partially explain the association between parity group and CY in this study. The variability in CY explained by parity group was higher than the variability explained by ΔBF D109-D1 and gestation length. This indicates that there are other factors associated to parity that contribute to the variability in CY; however, these have not been identified in this study. Furthermore, not all variability in CY explained by these two factors will be covered by the parity group. Nonetheless, this indicates that the gestation length and ΔBF D109-D1 might partially explain the difference in CY between parity groups observed in this study and therefore, they will be further discussed. Back fat at D85 of gestation also differed between parity groups and was correlated to CY but was not kept in the model. We cannot explain the different back fat between parity groups, although the relatively low feeding practices during gestation at this farm might be the cause of a gradual decrease in BF over successive parities.

The negative association between gestation length and CY was also found by Devillers *et al.* (2007). Milon *et al.* (1983) suggested that CY and gestation length were negatively associated due to a decreased BW_B and vitality of the piglets. These litter characteristics have shown to be important in determining CY (Devillers *et al.*, 2007), although we did not observe any differences in BW_B and t_{FS} between piglets born before D114 of gestation and piglets born after.

We propose a relatively easy nutrient balance model of sows at the end of gestation where on the one hand, the input of nutrients available for metabolic processes are derived from either feed or body reserves, whereas on the other hand, the loss of nutrients at the end of gestation are determined by the total litter BW_B and the loss of nutrients through colostrum. The feed intake and the litter BW_B were not associated with CY and sows with a higher CY also had a higher nutrient output through colostrum. Thus, as colostrum is mainly produced the week before farrowing (Devillers *et al.*, 2006), we would expect the use of body fat and protein reserves to increase with an increasing CY in order to obtain the proposed nutrient balance. Our results showed the opposite. The elevated use of body fat (ΔBF D109-D1) and body protein (C4 3 to 4 days before farrowing) was associated with a decreased CY. The parities 4 to 7 sows used more body fat and protein reserves during the last days before farrowing and this might be to cover their higher maintenance

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requirements compared to young sows (Noblet *et al.*, 1998) made even more prominent due to the low feed supply. The higher catabolic state of older sows did likely prohibit sows from producing colostrum at their full potential. It is an interesting observation that sows that are catabolic during the last days of gestation, eventually produce a lower CY as this indicates that the use of body reserves cannot fully compensate a nutrient intake below nutrient requirements.

Colostrum yield was negatively associated to the use of body protein before farrowing, whereas it was positively associated to the use of body protein at D1 of lactation. During the 24 h following parturition, the secretion of the mammary cells becomes abundant (Devillers *et al.*, 2006) and hence the body's protein can be used to deliver amino acids or glucogenic substrates to the mammary gland (Boyd *et al.*, 1995). Colostrum yield was negatively associated with NEFA at D1 of lactation, which again indicates the use of body fat reserves around farrowing should be prohibited.

The chemical composition of colostrum revealed high concentrations compared with other studies (Le Dividich *et al.*, 2004; Devillers *et al.*, 2007; Foisnet *et al.*, 2010) without showing a lower CY. Our study was performed in PIC sows of which colostrum composition was not described before. Farmer *et al.* (2007) showed that chemical colostrum composition differs between genotypes yet never as much as we observed. Sows in our study were mostly catabolic during the month before farrowing and we should consider this as a factor affecting colostrum composition.

We should be careful when extrapolating the associations between CY and changes in body condition observed in this study as most sows in our study were catabolic during observation probably due to the relatively low feed supply.

In conclusion, back fat changes between D85 and D109 of gestation were negatively associated to CY and parities 4 to 7 sows had a lower CY than parities 1 to 3 sows. We identified gestation length and the extent in which the body's energy and protein reserves were used the last days before farrowing as possible underlying factors possibly explaining part of the parity effect. Sows that were catabolic the week before farrowing seemed unable to produce colostrum to their full potential. Colostrum composition did not alter when colostrum yield increased. These findings indicate that a proper management of the sow's body condition during late gestation could be a tool to optimise the intrinsic capacity of the sow's colostrum yield.

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Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S1751731113001791

References

Barb CR, Hausman GJ and Houseknecht KL 2001. Biology of leptin in the pig. Domestic Animal Endocrinology 21, 297–317.

Boyd DR, Kensinger RS, Harrell RJ and Bauman DE 1995. Nutrient uptake and endocrine regulation of milk synthesis by mammary tissue of lactating sow. Journal of Animal Science 73, 36–56.

Devillers N, Le Dividich J and Prunier A 2006. Physiologie de la production de colostrum chez la truie. INRA Productions Animales 19, 29–38.

Devillers N, van Milgen J, Prunier A and Le Dividich J 2004. Estimation of colostrum intake in the neonatal pig. Animal Science 78, 305–313.

Devillers N, Farmer C, Le Dividich J and Prunier A 2007. Variability of colostrum yield and colostrum intake in pigs. Animal 1, 1033–1041.

Edwards SA 2002. Perinatal mortality in the pig: environmental or physiological solutions? Livestock Production Science 78, 3–12.

Ellendorf F, Forsling ML and Poulain DA 1982. The milk ejection reflex in the pig. The Journal of Physiology 333, 577–594.

Farmer C and Quesnel H 2009. Nutritional, hormonal, and environmental effects on colostrum in sows. Journal of Animal Science 87, 56–64.

Farmer C, Charagu P and Palin MF 2007. Influence of genotype on metabolic variables, colostrum and milk composition of primiparous sows. Canadian Journal of Animal Science 87, 511–515.

Foisnet A, Farmer C, David C and Quesnel H 2010. Relationship between colostrum production by primiparous sows and physiology around parturition. Journal of Animal Science 88, 1672–1683.

Franks PW, Loos RJF, Brage S, O'Rahilly S, Wareham NJ and Ekelund U 2007. Physical activity energy expenditure may mediate the relationship between plasma leptin levels and worsening insulin resistance independently of adiposity. Journal of Applied Physiology 102, 1921–1926.

Ji F, Hurley WL and Kim SW 2006. Characterization of mammary gland development in pregnant gilts. Journal of Animal Science 84, 579–587.

Kensinger RS, Collier RJ, Bazer FW, Ducsay CA and Becker HN 1982. Nucleic acid, metabolic and histological changes in gilt mammary tissue during pregnancy and lactogenesis. Journal of Animal Science 54, 1297–1308.

Le Dividich J, Rooke JA and Herpin P 2005. Nutritional and immunological importance of colostrum for the new-born pig. Journal of Agricultural Science 143, 469–485.

Le Dividich J, Herpin P, Paul E and Strullu F 1997. Effect of fat content of colostrum on voluntary colostrum intake and fat utilization in newborn pigs. Journal of Animal Science 75, 707–713.

Le Dividich J, Martineau GP, Thomas F, Demay H, Renoult H, Homo C, Boutin D, Gaillard L, Surel Y, Bouétard R and Massard M 2004. Acquisition de l'immunité passive chez les porcelets et production de colostrum chez la truie. Journées Recherche Porcine 36, 451–456.

Maes DGD, Janssens GPJ, Delputte P, Lammertyn A and de Kruif A 2004. Back fat measurements in sows from three commercial pig herds: relationship with reproductive efficiency and correlation with visual body condition scores. Livestock Production Science 91, 57–67.

Michal G 1999a. Carbohydrate metabolism and citrate cycle. In Biochemical pathways: an atlas of biochemistry and molecular biology (ed. G Michal), p. 43. John Wiley & Sons, Inc.; Spektrum Akademischer Verlag, New York, USA; Heidelberg, Germany.

Michal G 1999b. Amino acids and derivatives. In Biochemical pathways: an atlas of biochemistry and molecular biology (ed. G Michal), pp. 57–58. John Wiley & Sons, Inc.; Spektrum Akademischer Verlag, New York, USA; Heidelberg, Germany.

Milon A, Aumaitre A, Le Dividich J, Franz J and Metzger JJ 1983. Influence of birth prematurity on colostrum composition and subsequent immunity of piglets. Annals of Veterinary Research 14, 533–540.

Noblet J, Etienne M and Dourmad JY 1998. Energetic efficiency of milk production. In The lactating Sow (ed. MWA Verstegen, PJ Moughan and JW Schrama), pp. 113–116. Wageningen Pers, Wageningen, The Netherlands.

Noblet J, Dourmad JY, Etienne M and Le Dividich J 1997. Energy metabolism in pregnant sows and newborn pigs. Journal of Animal Science 75, 2708–2714.

Papadopoulos GA, Maes DGD, Van Weyenberg S, van Kempen TATG, Buyse J and Janssens GPJ 2009. Peripartal feeding strategy with different *n-6:n-3* ratios in sows: effects on sows' performance, inflammatory and periparturient metabolic parameters. British Journal of Nutrition 101, 348–357.

https://doi.org/10.1017/S1751731113001791 Published online by Cambridge University Press

Père MC and Etienne M 2007. Insulin sensitivity during pregnancy, lactation, and postweaning in primiparous gilts. Journal of Animal Science 85, 101–110.

Père MC, Etienne M and Dourmad JY 2000. Adaptations of glucose metabolism in multiparous sows: effects of pregnancy and feeding level. Journal of Animal Science 78, 2933–2941.

Quesnel H 2011. Colostrum production by sows: variability of colostrum yield and immunoglobulin G concentrations. Animal 5, 1546–1553.

Rooke JA and Bland IM 2002. The acquisition of passive immunity in the newborn piglet. Livestock Production Science 78, 12–23.

Salmon H, Berri M, Gerdts V and Meurens F 2009. Humoral and cellular factors of maternal immunity in swine. Developmental and Comparative Immunology 33, 384–393.

Shennan DB and Peaker M 2000. Transport of milk constituents by the mammary gland. Physiological Reviews 80, 925–951.

Thiex N 2002. Feeds. Journal of AOAC International 85, 270–273.

Vreken P, van Lint AEM, Bootsma AH, Overmars H, Wanders R and van Gennip A 1999. Rapid diagnosis of organic acidemias and fatty-acid oxidation defects by quantitative electrospray tandem-MS acyl-carnitine analysis in plasma. In Current views of fatty acid oxidation and ketogenesis – from organelles to point mutations (ed. PA Quant, and S Eaton), pp. 327–337. Kluwer, New York.

Weldon WC, Thulin AJ, MacDougald OA, Johnston LJ, Miller E and Tucker HA 1991. Effects of increased dietary energy and protein during late gestation on mammary development in gilts. Journal of Animal Science 69, 194–200.

https://doi.org/10.1017/S1751731113001791 Published online by Cambridge University Press