

Variability of colostrum yield and colostrum intake in pigs

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Colostrum yield and composition of 40 Landrace × Large White sows were determined from the onset of parturition until 24 h post partum. Colostrum yield was calculated by adding individual piglets' colostrum intakes for each litter. Colostrum was assayed for prolactin, progesterone, oestradiol-17 β , immunoglobulin G and its nutritional composition was determined. Piglets' individual colostrum intake averaged 300 ± 7 g and sows' colostrum yield averaged 3.67 ± 0.14 kg (minimum 1.91 kg, maximum 5.31 kg). Live weight and characteristics at birth (umbilical cord already ruptured, splayleg, difficulty to breathe) were the major factors influencing individual colostrum intake. Colostrum yield was not affected by litter size, tended to be influenced by parity ($P = 0.059$) and was lower when farrowing was induced ($P = 0.017$). On the other hand, no relationships were found between hormone concentrations in colostrum and colostrum yield. Mean piglet birth weight and litter weight variation at birth were related to colostrum yield ($r = 0.38$; $P = 0.015$ and $r = -0.34$; $P = 0.030$, respectively). These results suggest that determinism of colostrum yield depends, in part, on global vitality of the litter but seems to be, most probably, affected by the capacity of sows to produce enough colostrum for the whole litter. Further studies are needed to understand the endocrine regulation of colostrum secretion in sows.

Keywords: birth weight, colostrum, hormones, piglets, sows

Introduction

Pre-weaning mortality in swine production remains a major drawback, especially neonatal mortality, with at least 50% of pre-weaning deaths occurring within 3 days of birth (Tuchscherer *et al.*, 2000). Those piglets are characterised by a low birth weight and a low weight gain, which is related to a low colostrum intake (de Passillé and Rushen, 1989b; Milligan *et al.*, 2002). Therefore, low colostrum intake appears to be a major cause of neonatal death (Edwards, 2002). The roles of colostrum for piglet's thermoregulation, immunity and intestinal development are well established (see reviews by Xu *et al.*, 2000; Rooke and Bland, 2002; Le Dividich *et al.*, 2005). Colostrum intake by piglets depends not only on their ability to extract colostrum from teats but also on the ability of sows to produce enough colostrum for the whole litter (Hoy *et al.*, 1997). Indeed, negative effects of low birth weight and poor vitality (asphyxia during delivery, long time from birth to first suckling) on colostrum intake were demonstrated in

several studies (Herpin *et al.*, 1996; Tuchscherer *et al.*, 2000).

Although the factors influencing sow milk production have been studied for a long time, few studies have focussed on the factors determining colostrum production. Factors that may influence milk production include: litter and sow characteristics, such as litter size, litter weight, genotype and parity (Boyce *et al.*, 1997; Etienne *et al.*, 1998); sow hormonal background, such as circulating concentrations of prolactin, progesterone and cortisol (see reviews by Devillers *et al.*, 2006 and Farmer *et al.*, 2006); behaviour of the sow and piglets, such as alterations in nursing frequency (Auldust *et al.*, 2000); and environmental factors (Etienne *et al.*, 1998). The roles of prolactin and progesterone for the initiation of lactation and, consequently, for colostrogenesis have also been demonstrated (Taverne *et al.*, 1982; Farmer *et al.*, 1998). On the other hand, some studies suggest that litter size may not have any influence on colostrum yield (Milligan *et al.*, 2001; Le Dividich *et al.*, 2004). The present study used a method previously described (Devillers *et al.*, 2004b) for estimating colostrum intake by individual piglets and sow colostrum yield in order to determine factors that influence these two variables.

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Material and methods

Animals and measurements

In all, 22 primiparous and 18 multiparous Landrace × Large White sows were inseminated with semen from Piétrain boars and were housed with their litters (526 piglets) in individual farrowing crates (2.0 m × 2.5 m) with straw bedding. During pregnancy, sows were fed 1.1 kg per 100 kg live weight daily of a diet containing 13.3% crude protein (CP), 2966 kcal/kg of metabolisable energy (ME) and 0.49% lysine. Throughout lactation, they were fed a diet providing 17.3% CP, 3062 kcal/kg of ME and 0.8% lysine. On the day of farrowing, sows were offered 2.0 kg of the lactation diet. Thereafter, this amount was increased by 1 kg daily until *ad libitum* feeding. Water was supplied *ad libitum* throughout the experiment. Sows were weighed upon entrance in the farrowing rooms (the week preceding farrowing, i.e. days 107 to 110 of gestation). Parturition was induced (in 63% of the cases) on day 114 of gestation with 1 ml of prostaglandins (Alphabedyl[®], CEVA Santé Animale, Libourne, France). Parturitions were watched but observers interfered as less as possible in the farrowing process. The beginning (T_0) and the end of parturition were considered as the birth of the first and the last piglets, respectively. At birth, piglets were weighed and time of day was recorded. Because of their link to hypoxia during delivery (Herpin *et al.*, 1996), some birth characteristics were also recorded to assess vitality (umbilical cord already ruptured, difficulty to breathe (more than 5 s until first attempt to breathe), piglet still inside placental membranes). Piglets born in placental membranes were extirpated from them and reanimated, if necessary. No additional help or care was given. At 24 h after the onset of parturition (T_{24}), piglets were weighed again and the presence of splayleg was recorded. No cross fostering was done before T_{24} .

Colostrum intake by piglets between birth and T_{24} was estimated according to a previously described method (Devillers *et al.*, 2004b) whereby an equation was set up in similar environmental conditions (herd, housing, genetic lines) as in the present study to predict piglet's colostrum intake (CI in g) based on birth weight (BW_B in kg), weight gain [$(BW - BW_B)$ in kg], age (t in min) and the interval between birth and first suckling (t_{FS} in min) (see Eq. (1)).

$$CI = -217.4 + 0.217 \times t + 1861019 \times BW/t + BW_B \times (54.80 - 1861019/t) \times (0.9985 - 3.7 \times 10^{-4} \times t_{FS} + 6.1 \times 10^{-7} \times t_{FS}^2) \quad (1)$$

Since the latency to suck was not recorded in the present study, the mean interval between birth and first suckling was estimated to be 30 min (De Passillé and Rushen, 1989a). The standardisation of this factor has been discussed previously (Devillers *et al.*, 2004b) and an error of 15 min in the estimation of the interval from birth to first suckling induces an average error in CI of approximately 6 g/kg BW_B for a 25-h CI duration, which represents less than a 2% error. Colostrum yield by the sow was calculated

as the sum of intakes from each piglet within a litter during the 24 h following the onset of parturition.

Sampling and analyses

A sample of colostrum (100 ml) was collected manually across all teats at T_0 , T_2 , T_4 and T_{24} . At T_{24} only, colostrum ejection was induced with a 0.5 ml intravenous injection of oxytocin (Ocytovem[®], CEVA Santé Animale, Libourne, France). Colostrum was filtered through gauze and stored at 4°C. Within 24 h of collection, 5 ml of filtered colostrum was heated to 38°C, homogenised and ultra-centrifuged twice at $50\,000 \times g$ (0°C) for 1 h each time, before lactoserum was collected.

Colostrum samples were analysed for nutritional composition as well as hormonal and immunoglobulin G (IgG) concentrations. Prolactin (PRL) concentrations were determined using a previously described radio-immunoassay (Robert *et al.*, 1989) with a sensitivity of 1.8 ng/ml. Progesterone (P4) and oestradiol-17 β (E2) concentrations were determined using commercial kits (RIA kit, Immunotech, Marseille, France, ref. 2465 and 2464, respectively). Assay sensitivities were 0.6 ng/ml and 26 pg/ml, respectively. Nitrogen (N) content was determined according to the method of Dumas (Association of Official Analytical Chemists (AOAC) 7 024, 1831) based on sample pyrolysis and direct determination of N_2 using an automatic device (Leco FP-428, LECO Corporation, St Joseph, MI, USA). Crude proteins were estimated as $N \times 6.38$ (Gordon and Whittier, 1965) and total lipids were measured according to the Gerber method (AOAC, 1990). Lactose was assayed using an enzymatic method (Lactose/*D*-galactose test combination R-Biopharm – Roche, Darmstadt, Germany, ref. 0176303). Concentrations of IgG were measured by ELISA, as previously described (Devillers *et al.*, 2004a) and assay sensitivity was 23 ng/ml.

Statistics and data analyses

Statistical analyses were done with Statistical Analysis Systems Institute (2002) software. When performing analyses within litter, data for individual colostrum intakes of piglets were corrected for litter effect (General Linear Model (GLM) procedure) and particular relationships between individual colostrum intake of piglets and vitality or performance variables are presented as residues or as least squares means. Analyses of variance were used to test special relationships between colostrum intake and vitality variables or birth rank (MIXED linear model procedure). Regression analyses were used to describe links between colostrum intake and birth weight (regression (REG) and correlation (CORR) procedures). Regression analyses were also used at the litter level to explore the relationships between mean colostrum intake for the litter and litter size, mean birth weight and variation in birth weight (CV), as well as total litter weight.

Data related to colostrum yield of the sow were analysed using multivariate analyses, which is appropriate for such

descriptive studies. The partial least squares analysis (PLS procedure) was used to relate colostrum yield to other measured variables. PLS analysis works by extracting successive linear combinations of the predictors, called factors, thereby optimally explaining both the response variation (colostrum yield) and the predictors variation (covariates). Thereafter, special relationships between colostrum yield and variables mostly contributing to its modelling were explored using analyses of variance (parity, induction of farrowing) or regression analyses (duration of gestation, litter size, sow body weight, litter weight, colostrum composition).

Relationships between colostrum composition variables and performances were described using principal component analysis (PRINCOMP procedure) and Spearman correlations. Because of missing data, E2, P4 and PRL concentrations were pooled for T_0 and T_2 (T_{0-2}). Verification has been done before that there were correlations between concentrations at times T_0 and T_2 (E2: $r = 0.53$, $P < 0.001$; P4: $r = 0.71$, $P < 0.001$; PRL: $r = 0.88$, $P < 0.001$) and that there were no differences between means from these times (E2: $P = 0.32$; P4: $P = 0.15$; PRL: $P = 0.39$). Data given in the text are means \pm s.e.

Results

Reproduction performances

Reproduction performances of sows were generally consistent with national French results (Institut Technique du Porc (ITP), 2001). Average parity of the 40 sows was 2.2 ± 0.3 , ranging from 1 to 6. Body weight, 1 week before expected farrowing (days 108 to 110 of gestation) averaged 257.4 ± 5.1 kg and farrowing occurred at 114.1 ± 0.2 days of gestation. The mean duration of farrowing was 191 ± 15 min and litter size averaged 13.5 ± 0.5 , ranging from 8 to 21 piglets, with a mean of 0.35 stillbirths per litter. This particularly low number of stillbirths was probably due to supervision of farrowings. Average piglet birth weights and litter sizes were negatively linked ($r = -0.32$; $P = 0.041$) and an increase of one piglet per litter represented a decrease of 25 g in individual birth weight.

Colostrum intake by individual piglets and its variability

Among the 526 piglets born, 14 were stillborn and 23 died before T_{24} . Mean birth weight was 1.34 ± 0.015 kg, ranging from 0.45 to 2.30 kg. Colostrum intake between birth and T_{24} was evaluated to be negative for 17 piglets (mean = -41 g). Those piglets had a mean birth weight of 1.1 kg and lost more than 78 g between birth and T_{24} . Only two of them were still alive at weaning, and 14 died within 3 days of birth. Damm *et al.* (2005) reported that 72% of piglets that die within the first 4 days *post partum* have not consumed any colostrum. Therefore, colostrum intake of those 17 piglets was estimated to be 0. Mean colostrum intake of piglets, which were still alive at T_{24} , was 300 ± 7 g (217 ± 4 g/kg birth weight) with a maximum

colostrum intake of 710 g (450 g/kg birth weight) in 19 h. At birth, 3.0%, 2.5% and 14.9% of piglets, respectively, had difficulty in breathing, were stuck in placental membranes or had their umbilical cord already ruptured. At T_{24} , 11% of piglets had splayleg.

Analyses of intra-litter factors affecting colostrum intake by piglets were done on residues calculated from the litter effect analysis. Piglet birth weight was related to both individual colostrum intake (Figure 1; $r = 0.62$; $P < 0.001$) and relative colostrum intake (g/kg birth weight; $r = 0.21$; $P < 0.001$). Colostrum intake also differed between piglets with and without difficulty in breathing at birth, their umbilical cord already ruptured or splayleg (Figure 2). Analysis of the influence of birth order (divided into four categories) on colostrum intake and on birth weight showed no significant effect (Figure 3). Inter-litter regression analysis showed effects of average litter birth weight ($R^2 = 0.29$; $P < 0.001$), heterogeneity of litter birth weight (% CV; $R^2 = 0.18$; $P < 0.01$) and litter size ($R^2 = 0.49$; $P < 0.001$; Figure 4) on mean colostrum intake by the litter.

Colostrum yield of sows and its variability

Colostrum yield during the 24 h following the beginning of parturition averaged 3.67 ± 0.14 kg, ranging from 1.91 to 5.31 kg. The PLS analysis first considered 17 variables related to sow characteristics (parity, number of functional teats, sow body weight upon entrance in maternity, induction of farrowing, duration of gestation, duration of farrowing), litter characteristics (litter size, total litter weight at birth, mean birth weight of piglets born alive, variation in piglets' birth weights) and composition of colostrum (concentrations of E2, P4 and PRL at T_{0-2} and concentrations of CP, lactose, total lipids and IgG at T_0). In this first PLS analysis, the first two principal factors summarised 42.3% of the variability in colostrum yield. In further PLS analyses, seven variables were removed because of their weak contribution in the modelling of colostrum yield. In particular, the absence of relationship between colostrum

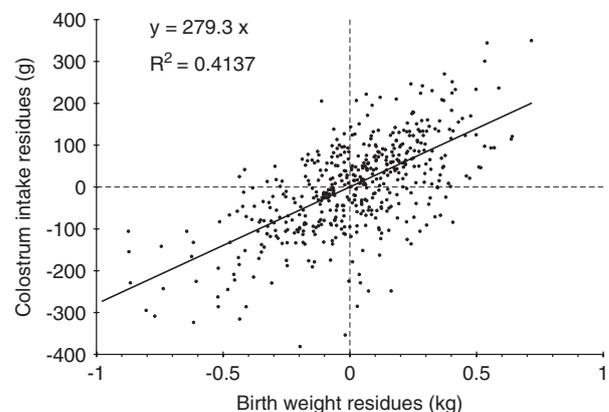


Figure 1 Intra-litter relationship between colostrum intake and birth weight. Data presented are residues calculated after correction from litter effect.

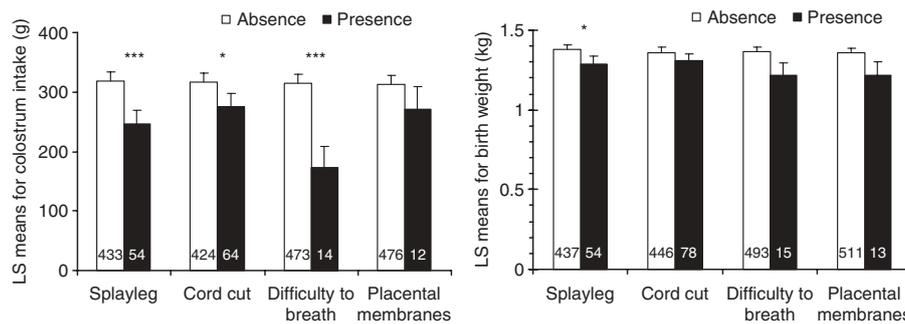


Figure 2 Effect of vitality traits on birth weight and colostrum intake. Numbers at bottom of bar graphs are numbers of piglets in each category. Data presented are least square means calculated after correction from litter effect. Error bars represent s.e. values. * $P < 0.05$, *** $P < 0.001$.

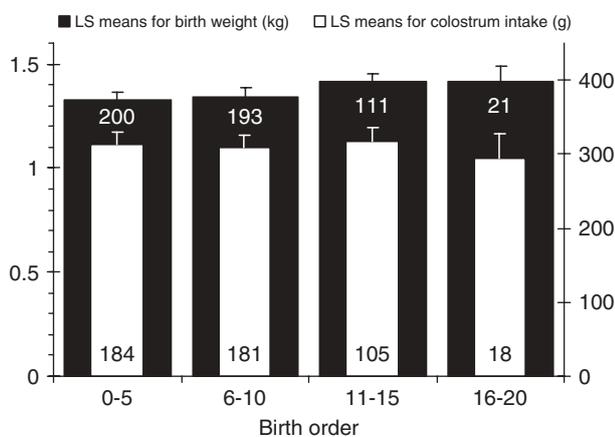


Figure 3 Effect of birth order divided in four categories on birth weight (black) and colostrum intake (white). Numbers at bottom and top of bar graphs are numbers of piglets in each category. Data presented are least square means calculated after correction from litter effect. Error bars represent s.e. values.

yield and litter size is shown in Figure 4. The 10 remaining variables are presented in Figure 5, the first two principal factors summarising 39.3% of the variability in colostrum yield. According to the first principal factor, on one hand, there was a positive relationship between colostrum yield, total and mean birth weight per litter, concentrations of IgG and protein at T_0 and sow body weight and parity, and on the other hand there was a negative relationship between colostrum yield and induction of farrowing, duration of gestation and concentrations of lactose at T_0 (Figure 5). According to the second principal factor, colostrum yield was negatively linked to variations in birth weights, but to a lesser extent than the associations noted with the first principal factor.

Analyses of particular relationships between colostrum yield and each of these variables were carried out. Simple analysis of variance on the effect of induction of parturition on colostrum yield showed a lower yield when farrowing was induced (induced: 3366 ± 126 g; not induced: 4165 ± 281 ; $P = 0.017$; t -test). However, this effect was somewhat confounded with the duration of gestation since only sows farrowing after 114 days of gestation were

induced (gestation length: when induced, 114.6 ± 0.1 and not induced, 113.3 ± 0.3 ; $P < 0.001$; t -test). Unfortunately, the unequal distribution of sows between durations of gestation and induction groups did not allow appropriate independent comparisons of these two variables on colostrum yield. Sow body weight and parity were strongly related ($r = 0.72$; $P < 0.001$) and duration of gestation showed negative correlations with parity ($r = -0.29$; $P = 0.07$) and body weight ($r = -0.34$; $P = 0.03$). Despite its contribution towards colostrum yield in the PLS analysis, body weight did not significantly influence colostrum yield ($P = 0.35$). On the other hand, when looking at the effect of parity (three categories were used, namely, primiparous, second or third parity, or parity 4 or more) on colostrum yield, sows of second and third parities had a greater colostrums production (means of $3435^a \pm 184$ g, $4278^b \pm 288$ g and $3616^{ab} \pm 288$ g, respectively, for the three groups; overall effect of parity $P = 0.059$).

Spearman correlation coefficients between colostrum yield and mean birth weight of piglets, total litter birth weight and variability of piglets' birth weights were 0.38 ($P = 0.015$), 0.28 ($P = 0.085$) and -0.34 ($P = 0.030$), respectively. There were no significant relationships between colostrum yield and concentrations of the various hormones at farrowing. However, the PLS analysis showed that colostrum yield was positively related to protein ($r = 0.045$; $P = 0.78$) and IgG ($r = 0.10$; $P = 0.53$) concentrations and negatively related to lactose ($r = -0.26$; $P = 0.11$) content in colostrum at the onset of farrowing. Colostrum composition and concentrations of various hormones in colostrum at farrowing, 2, 4 and 24 h *post partum* are shown in Figure 6. Relationships between colostrum composition and some sow characteristics, as determined by the principal components analysis, are shown in Figure 7 and a correlation matrix between those variables can be seen in Table 1. Figure 7 shows that a group of variables including P4, IgG and protein concentrations in colostrum around farrowing was diametrically opposed to lactose concentrations. A second group composed of protein, IgG concentrations at T_{24} , sow weight and parity was opposed to duration of gestation and colostrum lipid content.

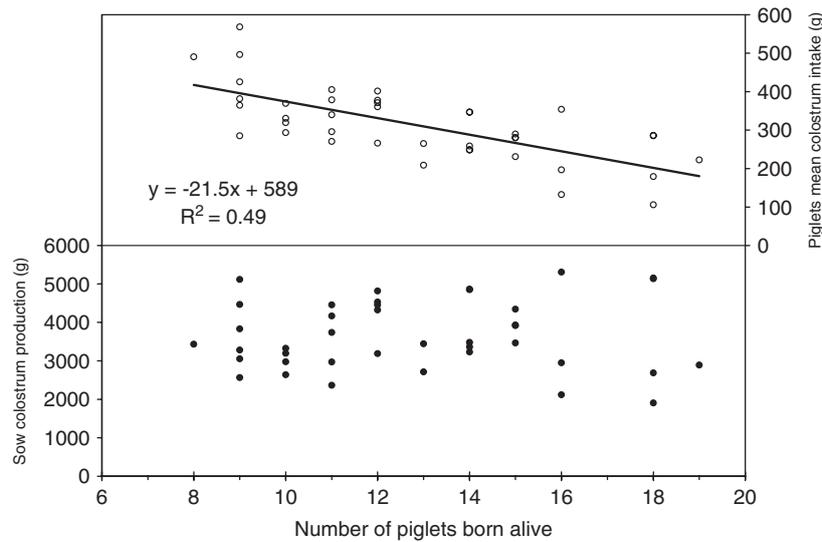


Figure 4 Effect of litter size on mean colostrum intake by piglets and sow colostrum yield.

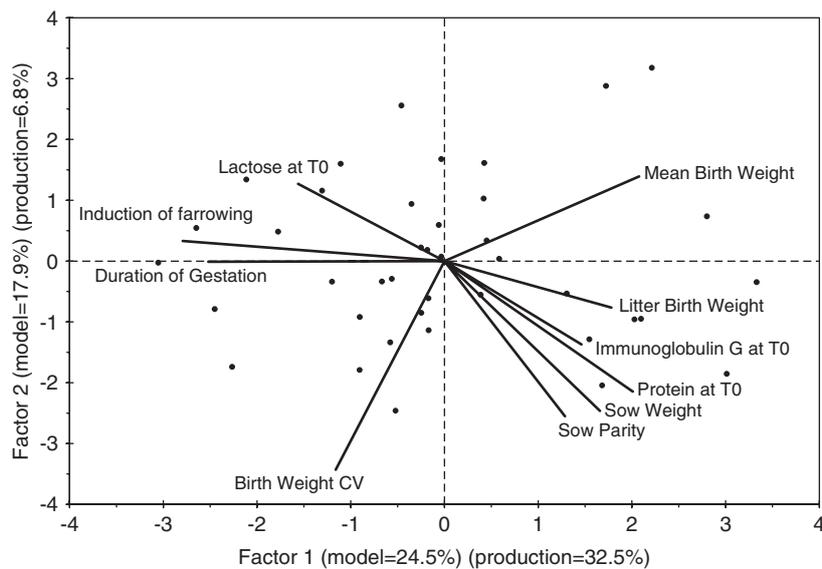


Figure 5 Result from partial least square analysis on colostrum yield. Lactose, immunoglobulin G and protein at T_0 are measured in colostrum at the onset of farrowing. Factor 1 summarises 24.5% of the general model information and 32.5% of the colostrum production variability. Factor 2 summarises 17.9% of the general model information and 6.8% of the colostrum production variability.

Discussion

Measurement of colostrum yield

Colostrum is produced by the mammary glands during a variable period ranging from 12 to 48 h after the onset of parturition. It is characterised by a high protein concentration, largely due to the presence of immunoglobulins, and a sharp drop (about 50%) in CP content occurs during the first 48 h (Klobasa *et al.*, 1987). In the present study, 60% of sows showed a drop in colostrum CP greater than 50% within 24 h *post partum* and the mean overall decrease for all sows was 52%. The first 24 h following the onset of farrowing is therefore an appropriate period for the measurement of colostrum yield.

To our knowledge, this is the first study directly assessing sow colostrum yield through the evaluation of colostrum intake by the whole litter. Previous studies provided some idea of colostrum production during the first 24 h following the onset of parturition, estimated at 3000 g, via the measurement of individual colostrum intake of only a few sow-reared piglets (Le Dividich and Noblet, 1981; Milon *et al.*, 1983). Yet, the weigh-suckle-weigh method used in those studies underestimates colostrum intake by approximately 31% (Rudolph, 1984). When accounting for this correction, a more precise estimate of sow colostrum yield would therefore be 4000 g, which is in agreement with the present results. Our measure of colostrum yield might also

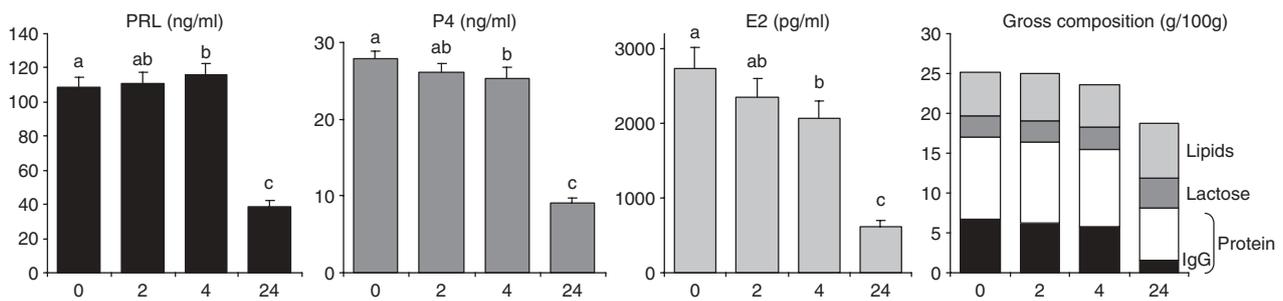


Figure 6 Concentrations of prolactin (PRL), progesterone (P4) and oestradiol-17 β (E2) in colostrum at the onset of farrowing (T₀) and 2, 4 and 24 h later. Values are means \pm s.e. Different letters indicate significant differences ($P < 0.05$). Composition of colostrum (means of concentrations of lipids, lactose, proteins including immunoglobulin G (IgG) at farrowing and 2, 4 and 24 h later.

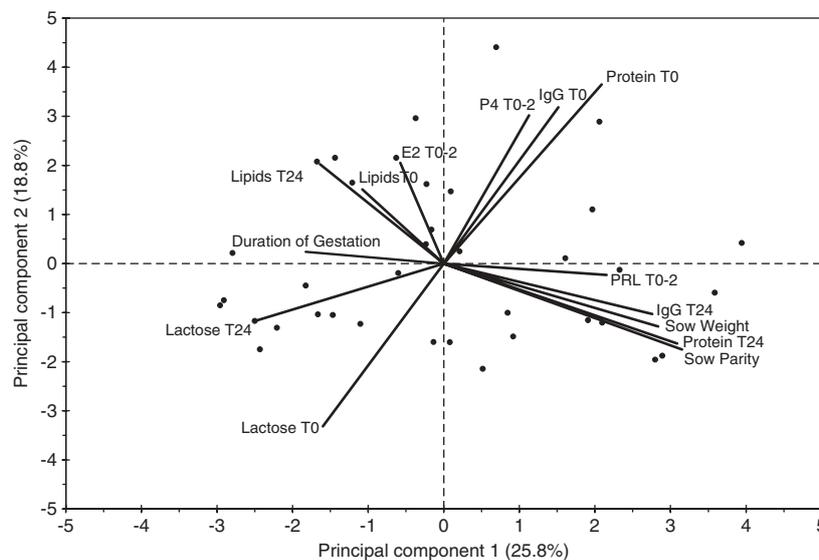


Figure 7 Results from the principal components analysis on colostrum composition and some sow-performance variables. The biplot of the first two principal components jointly represent 44.6% of the total variation.

have underestimated values since colostrum intake by piglets dead within 24 h after the onset of farrowing was not measured. However, those piglets most likely did not consume any colostrum, as indicated by their weight loss (Milligan *et al.*, 2001; Damm *et al.*, 2005).

Variability of colostrum yield and intake

Piglet characteristics. Colostrum intake by piglets was calculated using an equation based on their birth weight and their weight gain within 24 h of birth, therefore accounting for the strong relationship between colostrum intake and birth weight. However, while there was an overall increase in colostrum intake of 28 g per 100 g increase in birth weight, the equation used to estimate colostrum intake would suggest a 7-g increase in colostrum intake per 100-g increase in piglet birth weight (Devillers *et al.*, 2004b). Therefore, the impact of birth weight on colostrum intake is greater than what would be expected from the equation itself. Le Dividich *et al.* (2004) noted an increase of 18 g in piglet weight gain per 100-g increase in birth weight, which

is equivalent to 30 g of colostrum intake and is very close to the present results (1 g CI = 0.6 g birth weight; Devillers *et al.*, 2004b). Furthermore, relative colostrum intake (i.e. corrected for birth weight in g/kg) in the present study was also related to birth weight, indicating that heavier piglets may have a competitive advantage over lighter ones for colostrum access.

Although piglets being born later during farrowing have less time to consume colostrum, birth order was not related to either colostrum intake or birth weight, showing that piglets born later did catch up with others in terms of the amount of colostrum ingested (Bland *et al.*, 2003). Indeed, piglets tend to consume up to 30% of their 1st day colostrum intake during the first nursing bouts following birth (Fraser and Rushen, 1992) and during the first 6 h *post partum*, less than 75% of the litter is present at most nursing bouts (De Passillé and Rushen, 1989a). It is likely that after ingestion of a large amount of colostrum during the phase of continuous secretion, early-born piglets are asleep, thereby allowing late-born piglets the opportunity to suck. The negative influence of low vitality at birth,

Table 1 Matrix of correlations between concentrations of progesterone (P4) and oestradiol-17 β (E2) at T₀₋₂ (average of the two) and concentrations of lactose, crude proteins and IgG at T₀ in colostrum (r =Spearman's coefficient of correlation; P = P value for statistical difference; n = number of sows)

	[P4] at T ₀₋₂	[E2] at T ₀₋₂	[Lactose] at T ₀	[Protein] at T ₀
[E2] at T ₀₋₂	$r = 0.333$ $P = 0.041$ $n = 38$	–	$r = -0.027$ $P = 0.874$ $n = 38$	$r = 0.277$ $P = 0.093$ $n = 38$
[Lactose] at T ₀	$r = -0.382$ $P = 0.015$ $n = 40$	$r = -0.027$ $P = 0.874$ $n = 38$	–	$r = -0.634$ $P < 0.001$ $n = 40$
[Protein] at T ₀	$r = 0.443$ $P = 0.004$ $n = 40$	$r = 0.277$ $P = 0.093$ $n = 38$	$r = -0.634$ $P < 0.001$ $n = 40$	–
[IgG] at T ₀	$r = 0.278$ $P = 0.082$ $n = 40$	$r = 0.309$ $P = 0.059$ $n = 38$	$r = -0.289$ $P = 0.071$ $n = 40$	$r = 0.749$ $P < 0.001$ $n = 40$

IgG = immunoglobulin G.

especially hypoxia during delivery, on the piglet's ability to suckle (Herpin *et al.*, 2002) is confirmed by the lower colostrum intake of piglets with splayleg, ruptured umbilical cord or difficulty in breathing at birth. Those characteristics can therefore be useful to identify piglets at risk. In conclusion, low vitality and low birth weight impair the piglets' ability to successfully extract colostrum from the teats and reduce their chances of suckling later on, as nursings become synchronised (Pluske and Williams, 1996; Hoy *et al.*, 1997).

Litter characteristics. Contrary to what is seen with milk production (Auldist *et al.*, 1998), litter size did not affect colostrum yield, thereby confirming the absence of a litter size effect on piglets' growth during the first postnatal days (Milligan *et al.*, 2001; Le Dividich *et al.*, 2004). Piglets from larger litters therefore have less colostrum available on an individual basis. Higher litter birth weights tended to be related with higher colostrum yield and a greater heterogeneity in piglets' birth weights was negatively related to colostrum yield. These results are consistent with previous findings that greater heterogeneity in birth weights leads to poorer growth and higher mortality of piglets (Milligan *et al.*, 2002; Quiniou *et al.*, 2002). Therefore, the main factor determining colostrum intake by piglets was their body weight at birth, which is also the major determinant of their vitality and their ability to stimulate the udder in order to extract colostrum from the teats.

Sow characteristics. Colostrum intake does not depend solely on characteristics of the piglets but also on the sow's ability to produce it. In the PLS analysis, the duration of gestation, induction of farrowing, parity and sow weight all

contributed to the variation in colostrum yield. However, no clear effects were shown when the influence of each variable was analysed independently.

The effects of gestation length and induction of farrowing on colostrum yield are somewhat contradictory to earlier reports. Indeed, a lower colostrum yield was observed in sows with early-induced parturitions (day 109 of gestation) and this seemed to be due to lower birth weight and vitality of piglets (Milon *et al.*, 1983). Moreover, studies on the influence of prostaglandins on induction of lactation showed that sows with induced farrowings presented less risk of agalactia or mastitis (Einarsson *et al.*, 1975) and had only a slightly lower colostrum yield (Maffeo *et al.*, 1986). Nevertheless, it is important to consider that the distribution of sows across gestation lengths was not uniform in the present study and the effects of gestation length and farrowing induction were confounded to some extent. A study using a larger number of sows varying in gestation lengths is therefore needed to clearly determine their exact influences. Despite its contribution to the variation in colostrum yield, sow body weight was not, by itself, related to colostrum yield. On the other hand, parity had a slight influence on colostrum yield, with second and third parity sows having a higher yield of colostrum than sows from other parities. The same tendency was observed for milk production (Boyce *et al.*, 1997).

There is strong evidence for a role of progesterone (Liptrap, 1980; De Passillé *et al.*, 1993) and prolactin (Farmer *et al.*, 1998) in the initiation of lactation, yet no relationships between colostrum concentrations of these hormones and colostrum yield were established. Although hormonal concentrations in colostrum and plasma are well correlated during parturition (Devillers *et al.*, 2004a), the concentrations measured in colostrum reflect an average of

plasma concentrations during an undetermined period and slight differences may therefore go unnoticed. A positive relationship between milk production and milk lactose concentrations was previously reported in sows (White *et al.*, 1984), yet the inverse relationship found with the PLS analysis suggests that mechanisms regulating the synthesis of colostrum are different from those regulating milk synthesis.

Colostrum composition

Data on composition of colostrum was in accordance with previous reports (Le Dividich *et al.*, 2005). Hormonal concentrations in colostrum were also comparable with previously obtained results (Devillers *et al.*, 2004a), with the exception that E2 concentrations were greater during farrowing in the present study. Hormonal status regulates the synthesis of colostrum components and the PCA analysis provides a good summary of the relationships between hormone concentrations and colostrum composition. The negative correlations between lactose, and CP and IgG levels in colostrum confirmed the opposite relationship between the synthesis of lactose and the transfer of immunoglobulins in the mammary gland (Devillers *et al.*, 2004a). Moreover, P4 concentrations were positively correlated with IgG and CP and negatively correlated with lactose content in colostrum, confirming its stimulatory influence on the transfer of IgG from plasma to colostrum in the sow (Jackson *et al.*, 1995) and its inhibitory effect on lactose synthesis (Whitely *et al.*, 1990). Oestradiol-17 β was also shown to stimulate the transfer of IgG from plasma to colostrum in cows (Darton and McDowell, 1979) and this could also be the case in sows since a relationship between IgG and E2 concentrations in colostrum was observed.

Conclusion

This descriptive study provides the first estimate of colostrum yield using a method based on the measure of colostrum intake of the whole litter. Results demonstrate a large variability in colostrum yield among sows and suggest that determination of the factors affecting colostrum yield can be looked at based on two different hypotheses. In the event that sows do not limit the amount of colostrum available to the piglets, individual characteristics of the piglets, particularly birth weight and vitality, and consequently litter characteristics (heterogeneity of litter weight), would be the major determinants of colostrum intake by individual piglets. On the other hand, in the event that sows are limiting colostrum intake by the piglets, hormonal, environmental and nutritional factors could be responsible for the great variability in colostrum production.

In the present study, litter size, which is known to have a strong influence on milk production, did not affect colostrum yield. On the other hand, piglet weights, either individual or total litter weights, were slightly related to colostrum yield suggesting that, irrespective of litter size, vitality of the litter could be the major factor in determining

colostrum yield. At this early stage of lactation, the impact of udder stimulation by piglets is not likely in place yet and most of the colostrum is consumed in the few hours following parturition. A low colostrum yield may therefore be mainly attributed to a poor ability of the sow to produce colostrum, making the supply inadequate to meet the piglets' needs. However, we did not find any sow-related factor that clearly affected colostrum yield. The influences of parity, induction of farrowing and duration of gestation need to be confirmed and further studies are needed to investigate the endocrine regulation of colostrum secretion, especially the possible negative impacts of hormonal and metabolic disorders around parturition on the initiation of the lactation process.

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References

- Association of Official Analytical Chemists 1990. Official methods of analysis. AOAC, Washington, DC, USA.
- Auldust DE, Carlson D, Morrish L, Wakeford CM and King RH 2000. The influence of suckling interval on milk production of sows. *Journal of Animal Science* 78, 2026–2031.
- Auldust DE, Morrish L, Eason P and King RH 1998. The influence of litter size on milk production of sows. *Animal Science* 67, 333–337.
- Bland IM, Rooke JA, Bland VC, Sinclair AG and Edwards SA 2003. Appearance of immunoglobulin G in the plasma of piglets following intake of colostrum, with or without a delay in sucking. *Animal Science* 77, 277–286.
- Boyce JM, Smits RJ, Campbell RG and King RH 1997. The interrelationship between parity and litter weight on the milk production of sows. In *Manipulating pig production VI* (ed. PD Cranwell), p. 74. Australian Pig Science Association, Werribee, Australia.
- Damm BI, Pedersen LJ, Heiskanen T and Nielsen NP 2005. Long-stemmed straw as an additional nesting material in modified Schmid pens in a commercial breeding unit: effects on sow behaviour, and on piglet mortality and growth. *Applied Animal Behaviour Science* 92, 45–60.
- Darton PJ and McDowell GH 1979. The effect of oestrogen on selective transfer of IgG1 into mammary secretion of ewes. *Australian Journal of Experimental Biology and Medical Science* 57, 617–625.
- De Passillé AM and Rushen J 1989a. Suckling and teat disputes by neonatal piglets. *Applied Animal Behaviour Science* 22, 23–38.
- De Passillé AM and Rushen J 1989b. Using early suckling behavior and weight gain to identify piglets at risk. *Canadian Journal of Animal Science* 69, 535–544.
- De Passillé AM, Rushen J, Foxcroft GR, Aherne FX and Schaefer AL 1993. Performance of young pigs: relationships with periparturient progesterone, prolactin, and insulin of sows. *Journal of Animal Science* 71, 179–184.
- Devillers N, Farmer C, Mounier AM, Le Dividich J and Prunier A 2004a. Hormones, IgG and lactose changes around parturition in plasma, and colostrum or saliva of multiparous sows. *Reproduction Nutrition Development* 44, 381–396.
- Devillers N, Van Milgen J, Prunier A and Le Dividich J 2004b. Estimation of colostrum intake in the neonatal pig. *Animal Science* 78, 305–313.

- Devillers N, Le Dividich J and Prunier A 2006. Physiologie de la production de colostrum chez la truie. *INRA Productions Animales* 19, 29–38.
- Edwards SA 2002. Perinatal mortality in the pig: environmental or physiological solutions? *Livestock Production Science* 78, 3–12.
- Einarsson S, Gustafsson B and Larsson K 1975. Prostaglandin induced parturition in swine with some aspects on prevention of the MMA (metritis, mastitis, agalactia) syndrome. *Nordisk Veterinaermedicin* 27, 429–436.
- Etienne M, Dourmad JY and Noblet J 1998. The influence of some sow and piglet characteristics and of environmental conditions on milk production. In *The lactating sow* (ed. MWA Verstegen, PJ Moughan and JW Schrama), pp. 285–299. Wageningen Press, Wageningen, Netherlands.
- Farmer C, Devillers N, Rooke JA and Le Dividich J 2006. Colostrum production in swine: from the mammary glands to the piglets. *CAB reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 1, 1–16.
- Farmer C, Robert S and Rushen J 1998. Bromocriptine given orally to periparturient of lactating sows inhibits milk production. *Journal of Animal Science* 76, 750–757.
- Fraser D and Rushen J 1992. Colostrum intake by newborn piglets. *Canadian Journal of Animal Science* 72, 1–13.
- Gordon GO and Whittier EO 1965. Proteins of milk. In *Fundamentals of dairy chemistry* (ed. BH Webb and AH Johnson), pp. 54–90. Avi Publishing Company, Westport, CT, USA.
- Herpin P, Le Dividich J, Hulin JC, Fillaut M, De Marco F and Bertin R 1996. Effects of the level of asphyxia during delivery on viability at birth and early postnatal vitality of newborn pigs. *Journal of Animal Science* 74, 2067–2075.
- Herpin P, Damon M and Le Dividich J 2002. Development of thermoregulation and neonatal survival in pigs. *Livestock Production Science* 78, 25–45.
- Hoy S, Lutter C, Puppe B and Wahner M 1997. The influence of early postnatal piglet vitality on live weight gain and mortality. *Animal Research and Development* 45, 89–101.
- Institut Technique du Porc 2001. Technical economic management results over 25 years. In *Pork performance 2000* (ed. ITP), pp. 52–66. ITP edition, Paris.
- Jackson JR, Hurley WL, Easter RA, Jensen AH and Odle J 1995. Effects of induced or delayed parturition and supplemental dietary fat on colostrum and milk composition in sows. *Journal of Animal Science* 73, 1906–1913.
- Klobasa F, Werhahn E and Butler JE 1987. Composition of sow milk during lactation. *Journal of Animal Science* 64, 1458–1466.
- Le Dividich J and Noblet J 1981. Prise de colostrum, thermorégulation et production de chaleur chez le porcelet nouveau né en relation avec le milieu thermique. *Journées de la Recherche Porcine en France* 13, 11–16.
- Le Dividich J, Martineau GP, Thomas F, Demay H, Renoult H, Homo C, Boutin D, Gaillard L, Surel Y, Bouetard R and Massard M 2004. Acquisition de l'immunité passive chez les porcelets et production de colostrum chez la truie. *Journées de la Recherche Porcine en France* 36, 451–456.
- 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.
- Liptrap RM 1980. Prostaglandin F₂ alpha and progesterone in experimental hypogalactia in sows. *Research in Veterinary Science* 29, 240–247.
- Maffeo G, Redaelli G, Ballabio R and Baroni P 1986. Milk production in sows after spontaneous delivery and after delivery induced by PGF₂alpha analogues. *Zuchthygiene* 21, 8–17.
- Milligan BN, Fraser D and Kramer DL 2001. Birth weight variation in the domestic pig: effects on offspring survival, weight gain and suckling behaviour. *Applied Animal Behaviour Science* 73, 179–191.
- Milligan BN, Fraser D and Kramer DL 2002. Within-litter birth weight variation in the domestic pig and its relation to pre-weaning survival, weight gain, and variation in weaning weights. *Livestock Production Science* 76, 181–191.
- 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. *Annales de Recherches Vétérinaires* 14, 533–540.
- Pluske JR and Williams IH 1996. Split weaning increases the growth of light piglets during lactation. *Australian Journal of Agricultural Research* 47, 513–523.
- Quiniou N, Dagorn J and Gaudré D 2002. Variation of piglets' birth weight and consequences on subsequent performance. *Livestock Production Science* 78, 63–70.
- Robert S, De Passillé AM, St-Pierre N, Dubreuil P, Pelletier G, Petitclerc D and Brazeau P 1989. Effect of the stress of injections on the serum concentration of cortisol, prolactin and growth hormone in gilts and lactating sows. *Canadian Journal of Animal Science* 69, 663–672.
- Rooke JA and Bland IM 2002. The acquisition of passive immunity in the newborn piglet. *Livestock Production Science* 78, 13–23.
- Rudolph BC 1984. Use of deuterium oxide as an estimator of milk intake and body composition of nursing pigs and the effect of oxytocin administration to the dam on early lactational performance. PhD thesis, University of Kentucky, Lexington.
- Statistical Analysis Systems Institute 2002. SAS, release 9.1. SAS Institute Inc., Cary, NC, USA.
- Taverne M, Bevers M, Bradshaw JMC, Dieleman SJ, Willems AH and Porter DG 1982. Plasma concentrations of prolactin, progesterone, relaxin and oestradiol-17 β in sows treated with progesterone, bromocryptine or indomethacin during late pregnancy. *Journal of Reproduction and Fertility* 65, 85–96.
- Tuchscherer M, Puppe B, Tuchscherer A and Tiemann U 2000. Early identification of neonates at risk: traits of newborn piglets with respect to survival. *Theriogenology* 54, 371–388.
- White CE, Head HH, Bachman KC and Bazer FW 1984. Yield and composition of milk and weight gain of nursing pigs from sows fed diets containing fructose or dextrose. *Journal of Animal Science* 59, 141–150.
- Whitely JL, Hartmann PE, Willcox DL, Bryant-Greenwood GD and Greenwood FC 1990. Initiation of parturition and lactation in the sow: effects of delaying parturition with medroxyprogesterone acetate. *Journal of Endocrinology* 124, 475–484.
- Xu RJ, Wang F and Zhang SH 2000. Postnatal adaptation of the gastrointestinal tract in neonatal pigs: a possible role of milk-borne growth factors. *Livestock Production Science* 66, 95–107.