Primiparous sow behaviour on the day of farrowing as one of the primary contributors to the growth of piglets in early lactation

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Océane Girardie[1]✉, Denis Laloë[2], Mathieu Bonneau[3], Yvon Billon[4], Jean Bailly[4], Ingrid David[1] & Laurianne Canario[1]

Large White and Meishan sows differ in maternal ability and early piglet growth. We investigated the relationships between 100 maternal traits, grouped into 11 blocks according to the biological function they describe and litter growth over three successive periods after birth (D0–D1, D1–D3 and D3–D7; D0 starting at the onset of farrowing), as a measure of sow investment in early piglet production. Within- and between-breed variation was exploited to cover a maximum of the variability existing in pig maternal populations. The objective was to quantify the contribution of maternal traits, including functional traits and behavioural traits, to early litter growth. Multivariate analyses were used to depict correlations among traits. A partial least square multiblock analysis allowed quantifying the effect of maternal traits on early growth traits. Partial triadic analyses highlighted how sow behaviour changed with days, and whether it resulted in changes in litter growth. Several behavioural traits (standing activity, reactivity to different stimuli, postural activity) and functional traits (body reserves, udder quality) at farrowing contributed substantially to litter growth from D0 to D7. Sow aggression towards piglets and time spent standing at D0 were unfavourably correlated to D1–D3 litter growth. Time spent lying with udder exposed at D0 was favourably correlated to D1–D3 litter growth. The farrowing duration was negatively correlated to D0–D1 and D1–D3 litter growth. Furthermore, D3–D7 litter growth was positively correlated to feed intake in the same period. Several behavioural traits and some functional traits influence early litter growth. The contribution of sow behaviour was greater in the critical period around farrowing than in later days.

Scarce information exists on the determinism of neonatal growth in piglets. Studies based on birth weight tend to indicate that early growth contributes to piglet survival and growth until weaning[1–5]. Like in other mammalian species, growth depends mainly on the dam maternal ability, which encompasses a large set of physiological, functional and behavioural features. Maternal effects are predominant until weaning, to determine litter growth[6,7]. They are reflected in milk production[8–10] which results from hormonal changes, the use of body reserves built in gestation[11] and feed intake[12]. Other functional characteristics come into play to define piglet production. Piglet suckling activity[9,13,14] depends on teat functioning, and even the teat interval influences milk consumption along the udder according to litter size[15–17].

Upstream of piglet births, the cascade of endocrine and behavioural changes in the sow can have major consequences on piglet production if changes are not sequenced adequately. The endocrine changes that occur prior to farrowing influence the later farrowing and lactation processes. They stimulate nest building[18] depending on environmental factors such as the provision of space and straw[19]. Satisfactory nest-building activity coincides with oxytocin secretion in the hours before farrowing[20], and has a major influence on the farrowing process and sow behaviour, which contributes to growth even up to weaning[21].

[1]UMR1388 GenPhySE, INRAE, Université de Toulouse, INPT, 31326 Castanet, Tolosan, France. [2]UMR1313 GABI, INRAE, Université Paris-Saclay, AgroParisTech, 78350 Jouy-en-Josas, France. [3]UR0143 ASSET, INRAE, Petit-Bourg, France. [4]UE GenESI, INRAE, Le Magneraud, 17700 Surgères, France. ✉email: oceane.girardie@inrae.fr

The total absence of restraint for lactating sows could, become the dominant system in a few years' time. The pig industry would benefit from producing sows that ensure the satisfactory growth of a greater number of piglets up to weaning. With move to looser housing, the correct timing for different activities around farrowing to prepare lactation and develop care for newborn piglets is crucial. To date, the impact of housing condition (cage versus pen) on litter growth remains lowly documented. The study by Loftus et al.[22] showed no difference in litter growth between the two systems, while the studies by Pedersen et al.[23] and Nowland et al.[24] were slightly in favour of looser systems. Conversely, the literature is full of studies comparing the behaviour of sows in the two systems. Moving sows towards less constraining systems will exacerbate the expression of their behaviour. In pen, sows spend more time preparing their nest (149 min vs. 101 min) 4 to 12 h prepartum[25], and can be twice as active as in crate[26] but are less restless at farrowing and more careful towards piglets[27]. One study highlighted that early piglets growth depends on sow behaviour in the period of farrowing, with a moderate correlation of 0.30[28].

In pen, more positive maternal behaviour in early lactation is expected[25,29,30] as well as less savaging[31]. In addition to a good milk supply, positive maternal behaviour such as caution when changing posture and response to piglet distress calls, is decisive in maintaining production level as compared to pen. But measuring maternal behaviour is still complicated, as it relies on appreciation by the human eye. Computer vision analysis that consists in locating the animal in the image and then estimating several features, has emerged as an efficient tool to monitor behaviour in the long term and on many animals. Artificial Intelligence (AI) enables to detect different sow postures and other activities with a good accuracy[32–37]. Restlessness at farrowing is unfavourable to piglet growth in pen but not in free-range systems[38,39]. In a study on the 24 h around farrowing, Illmann et al.[38] showed that the number of postural changes at farrowing was positively correlated to piglet growth on the first day after birth. With AI, we previously draw connections between sow activity pattern around farrowing and the performance of piglets in early lactation[39]. Early growth of piglets from sows that changed postures more often to hide the udder on the day of farrowing was lower than that of sows that did not hide the udder[39].

Individual differences in maternal ability are maintained in populations by adaptive processes. While large progress was made in lactation performance and thus in the nutritional aspects of piglet production, sow behaviour was generally not considered in breeding programs.

The objective of the current study was to explore the variation in associations between sow maternal traits and early litter growth. This study was based on the aggregation of data from 21 Large-White (LW) sows and 22 Meishan (MS) gilts that were kept in individual farrowing pens with provision of straw for nest-building. The use of breeds that contrast in maternal ability allowed accessing a large variation in maternal traits and in their relationship with piglet growth[35,40]. Large White sows selected for lean growth produce litters that grow faster than that of Meishan sows, due to a higher milk production[28,39,41]. They differ markedly in behavioural reactivity[42] but not in general behaviour in the days after farrowing[39]. We merged data on these 2 breeds whose biology and behavioural reactivity are on average very different. They differ drastically in metabolism, body size, feed intake and thus in the ability to invest in piglet production[36], and also in teat functionality and litter size. The focus is especially relevant on primiparous sows for which sizable maternal effects come into play[43]. They face for the first time an individual environment, and they eventually experience piglet neophobia, which has possible repercussions on farrowing duration and colostrum production[44]. We assume that sow postural activity can be used as a global indicator of sow maternal behaviour and health, and that its longitudinal monitoring allows identifying changes in sow activity that affect piglet production. Artificial intelligence was applied to image analysis to depict sow behaviour in the days around farrowing. Although some studies analysed the relationship of certain aspects of maternal behavioural traits with piglet performance, only few have accounted for sow functional and behavioural traits simultaneously[45,46]. We assumed that both functional and behavioural traits interplay to determine early litter growth. We analysed the relationships of 100 maternal traits measured from entrance into the farrowing unit to 7 days after farrowing, with litter growth repeatedly measured in the week after birth.

Results

Description of the data base

Breed differences in maternal traits are given in Additional file 1. At farrowing, LW sows were significantly older (432 days vs. 394 days, $p < 0.0001$), heavier (240 kg vs. 169 kg, $p < 0.0001$) and had a larger amount of protein content (33.8 kg vs. 12.9 kg, $p < 0.0001$) than MS sows. They also gave birth to larger litters than MS sows (15.0 vs. 12.7, $p = 0.02$). MS sows had a larger amount of fat reserves (backfat depth: 49.4 mm vs. 24.1 mm, $p < 0.001$; fat content: 102 vs. 84 kg, $p < 0.0001$) and more numerous total and functional teats than LW sows. The two breeds also differed in several behavioural traits, but not in the time budgets of postural activity and standing activity. The LW sows vocalized more than MS sows in all observational situations, and they were more aggressive towards humans and piglets, and rested less during the farrowing process (131 vs. 287 postural changes, $p = 0.02$).

The FAMD (Factorial Analysis of Mixed Data) applied to the 100 variables showed a clear separation between the two breeds on the first axis (21.5% of data variation explained (inertia), while the second axis explained only 7.0% of data variation). For an overview of the range of associations between variables and early litter growth that could be detected in a commercial population, we analysed the associations between the multitude of variables that describe maternal ability independent of the sow breed and litter size factors. The correction was applied to each of the 100 variables using linear models and residuals were used as variables of interest in subsequent analyses.

Relative influence of the blocks of maternal traits on litter growth according to the MBPLS analysis

The relationship between the 100 maternal traits (explanatory variables **X**) and the three litter weight gains (variable to be explained **Y**) were measured with the multiblock analysis. The first three dimensions of the multiblock analysis accounted for 76.9% of the total inertia in data structure (55.3%, 11.4% and 10.2%, respectively). D0–D1 litter weight gain (LWG_{0-1}) was strongly correlated to other weight gains, 0.61 with D1–D3 litter weight gain (LWG_{1-3}) and 0.46 with D3–D7 litter weight gain LWG_{3-7}) and LWG_{1-3} was lowly correlated to LWG_{3-7} (0.23).

The Block Importance (BlockImp) to quantify the importance of each of the 11 blocks (**X**) to explain the three LWG (**Y**) is presented in Table 1. Given this statistic, only the two blocks of sow activity while standing at D0 and udder quality were significantly correlated to the LWG on the three periods ($BlockImp_{X7} = 15.50\%$ $[10.55; 25.45]_{95\%}$; $BlockImp_{X3} = 14.98\%$ $[12.11; 22.66]_{95\%}$). Even if their CI (Confidence Interval) included the threshold value of 0.091 (= 1/11), three other blocks showed an average BlockImp value greater than 0.091, underlying also a substantial contribution to early litter growth. Those were blocks describing body reserves ($BlockImp_{X2} = 11.98\%$ $[6.06; 21.05]_{95\%}$), reactivity at farrowing ($BlockImp_{X5} = 11.10\%$ $[4.34; 18.84]_{95\%}$), and postural activity before D0 ($BlockImp_{X9} = 10.85\%$ $[4.68; 14.67]_{95\%}$).

The importance index (VarImp) quantified the importance of each of the 100 variables within block on the three periods of LWG. The VarImp index of the 29 maternal traits with the highest importance over the three LWG periods (VarImp > 1/100%) is given in Fig. 1. These 29 maternal traits explained 85% of the variation in LWG in the three periods ($LWG_{0-1,}$ LWG_{1-3} and LWG_{3-7}). Of these 29 variables, five variables in blocks $\mathbf{X_7}$ and $\mathbf{X_3}$ had a significant effect on LWG in early lactation (D0 to D7): time spent doing something other than eating and drinking when the sow is standing on D0 ($VarImp_{otherD0} = 9.06\%$ $[3.48; 17.97]_{95\%}$, $\mathbf{X_7}$); time spent eating on D0 ($VarImp_{eatD0} = 11.73\%$ $[7.21; 22.84]_{95\%}$, $\mathbf{X_7}$); teat diameter 0.5 to 1 and 1 to 1.5 ($VarImp_{0.5to1} = 3.02$ $[1.40; 5.75]_{95\%}$, $VarImp_{X1to1.5} = 4.24$ $[1.82; 8.01]_{95\%}$, $\mathbf{X_1}$); and number of none functional teats at D7 ($VarImp_{NofunctionalD7} = 2.96$ $[1.47; 5.77]_{95\%}$, $\mathbf{X_1}$) . These five maternal traits explained 31.01% of LWG in the three periods. Additional maternal traits in blocks $\mathbf{X_5}$, $\mathbf{X_2}$ and $\mathbf{X_3}$, had a substantial influence on LWG in the three periods but were associated with large confidence intervals: aggression (piglets) ($VarImp_{Aggression(piglets)} = 8.96$ $[-2.81; 17.72]_{95\%}$, $\mathbf{X_5}$), amount of body protein content ($VarImp_{ProteinContent} = 4.77$ $[-2.00; 9.44]_{95\%}$, $\mathbf{X_2}$), body weight before farrowing ($VarImp_{BodyWeight} = 3.05$ $[-2.44; 6.06]_{95\%}$, $\mathbf{X_2}$), and irregularity of teat interval ($VarImp_{irregular} = 4.17$ $[-0.45, 8.27]_{95\%}$, $\mathbf{X_3}$). These four maternal traits explained 20.95% of LWG in early lactation.

Relationships between maternal traits and the 3 LWG considering the first three axes of the PLS multiblock analysis are shown in Fig. 2. LWG_{0-1} and LWG_{3-7} were orthogonal to LWG_{1-3} on the representation according to axes 1 and 2, and also according to axes 2 and 3. The % of MS piglets in the litter (%MS, $\mathbf{X_1}$), reaction before entering the pen (Pen ease of entrance: 0, $\mathbf{X_4}$), and time spent lateral lying at D0 (LL_D0, $\mathbf{X_{10}}$) were positively correlated to LWG_{0-1} and LWG_{3-7}. Conversely, time spent doing something other than drinking and eating while standing at D0 (Something other_D0, $\mathbf{X_7}$) and on the days after (Something other_ after D0, X_8), time spent standing at D0 (ST_D0, $\mathbf{X_{10}}$) and lateral lying with udder exposed after (LLU_after D0, X_{11}) and aggression towards piglets at D0 (Aggression(piglets), $\mathbf{X_5}$) were negatively correlated to LWG_{0-1} and LWG_{3-7}. LWG_{1-3} was positively correlated to the time spent doing something other than drinking and eating while standing in the days after D0 (Something other_afterD0, $\mathbf{X_8}$), with time spent drinking before D0 (Drinking_before D0, X_6), and with aggression towards piglets at D0 (Aggression(piglets), $\mathbf{X_5}$). However, LWG_{1-3} was negatively correlated to time spent sternal lying before D0 (SL_before D0, $\mathbf{X_9}$), at D0 (SL_D0, $\mathbf{X_{10}}$) and after D0 (SL_after D0, $\mathbf{X_{11}}$), and protein content and body weight ($\mathbf{X_2}$).

Temporal variation in the relationship of sow behaviour traits with litter growth according to the PTA analysis

In summary, on the basis of the multiblock analysis, sow behavioural traits on the day of farrowing and during the first day of lactation were more correlated to the 3 LWG than other maternal traits. The blocks "standing

Block	Mean (%)	95% confidence interval
Standing activity—D0 (X_7)	15.50	10.55; 25.45
Udder quality (X_3)	14.98	12.11; 22.66
Body reserves at entrance (X_2)	11.98	6.06; 21.05
Reactivity at farrowing (X_5)	11.10	4.34; 18.84
Postural activity—Before D0 (X_9)	10.85	4.68; 14.67
Postural activity—D0 (X_{10})	8.40	2.41; 12.27
Reactivity at entrance (X_4)	6.69	3.00; 8.87
Farrowing performance and environment (X_1)	6.17	− 0.50; 7.81
Postural activity—After D0 (X_{11})	5.99	− 0.98; 9.17
Standing activity—After D0 (X_8)	4.67	− 4.27; 6.35
Standing activity—Before D0 (X_6)	3.68	− 5.34; 5.70

Table 1. The importance index of the 11 explanatory blocks for early litter growth. Multiblock partial least-squares (mbPLS) regression of early litter growth explained by farrowing performance and environment ($\mathbf{X_1}$), body reserves at entrance ($\mathbf{X_2}$), udder quality ($\mathbf{X_3}$), reactivity at entrance ($\mathbf{X_4}$), reactivity at farrowing ($\mathbf{X_5}$), standing activity—Before D0 ($\mathbf{X_6}$), standing activity—D0 ($\mathbf{X_7}$), standing activity—After D0 ($\mathbf{X_8}$), postural activity—Before D0 ($\mathbf{X_9}$), postural activity—D0 ($\mathbf{X_{10}}$) and postural activity—After D0 ($\mathbf{X_{11}}$). The BlockImp index represents the relative contribution of each explanatory block to litter growth and satisfies ∑kBlockImpk = 100% for K = 1 to 11 ± the 95% confidence interval around the estimate.

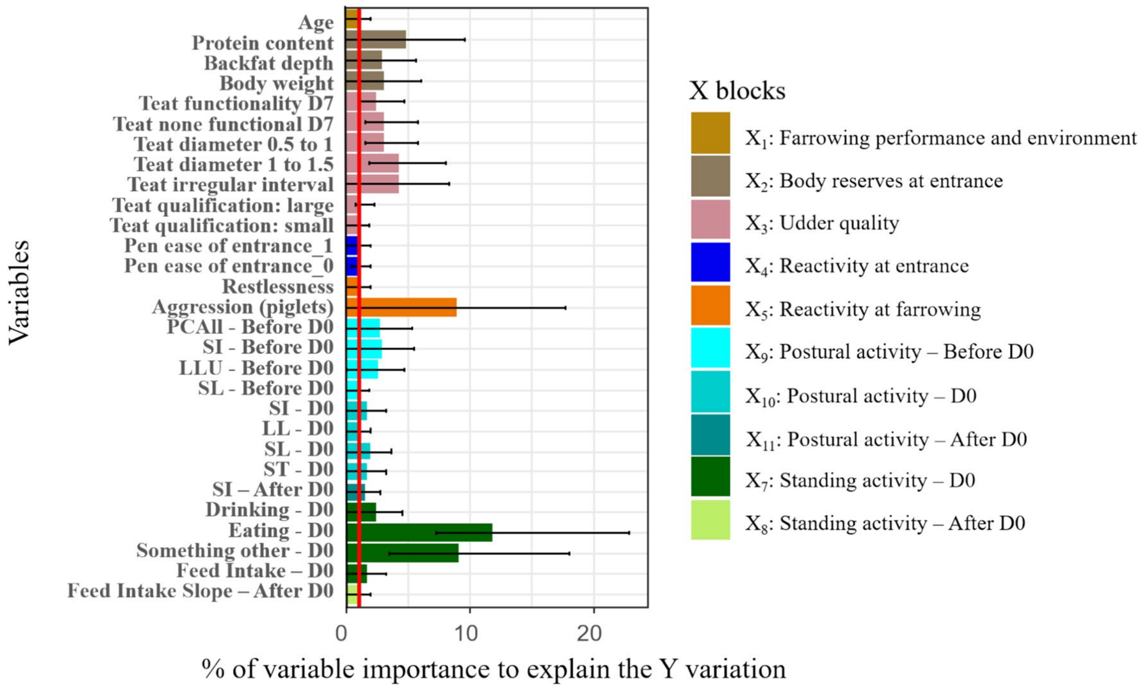

Figure 1. The VarImp Index of the 29 most important maternal traits (VarImp > 0.89%) with associated 95% confidence interval. The threshold value is indicated with the vertical red line at 1/100% = 1%. Multiblock analysis of the three LWG (**Y**) explained by farrowing performance and environment ($\mathbf{X_1}$), body reserves at entrance ($\mathbf{X_2}$), udder quality ($\mathbf{X_3}$), reactivity at entrance including reaction when the sow enters the pen PenEntry_1 (enter rapidly) and PenEntry_0 (observe before entering the pen, $\mathbf{X_4}$), reactivity at farrowing ($\mathbf{X_5}$), standing activity—Before D0 ($\mathbf{X_6}$), standing activity—D0 ($\mathbf{X_7}$), standing activity—After D0 including the time to resume eating (Feed Intake Slope—After D0, $\mathbf{X_8}$), postural activity—Before D0 including PCAll_before (number of postural changes before farrowing), time spent sitting (SI), time spent lateral lying with udder exposed (LLU) and time spent sternal lying (SL, $\mathbf{X_9}$), postural activity—D0 including time spent sitting (SI), time spent lateral lying (LL), time spent sternal lying (SL) and time spent standing (ST, $\mathbf{X_{10}}$) and postural activity—After D0 including time spent sitting (SI,$\mathbf{X_{11}}$).

activity" and "postural activity" were built from the longitudinal analysis of video images with convolutional neural networks (CNN). A Partial Triadic Analysis (PTA) was carried out to analyse the temporal effect of these two activity blocks on the 3 LWG. The correlations of postural activity traits and standing activity traits with LWG were estimated for the three periods D0–D1, D1–D3 and D3–D7. Referring to the vector correlation matrix, the structures of the three period tables according to postural activity changed with time. The correlation of the D0–D1 table was 0.62 with the D1–D3 table and 0.54 with the D3–D7 table.

The three tables were involved in the construct of the compromise, with inputs ranging between 0.5 and 0.61 αk. The D0–D1 table contributed less to the construct of the compromise table (αk: 0.5 and Cos^2: 0.83) than the two other tables and the D1–D3 table contributed more than the two other tables (αk: 0.61 and Cos^2: 0.92).

The first axis of the compromise table explained 48% of the variation of the data and the second axis 28% (Fig. 3A). On the factorial map of projection according to axes 1 and 2, axis 1 was highly defined by time spent lateral lying with udder exposed (LLU) and axis 2 by time spent sitting (SI) and spent sternal lying (SL) in opposite directions. Referring to the compromise table, LWG_{0-1} was mainly correlated to the number of postural changes (PCAll and PCStopNurse, Fig. 3A). LWG_{1-3} and LWG_{3-7} were lowly explained by postural activity.

None of the data structures per period (nb. of postural changes and postural activity from one of the three periods analyzed jointly) deviated from the compromise (Fig. 3B,D,F). The association between LWG and sow restlessness was low but more pronounced in the D0–D1 period than in the following periods. The LWG was lowly correlated to sow activity in the D1–D3 period. A low but substantial association between LWG and time spent lateral lying (LL) was observed on the D3–D7 period and not in the two previous periods (Fig. 3 C, E and G).

Referring to the vector correlation matrix, the structures of the three periodic tables changed over time as a function of standing activity. The correlations to the D0–D1 table decreased from 0.50 (D1–D3) to 0.25 (D3–D7). The compromise was defined with a weighted average of the three tables. The participation of each table in the calculation of the compromise ranged between 0.51 and 0.65 αk. The D1–D3 table had a higher contribution (αk: 0.65 and Cos^2: 0.90) to the calculation of the compromise than the other two tables (αk: 0.51 and 0.57; Cos^2: 0.74).

The first two axes of the compromise table explained 86% of the variation (axis 1: 55%; axis 2: 31%, Fig. 4A). On the factorial map of the projection along axes 1 and 2, axis 1 was defined by feed intake and time spent drinking while standing in opposite directions, and axis 2 was defined by time spent doing something else while

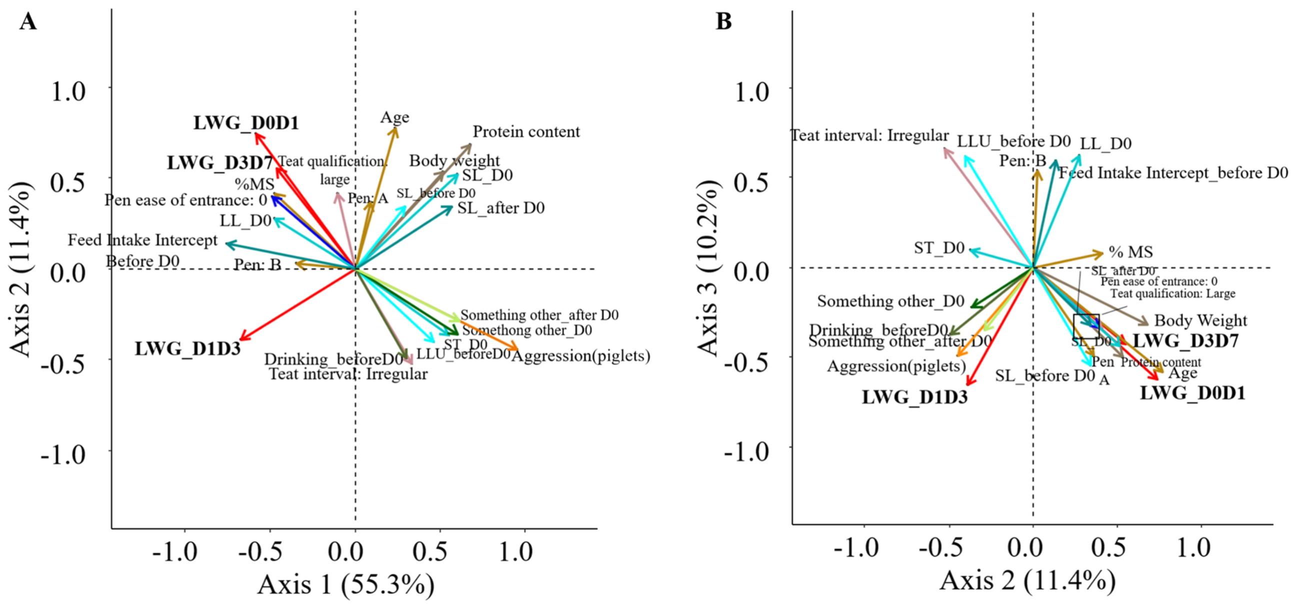

Figure 2. Plots of variables the most commonly represented on (**A**) the two first dimensions and (**B**) dimensions two and three (>|0.3|) of the multiblock analysis for the three litter gains (**Y**) explained by the 100 maternal variables grouped into 11 blocks: farrowing performance and environment including age of sow at maternity entrance (Age), the % of MS piglet in a litter (%MS), and pen location in maternity (**A** and **B**, $\mathbf{X_1}$), body reserves with proteins content (Proteins) and weight (Body weight, $\mathbf{X_2}$), teat quality including teat interval (irregular) and length of teats (large, $\mathbf{X_3}$), reactivity at entrance including reactivity at entering the pen (PenEntry_0: observe before enter, $\mathbf{X_4}$), reactivity at farrowing including sow aggressive towards piglet (Aggression(piglets), $\mathbf{X_5}$), standing activity—Before D0 including the time to resume eating (Intercept_before) and the time spent drinking (Drink_before, $\mathbf{X_6}$), standing activity—D0 including time spent doing something other than eating and drinking when sow are standing (Something other_D0, $\mathbf{X_7}$), standing activity—After D0 including time spent doing something other than eating and drinking when sow are standing (Something other_after D0, $\mathbf{X_8}$), postural activity—before D0 including time spent lateral lying with udder exposed (LLU_ before D0), time spent sternal lying (SL_before D0, $\mathbf{X_9}$), postural activity—D0 including time spent lateral lying (LL_D0), sternal lying (SL_D0), and standing (ST_D0, $\mathbf{X_{10}}$) and postural activity—After D0 including time spent sternal lying (SL_after D0, $\mathbf{X_{11}}$).

standing. On the compromise, LWG_{0-1} was mainly correlated to time spent eating (Fig. 4A). LWG_{1-3} and LWG_{3-7} were weakly explained by standing activity.

Feed intake and standing activity (analysed jointly in one period) did not significantly deviate in position from that of the compromise (Fig. 4B,D,,F). The association between LWG and time spent eating (and feed intake as well) was low but more pronounced in the D0–D1 period than in following periods. LWG_{3-7} was negatively correlated to time spent doing something other than eating or drinking while standing in the D3–D7 period (Fig. 4C,E,G).

The partial triadic analysis and the multiblock analysis indicated a stronger relationship of D0–D1 litter growth with sow behaviour on the day of farrowing than in the other periods.

Discussion

The period around farrowing is the scene of numerous hormonal and metabolic changes in sows. There is great variability in their response to changes in their physical and social environment, i.e. birth of the piglets. A lack of synchronisation between variations in hormonal concentrations can have consequences on colostrum production and even lactogenesis. Similarly, the incorrect pattern of behavioural activities around farrowing may have an impact on piglet production.

Sows start lactation relying on body reserves. Protein reserves play an important role in milk quantity and quality[47,48] and therefore in litter growth[49]. Body composition determines how many resources the sow can mobilize[49]. We showed a positive association between primiparous sow body weight and body composition at farrowing, and early postnatal growth. The explanation is the ability of larger sows to mobilise more reserves[50,51]. In our study, litter weight gain on day 1 was also correlated to sow age. Age is linked to the sow's level of physical maturity. More mature sows require less resource allocation to their own growth. They can commit more resources to colostrum production and milk production than less mature sows[52,53]. Selection for lean growth results in faster-growing sows[6,54] with increased crude protein requirements. Sometimes this tends to reduce the growth of lactating piglets since milk yield has increased but not proportionally to litter size[55].

Piglet colostrum intake influences growth through to weaning[56–58]. Colostrum production is approximated by litter weight gain on day 1 of lactation[59,60]. Very few studies established that colostrum production depends

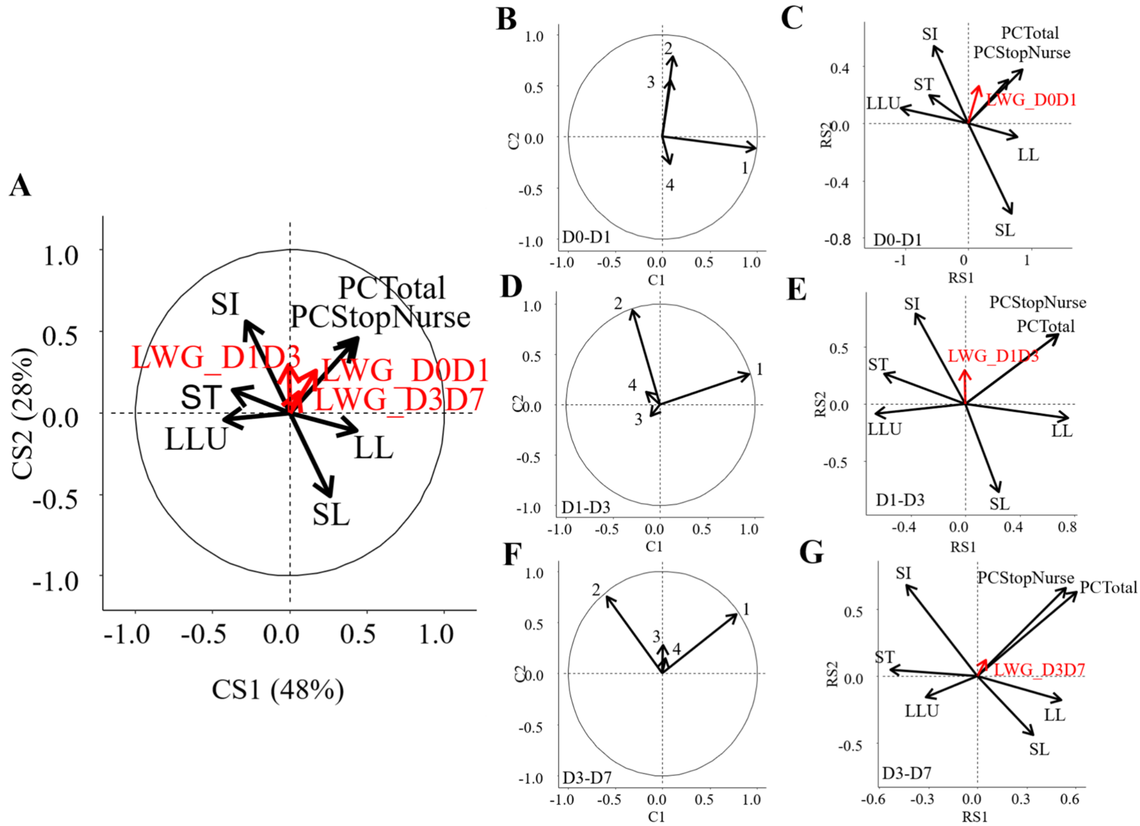

Figure 3. Partial triadic analysis of postural activity and early piglet weight gain. (**A**) Variable representation in dimensions 1–2 of the compromise. (**B**,**D**,**F**) Deviations from the compromise: (**B**) on the D0–D1 period; (**D**) on the D1–D3 period; (**F**) on the D3–D7 period. Arrows 1 to 4 were the principal axes of a given table projected on the compromise of the first two axes; the distance between arrows and axes shows the deviation between a table and the compromise. (**C**,**E**,**G**) Loadings of variables on Tables of periods D0–D1, D1–D3 and D3–D7.

on body protein level[61]. Results obtained by Cools et al.[62] considering multiparous sows tend to disagree with our finding on primiparous sows. In their population, larger sows had lower D0–D1 piglet weight gain.

Directing protein and energy sources towards lactation is crucial[53,61]. Although mobilised secondarily (especially in young sows[52]), fat is also a favourable source of energy for milk yield and piglet growth[63]. Leaner sows at the end of gestation are expected to have a lower mammary development[64]. But in review on Quesnel et al. 2019[65] pointed out that feeding sows a higher-fat feed increases the protein content of colostrum and milk. Body fat was not strongly correlated to early litter growth in our study of primiparous sows.

However, the period around farrowing is accompanied by a loss of appetite, especially on the day of farrowing, which can continue until the middle of the first week of lactation[62,66]. This happens more markedly in sows fed twice a day rather than ad libitum[67]. These sows suffer from an energy deficit that possibly impacts early litter growth[68]. Dietary protein intake must be sufficient in the 3 days before farrowing (intercept). Otherwise protein restriction can lead to lower milk yield from the start of production[69], resulting in impaired litter growth rate . Late gestation feeding was a contributor to early litter growth in our study.

The protein content of feed is rapidly used for milk production[10]. If the diet is low in protein, the sow draw even more proteins from its body reserves to satisfy the needs of the mammary gland, which switches to lactating status. Marti et al.[67] showed that time gap between the last pre-farrowing feeding phase and farrowing may influence early growth.

Sows that assimilate more protein have piglets that gain up to 52 g/d more in body weight as compared to those of other sows[70]. Early litter growth depends on the sow eating and drinking enough in the days after farrowing to support milk production (feeding[45,71]). Feeding levels did not appear significant in our study. It was the speed of resumption of feeding (regression slope) that partly explained early litter growth. Strathe et al.[45] showed that an additional 1 kg of feed ingested per day can increase litter weight gain during lactation by 220 g to 440 g/d.

A drop in water consumption on the day of farrowing is also expected according to Fraser and Phillips[72]. We showed the importance of pre-farrowing watering on the start of milk production. According to our study, primiparous sows that spend more time eating and drinking on the day of farrowing have a greater weight gain of their piglets on the following days. It is important that sows take care of their maintenance on this specific day. Fraser and Phillips[72] describe a progressive resumption of watering correlated to litter weight gain during the first 3 days of lactation. Post-farrowing watering was not a contributor to early litter growth in our study.

The mammary gland develops in the days around parturition[73] and continues to develop throughout lactation[10]. Piglets can be limited in their milk intake and therefore growth if too many teats are non-functional

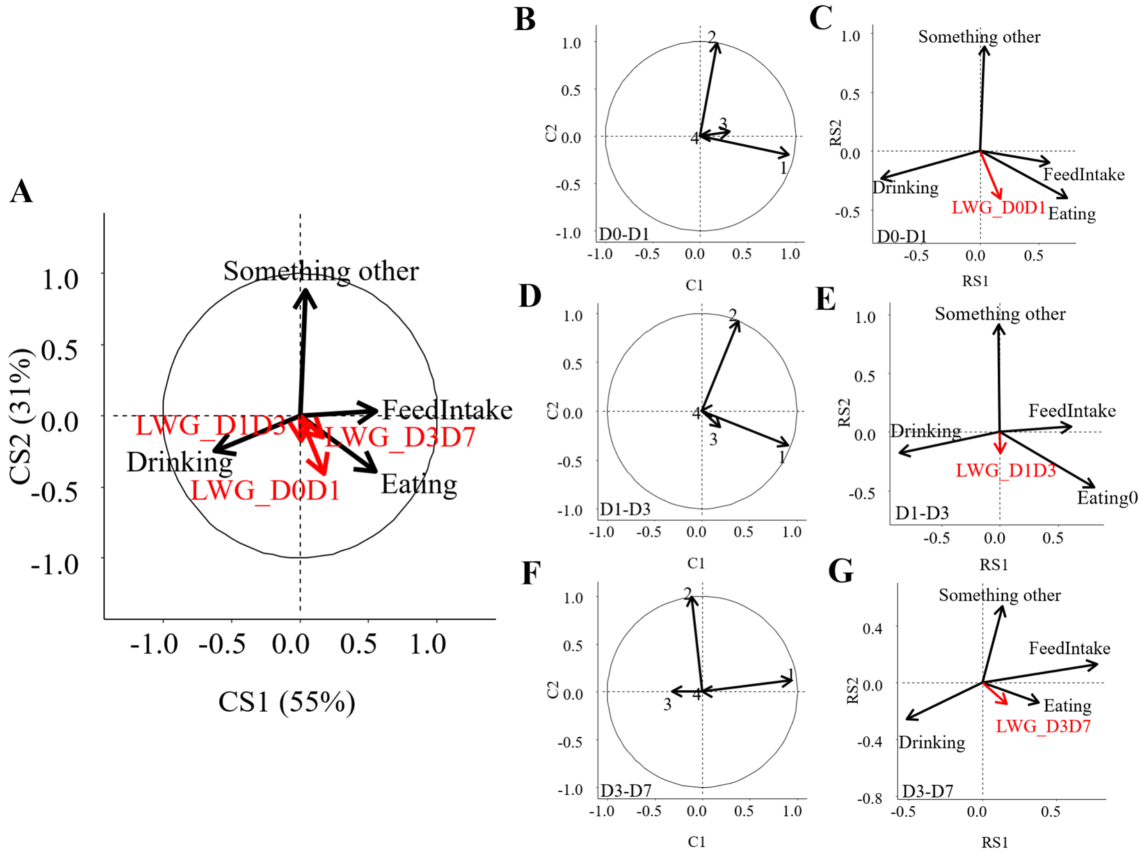

Figure 4. Partial triadic analysis of standing activity and early litter weight gain. (**A**) Variable representation in dimensions 1–2 of the compromise. (**B**,**D**,**F**) Deviations from the compromise: (**B**) on the D0–D1 period; (**D**) on the D1–D3 period; (**F**) on the D3–D7. Arrows 1 to 4 were the principal axes of a given table projected on the compromise of the first two axes; the distance between arrows and axes shows the deviation between a table and the compromise. (**C**,**E**,**G**) Loadings of variables on Tables of periods D0–D1, D1–D3 and D3–D7.

relative to litter size, and if some physical characteristics of the udder impairs suckling[10,74,75]. We were interested in the regularity of teat implantation along the udder, which can contribute to piglet competition at the udder[76] and thus limited access to milk. We confirmed that if teats are implanted too close together on each of the two udder lines, early litter growth[74] is penalised. Moreover, piglets, especially small ones, have difficulty grasping longer, larger-diameter teats[74,75]. In our study, diameter was negatively correlated to early litter growth. Finally here, some sows restricted piglet access to teats from day 1[17] resulting in the drying out of initially functional teats. This dehydration, visible at the end of the first week, was also negatively correlated to early litter growth. Genetic selection has led to effective progress on milk production[77] but less clear progress on teat functionality[55]. Often less studied, udder quality appeared to be a key contributor to early litter growth. It is worth considering it further to improve populations.

Anxiety can affect early litter growth if it has disruptive effects on maternal behaviour and milk production, as shown in rats[78]. In sows, selection for lean growth increased sensitivity to stress by negative associations with cortisol production[79]. The disrupted sequence of activities around farrowing can increase stress[80,81]. A peak of cortisol concentration is observed around farrowing[82]. This stress is involved in regulating the onset of lactation. It inhibits the release of oxytocin, which is essential for farrowing[80] and stimulates colostrum secretion and ejection. Consistently, primiparous sow apprehension at entering the pen, i.e., a novel and individual environment, was negatively correlated to early litter growth. Reactivity at entrance is perhaps related to chronic stress which explains why maternal capacity was reduced in those sows.

Several time budget components emerged from the analyses of the periods before farrowing and on the day of farrowing as important contributors to early litter growth. This result is in line with a previous study in which time budget components (time spent in a posture each day) were linked to early piglet growth[39]. Restlessness before farrowing and at farrowing as perceived by animal caretakers, had a positive influence on litter weight gain in agreement with Illman et al.[38]. In Girardie et al.[39], restlessness after farrowing also had a substantial effect on piglet performance. Activity data was acquired using convolution neural networks. These methods are increasingly used to describe animal activity and posture behaviours (sow nursing behavior[83]; lying pattern[33]). Developments in image analysis will enable progress in defining novel selection criteria to improve piglet production[34,39] since behaviour can be moderately heritable[84]. Devices with CNNs will make it possible to monitor and study sow behaviour continuously and in large populations.

Pre-farrowing postural activity was a more important contributor to early litter growth than postural activity on the day of farrowing. Sows that spent more time lateral lying with udder exposed had lower early litter growth than other sows until the middle of the first week of lactation. In contrast to Yun et al.[85], we found that pre-farrowing exploratory behaviour, which we equate with nest-building activity, had no favourable effect on litter weight gain. Yet sows actively engaged in nest-building before farrowing calm down and remain lying down for farrowing. This facilitates colostrum intake and fewer piglets are starving to death[86].

Building a nest prepartum is significant for performance, as it affects the endocrine regulation of maternal behaviour even after farrowing[18]. It results in improved hormonal balance in the sow and better colostrum quality[87], maternal responsiveness to piglets and nursing behaviour[88,89]. Nest-building activity is even expected to determine sow attitude towards their piglets, e.g., lying with caution or not[85,90].

Pre-farrowing restlessness, a good indicator of nest-building, was correlated to performance in early lactation in our study. The daily intake of straw activates nest-building and gives rise to an increase in metabolic processes and circulating oxytocin concentrations[30]. Therefore it reduces post-farrowing cortisol levels and favours piglet colostrum intake[91]. We recommend investigating further on the use of image analysis for recording nest building as this activity is an iceberg indicator of maternal capacity in early lactation.

We were unable to quantify the frequency and duration of nursing activity, which determines much of the litter growth to weaning[21,92]. Some sows limit piglet access to the udder and milk intake. Litters from sows lying more on the belly had lower weight gain until the middle of the first week. Conversely, the time spent sitting on the day of farrowing had a favourable influence on early litter growth on the same period. The advantages of detecting different sow postures are therefore numerous. With deep-learning, it could be possible to detect the nursing activity of sows kept in individual pens[83] and the suckling activity of piglets[93,94]. Regular teat stimulation by piglets on the first day after farrowing maintains colostrum production, favours the lactation process and increases milk yield[95]. Piglets' access to teats could be monitored and related to the increase in non-functionality teats at the start of lactation. Trials have already been carried out, but AI methods are not trained sufficiently to predict nursing activity with accuracy.

Jensen[96] suggested that rooting might continue in parturient sows that experience stress until sufficient feedback is obtained. Also, such continuation of the activity can reflect the perception of an unsatisfactory nest environment or the will to improve it[97]. On the day of farrowing, a greater number of behaviours related to standing activity were found to be important for early litter growth. This growth is lower in sows whose activity while standing is other than eating and drinking at D0. These sows are motionless observers and explorative, with activities directed towards structures and substrate. The strong relationship highlighted with piglet production is likely explained by delayed nest-building activity[30,98] or nest-arranging. Exploratory behaviour on the day of farrowing was a main contributor to early litter growth. It can even correlate to piglet weight at weaning[21].

At farrowing, sow aggression towards piglets was mainly attributable to Large White sows. Stress, by interrupting hormonal control, may be the causal factor[99]. This aggressive reaction correlates with plasma oxytocin levels[100] and depends on genes involved in anxiety[101]. These aggressive sows are more restless before farrowing than non-savaging sows[102]; often they change of posture more frequently at farrowing[103] and have a longer farrowing process[103]. Aggression towards piglets emerged as a main contributor to early litter growth in our study of primiparous sows. Sows aggressive towards piglets certainly restrict access to the udder. In response, piglets may adopt an avoidance behaviour towards their mother that limits milk intake. Milk production would be affected on the following days[16]. Marchant Forde[104] reported a 59 g/d lower growth in the first week of lactation in piglets born to savaging sows. Nevertheless, savaging sows may subsequently express good maternal behaviour. Although breeders chose animals based on their behaviour and remove savaging sows from the herd, a residual proportion of sows with such inappropriate behaviour is present in maternal lines. Genetic selection can provide solutions[105].

The importance of both sow functional traits and behavioural traits on early litter growth corroborated the expectation of good maternal ability for the success of piglet production. Stratz et al.[21] combined these 2 types of measures to define sows with high potential for nursing. Good sows combine greater teat functionality and udder development, with exposure of the udder in the lying posture during farrowing and nursing piglets to satiety. Our results argue in favour of improving sow nursing capacity through genetic selection. Selection for litter weight gain can be considered[6]. Sow behaviour varies greatly from day to day around farrowing[29,106], justifying a longitudinal approach to behavioural analysis. There are associations between different or the same behaviours performed in separate time windows[39]. With the transition to looser housing systems, it will be beneficial to select for certain facets of sow behaviour to maintain production performance. We addressed the question of the stability of relationships between sow behaviour and litter weight gain over time. Sow frequency of postural changes was more associated with early litter growth on the first day after onset of farrowing. Although the pattern of correlations among behavioural traits remained the same over time, it was less and less correlated to early litter growth with advancing lactation. In particular, sow restlessness had less and less impact on early litter growth. Accordingly, Valros et al.[107] found no association of sow restlessness after D3 with piglet growth in lactation. Sow behaviour has less and less influence on litter growth over the days, as it tends to become more uniform between sows synchronising their activities. The current analysis showed that selection must be made within a well-defined time window. A noticeable result was that prepartum activity can predict primiparous sow behaviour after farrowing and piglet production in early lactation. Therefore, farrowing difficulties could be anticipated by the farmer.

Conclusion

The start of lactation is punctuated by the majority of piglet losses, making this period unstable for the sow and its litter. The current study described the relationship between a wide range of maternal traits and early litter growth. Several components of resource mobilisation and behaviour—reactivity at maternity entrance, activity before farrowing and savaging—influenced subsequent litter growth markedly. Sows that spent less time drinking and eating on the day of farrowing had lower early litter growth. Udder characteristics also influenced litter performance. Sow behaviour can be used to detect litters at risk of lower growth. Functional and behavioural factors have interrelated roles on litter growth in early lactation.

Material and method

Ethical statement

The experimental protocol was designed in compliance with the legislations of the European Union (Directive 86/609/EEC) and France (Decree 2001–464 29/05/01) for the care and use of animals (Agreement For Animal Housing Number C-35-275-32). All experiments were performed in accordance with relevant guidelines and regulations and were approved by the ethical committee of the Midi-Pyrénées Regional Council (authorization MP/01/01/01/11). Reporting in the manuscript follows the ARRIVE guidelines recommendations.

Animals and housing

This study was based on a crossbreeding scheme, set up to quantify direct and maternal effects on piglet development during the suckling phase (the present study) and the intrauterine phase (e.g., study[108] on the same sows in second parity). The experimental design is described in Girardie et al.[39] This design included 21 primiparous LW sows and 22 primiparous MS sows. raised at the Le Magneraud INRAE GenESI experimental farm (doi: https://doi.org/10.15454/1.5572415481185847E12) into 5 farrowing batches from november 2010 to february 2011. Sows were managed in a batch system, with a 3-week interval between successive batches. To optimise the variation in maternal and paternal origins, sows were inseminated with mixed semen from the two breeds. In total, 3 LW boars and 3 MS boars were used. Sows were inseminated with a mix of semen of MS and LW boars, so that each sow produced both purebred and crossbred piglets. As a consequence, four piglet genetic types were produced (dam/sire): LW purebred (LW/LW), LW crossbred (LW/MS), MS purebred (MS/MS) and MS crossbred (MS/LW). Sows were vaccinated for ery-parvo-leptovirus at 180 and 208 days of age. As part of an experimental population, those gilts were chosen according to good health status.

During gestation, sows were kept in groups of females of the same breed. Sows were moved from the gestation pen to the farrowing room approximately one week before farrowing (7.5 ± 1.86 days before farrowing). Then, they were kept in individual farrowing pen (2.86 m × 2.55–7 m^2) with a concrete floor covered with straw and bounded by 1.2 m high cement walls on the four sides. The pen contained protective bars along the walls as well as a creep area with a heat lamp. Restraining bars of the farrowing crate were in open mode and hardly ever used on a very short period for sows that savaged piglet(s). The floor was covered with a thin bed of 2 kg of fresh straw that was changed every morning, the quantity of which was adjusted around the time of farrowing according to its use by the sow. The LW and MS sows were placed alternately in adjacent pens.

Farrowing was not induced. Two sows received an oxytocin injection. To assess the sow ability to raise its biological litter, crossfostering was not allowed. Intervention of caretakers was limited to releasing piglets from foetal membranes at birth and saving piglets trapped under the sow, i.e., piglets partially crushed or blocked against the pen structure. The room was lit both by natural daylight and artificial lighting all around the clock. Farrowing supervision was facilitated by video watching from a room outside the farrowing unit.

Piglet measurements

At birth (D0), piglets were dried with straw and drying paper, weighed, sexed and marked on their back with a number corresponding to their birth order, and blood sampled was taken from the umbilical cord (Canario et al., 2014). Once back in the farrowing pen, piglets were not assisted to find a teat. Each piglet was also weighed again 24 h after birth (D1), and 3 days (D3) and 7 days (D7) after birth. Weighing was carried out in the central corridor of the farrowing unit. They were also tail docked and received iron injection 24 h after birth. The time for weighing the litter at 24 h was determined according to the birth time of the last piglet as starting point. In the case of irregular births at the end of farrowing, the penultimate birth time was used as starting point. The piglet weight gain on D0 to D1, D1 to D3 and D3 to D7 were calculated for each piglet and summed per sow to obtain weight gain of each litter on D0-D1 (LWG_{0-1}), D1-D3 (LWG_{1-3}) and D3-D7 (LWG_{3-7}). Piglet mortality was recorded daily. Each dead piglet was weighed, and its weight gain before death was included in the computation of litter weight gain in the period including its death.

Sow measurements

The behavioural and physiological characteristics of each sow were established on the basis of 100 variables recorded or calculated on each sow.

Farrowing performance and environment

Litter size, the number of piglets born alive, age of the sow at farrowing (in days), the % of MS piglets in the litter (number of MS piglets/litter size * 100) and farrowing duration (in minutes) were recorded for each sow. Piglet genotype was confirmed using a tail sample and molecular analysis with a set of microsatellite markers. Farrowing duration was defined as the interval between birth of the first piglet and the last piglet in the litter (minimum = 30 min and maximum = 390 min). Each farrowing room included 8 pens. The pen identity was set as an environmental variable with four categorical values (A, B, C and D)[39] according to position in the farrowing room. Pen A was designated as the pen that was the nearest to the weighing area in the central corridor and D as the pen that was the furthest from the weighing area. The farrowing unit included large windows located on front wall of the farrowing room to allow natural light and air to enter with manual adjustment. The farrowing room had dynamic ventilation with air extraction via two chimneys located 2 m above the floor. The chimneys opened and closed automatically (Fancom control box) and there was no cooling (see Additional File 3).

Body reserves at entrance in the farrowing unit
Before leaving the gestation unit, sows were weighed (weight in kg) and backfat was measured by ultrasound at 6 locations, on each side of the spine, 4 cm from the middorsal line at the shoulder, the last rib, and the hip joint, respectively, using a real-time ultrasound device with probe HLV-375M at 7.5 MHz frequency. Skin thickness was not considered in the measurement. The backfat depth was calculated as the average of the six measurements. Sow content in lipids, proteins and energy was calculated using the equation developed by Dourmad et al.[109]:

$$Lipid\ content\left(kg\right) = -26.4 + 0.221 body\ weight + 1.331 backfat$$

$$Protein\ content\left(kg\right) = 2.28 + 0.178 body\ weight - 0.333 backfat$$

$$Energy\ content(MJ) = -1.074 + 13.65 body\ weight + 45.94 backfat$$

Lipid content and protein content represent the availability of lipids and proteins for functions such as growth and milk production. Energy content provides approximate information on the ability to mobilize energy created by the sow itself to fulfill maintenance requirements, growth and milk production.

Feed intake
Sows were fed a lactation feed diet from entrance in the farrowing unit twice daily at 8:00 am and 4.30 pm. They had fresh access to water in a low-pressure nipple-drinker. See Additional File 2 for the composition of feed. Sows were fed twice daily, at 8 a.m. and 4 p.m. with a feed of 0.7 kg/L density. Feed allowance was progressively increased by 1 kg each day until an ad libitum level around D5 of lactation. The volume (V) of feed intake was measured by subtracting the volume of refusal from the given amount. The volume of feed intake was recorded twice a day and summed daily. In this study, the volume was transformed in kg. The daily feed intake in kg was calculated as V*0.7. Feed quantity was adjusted according to feed intake. If sows ate all the feed volume a given day, they received 0.5 L more feed the next day. If sows did not finish their meal, they received 0.5L less feed the day after. A random regression was applied to these longitudinal data in each of the period of several days (before D0, after D0), with smoothing using the Nadaraya-Watson estimator in order to summarise the dynamic of the feed intake for each individual into two variables per period, the intercept and the slope.

Udder quality
Udder quality was determined by assessment at the middle of the udder, with measurements while sow in standing posture. Teat qualification was assessed by sight according to average teat length. It was noted as little, medium, large or heterogenous, this is a visual observation and represent a qualification for the udder. The number of teats and their functionality were recorded at 24 h and 7 days after farrowing. In early lactation, a proportion of the teats that are functional are not used, and they progressively turn nonfunctional[74]. Functional teats were defined as teats that produced milk (milk ejected at hand milking). A teat was categorized nonfunctional when dry, false, invaginated, or with an abscess or injury. The average interval between adjacent teats on the same row was measured with a tape measure (cm). According to this distance established by sampling along the udder, information on the regularity of inter-teat interval was noted (regular, irregular). Teat diameter was measured at tip of several teats with a tape measure and a qualification of average teat diameter was recorded (0.5 to 1 cm, 1 to 1.5 cm or 1.5 to 2 cm).

Behaviour obtained from video image analysis
A 2D camera was fixed above each pen to film the sow 24 h a day. The video recording started 3 days before farrowing (D-3) and stopped 7 days after farrowing (D7 of lactation) for all sows. Sow behaviour was extracted from the video recording using convolution neural networks[39]. A Yolo-v2 object detection CNN was used to detect the sow on the image and predict its posture. Yolo was combined with resNet50 for feature extraction. The automatically registered behaviours were (1) postures: standing (ST), sitting (SI), sternal lying (SL), lateral lying (LL) and lateral lying with udder exposed (LLU); (2) standing activity: eating, drinking and doing something else (exploring or rooting). Other variables describing sow behaviour were obtained from notations on farm. This approach made it possible to quantify postural activity during the time spent daily in different postures, postural changes, and, specifically, standing activity that included being in motion or not, and exploring or not the environment in addition to maintenance activities.

Reactivity at entrance
The difficulty to get out of the trailer indicated ease at handling and was noted on a scale from − 1 to + 1 (− 1 = difficulty to get out, 0 = easy, and + 1 = very easy to get out). The adaption to the farrowing pen was noted by observing the ease to enter the farrowing pen on a scale from − 1 to + 1 (1: enter rapidly; 0: observe before entering and enter alone and − 1: forced to enter), and sow vocalisations (0 = no vocalisation and 1 = ≥ 1 vocalisation(s)) and sow posture (lying, sitting or standing) 30 min and 1 h after entrance in the farrowing unit. Habituation to human was also observed with a test inspired by Grandinson et al.[110] This test consists of observing the reaction of the sow when a human is at a distance outside the pen and next, inside the pen, in hand contact. Information recorded related to sow behaviour (positive: observe, approach or attentive to human, negative: elusive, worried

or motionless, or in continuity with behaviour before the test starts), vocalisation (0 = no vocalisation; 1 = ≥ 1 vocalisation), initial posture when the test starts (lateral lying, sternal lying, sitting and standing), and the index of postural change described in Grandinson et al.[110].

Reactivity at farrowing
During the farrowing process, caretakers recorded sow restlessness (0/1), sow aggression towards piglets (0/1) i.e., sow savaging one or more piglet and sow aggression towards human (0/1), i.e., sow moving briskly towards human.

Postural activity and standing activity
The 43 individuals were chosen on the basis of complete video longitudinal recording among 48 sows. The time spent in each posture and in each activity while standing was calculated for three periods: before farrowing, on the day of farrowing and after farrowing. Postural activity and standing activity were analysed as time budgets. This involves transforming compositional data into Centered Log Ratio (CLR)[111] before analysis. This transformation allows each posture or each activity to be considered in relation to the others, with the sum of all postures and of all standing activities equal to 1. Two specific amounts of postural changes were also calculated from the behaviour prediction database: an average daily number of postural changes per period was calculated as the total number of postural changes divided by the number of days in the period (PCAll). The same computation was applied for the number of postural changes hiding the udder (PCStopNurse)[39].

Statistics

Data exploration
Mean or proportion per breed was calculated for each variable. To evaluate if there was a significant difference between breeds, a Student t test was applied to quantitative variables except aggressive behaviour for which an exact Fisher test was applied). A generalized linear model was performed for binomial variables and a cumulative link model for multimodal qualitative variables. In order to describe the overall structure of the data, a Factorial Analysis of Mixed Data (FAMD) was used. FAMD is a factorial analysis that can handle a mix of continuous and categorical variables[112]. Categorical variables are transformed into 0/1 variables. Note that FAMD is similar to PCA when there are only continuous variables and to MCA when there are only categorical variables. For more detail, see Husson et al.[113].

All the variables were corrected for the breed effect and litter size at D0 with a linear model. They were column centered and scaled to unit variance The residuals of this model were used in the following two analyses.

Multiblock analysis
The multiblock Partial Least Squares (mbPLS)[114] analysis was used to explore the potential drivers that could influence/explain early litter growth. It is an extension of the PLS method to the multiblock case, i.e., where a dataset **Y** is to be explained or predicted by a dataset **X** that is organised into K blocks: X = (X1,…,Xk). In this study, we studied the link between LWG at three periods after farrowing (**Y**, matrix *N*x3, where *N* is the number of sows) and 100 maternal traits. The latter were grouped into 11 blocks that included farrowing performance and environment ($\mathbf{X_1}$, seven variables), body reserves at entrance into the farrowing unit ($\mathbf{X_2}$, five variables), udder quality ($\mathbf{X_3}$, 15 variables), reactivity at entrance ($\mathbf{X_4}$, 36 variables), reactivity at farrowing ($\mathbf{X_5}$, three variables), postural activity before D0 ($\mathbf{X_6}$, six variables), postural activity at D0 ($\mathbf{X_7}$, six variables), postural activity after D0 ($\mathbf{X_8}$, six variables), standing activity before D0 ($\mathbf{X_9}$, four variables), standing activity at D0 ($\mathbf{X_{10}}$, four variables) and standing activity after D0 ($\mathbf{X_{11}}$, four variables). The variables included in each block were those presented in the Sow Measurements section.

The multiblock analysis is a latent variable procedure detailed in Bougeard et al.[114]. Briefly, it consists of three steps (Fig. 5).

First, each of the (K + 1) datasets, i.e., Y and (X_1,…X_k), are summarised by the latent variables u and (t_1,…t_k), respectively. Second, a global latent variable t is derived as a weighted sum of the t_k, so that the squared covariance of t and u is maximised.

$$t = \sum_k a_k t_k, \text{ with } \sum_k a_k^2 = 1$$

Third, the method provides interpretation tools such as the Block Importance that is equal to a_k^2, and the Variable Importance, equal to the product of the Block Importance and the weight of the variable in the latent variable. Since both Block Importance and Variable Importance sum to 1, these values can be interpreted as percentage. The significance of Block Importance and Variable Importance can be appreciated via a bootstrap procedure (999 samples). An explicative block was significantly important for LWG if its 95% confidence interval did not include the threshold value 1/11 (= 0.091). In addition, an explicative variable was significantly important for LWG if its 95% confidence interval did not include the threshold value 1/100 (= 0.01).

Partial triadic analysis
To better comprehend the evolution of the relationships between variables over time, we carried out a Partial Triadic Analysis (PTA)[116,117]. PTA is the analysis of a three-dimensional matrix (sows × variables × periods, Fig. 6). In this study, three periods of time (= three tables) were considered on the same animals and variables.

PTA consists of three computations[116,117]:

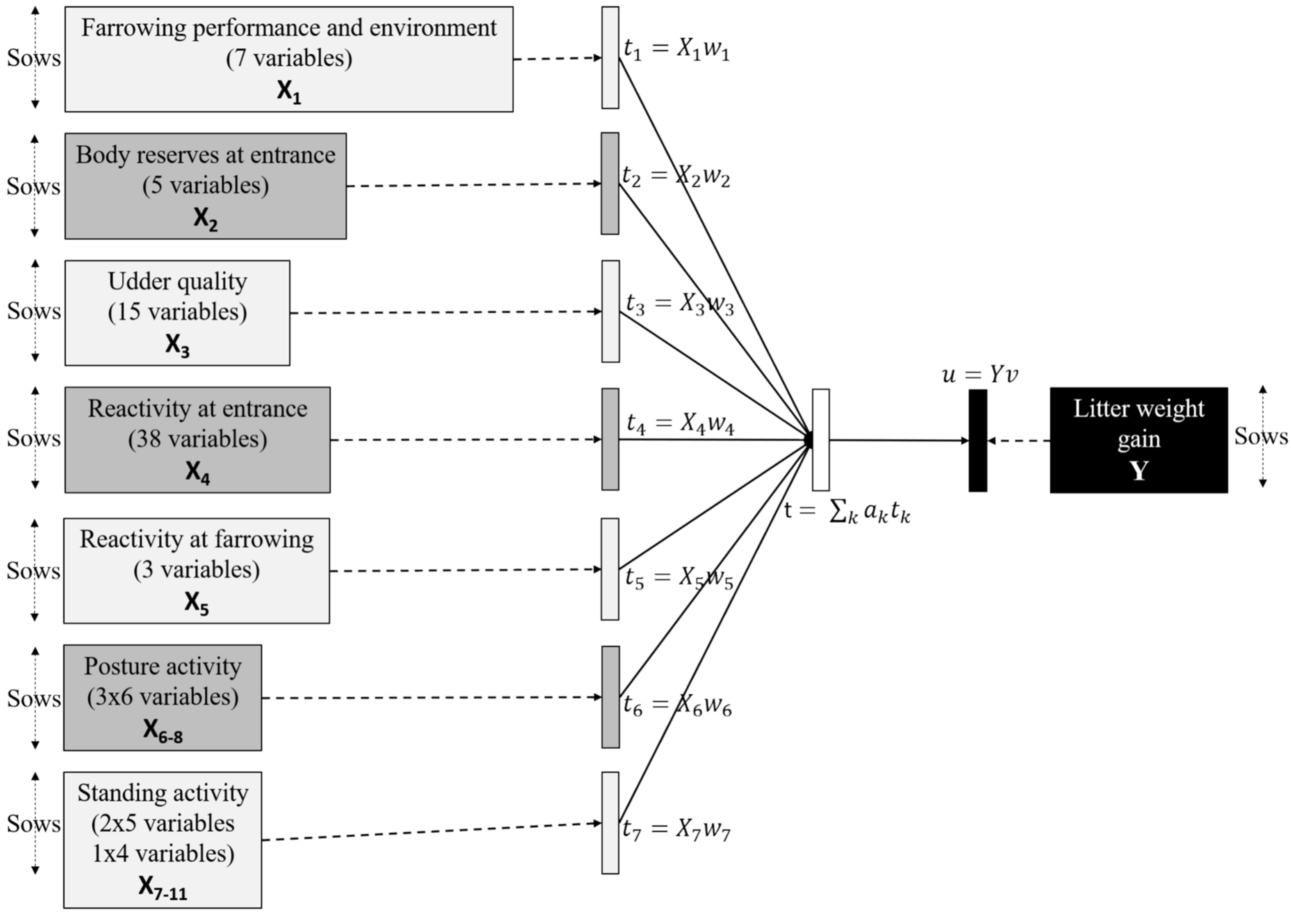

Figure 5. Illustration of the multiblock Partial Least Square regression inspired by Bougeard et al.[115]. The graph illustrates the relationship between the response block (Y) and the explanatory blocks (X_1, …, X_{11}) with their latent variables. t_K represents the latent variables for the explanatory blocks and u represents the latent variable for the response block. t_K is a weighted sum of the variables included in the block ($X_k w_k$) and the same for u (Yv). t is a global variable that summarised the information of each block as $t_i = \sum_{k=1}^{11} a_k t_{ki}$ for sow i. The weighting a_k is proportional to the contribution of block k to the variability of the **Y** block includingLWG_{0-1}, LWG_{1-3} and LWG_{3-7} and considering that $\sum_k a_k^2 = 1$.

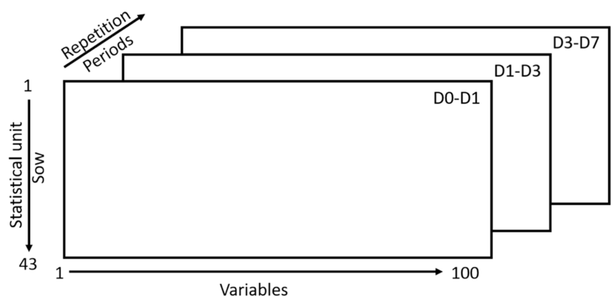

Figure 6. Matrices used in the Partial Triadic Analysis inspired by Thioulouse[117]. The D0–D1 table includes data collected in the period between day 0 and day 1 after farrowing. The D1–D3 table includes data collected in the period between day 1 and day 3 after farrowing. The D3–D7 table includes data collected in the period between day 3 and day 7 after farrowing.

- the interstructure with the so-called RV coefficient, which measures the similarity among tables. The RV coefficient, ranging between − 1 and 1, has the same interpretation as a correlation coefficient.
- The compromise, or consensus table, that is a weighted average of the 3 tables to observe the average relationships between variables.
- The intrastructure, which allow analysing the specificity of each table compared to the compromise table. It is obtained by the projection of each of the 3 tables (rows and columns) onto the compromise table.

A PTA was run separately for standing activity and for postural activity between D0 and D7. For each PTA, LWG_{0-1}, LWG_{1-3} and LWG_{3-7} were added as supplementary variables to evaluate the link between standing activity and postural activity and litter average daily gain.

Multivariate and statistical analyses were performed using the ade4 package[118] from R[119].

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request. The system used during the current study are available from the corresponding author upon reasonable request.

Code availability

The custom code and mathematical algorithm used in this study can be obtained at[120].

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Author contributions

L.C. conceived the project. L.C., Y.B., and J.B. carried out the experiment. M.B. supervised the automated video analysis of sow behavior. O.G., L.C., I.D., and D.L. participated in the data analysis. O.G., L.C., I.D, DL contributed to writing the manuscript. All authors contributed to the article and approved the submitted version.

Competing interests

The authors declare no competing interests.

Additional information

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Correspondence and requests for materials should be addressed to O.G.

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