AUTHORS

by Charlotte Gaillard & Jean-Yves Dourmad

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GESTATION

APPLICATION OF A PRECISION FEEDING STRATEGY FOR GESTATING SOWS

HIGHLIGHTS

- Precision feeding aims at adjusting feed supply to individual nutrient requirements.
- Precision feeding reduced reducing protein intake and feeding costs.
- Environmental load decreased with precision feeding.
- Reproductive performance was not affected by precision feeding.
- Feeding behaviors were barely affected by precision feeding.

KEY TAKEAWAYS

1. Precision feeding in gestation can be used to reduce lysine intake without sacrificing corresponding reproductive throughput.

2. Precision feeding can be used as a tool to reduce protein intake and feed costs, without sacrificing overall performance.

3. Precision feeding allows for analyzing feeding behaviours, which can serve as a management indicator for animal husbandry measures.

4. Compared to traditionally fed sows, precision fed sows showed a reduction of lysine intake, nitrogen excretion, phosphorus excretion, and feed costs per gestation. All of this, without sacrificing sow condition nor reproductive capabilities.

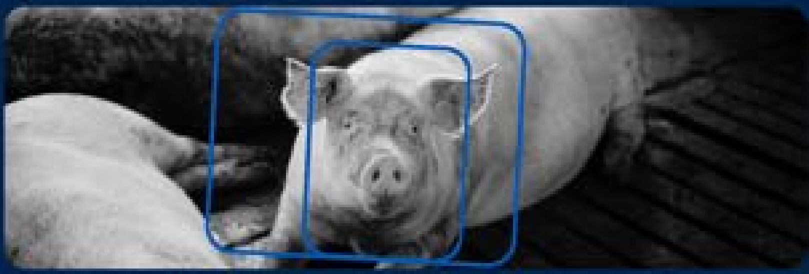
ABSTRACT

Simulations of precision feeding (PF) in which gestating sows were individually fed a daily mixture of two diets with different amino acid contents indicated a reduction in protein intake, feed costs, and environmental losses compared to sows fed a conventional single diet (CF). These results have not been verified on farm. Thus, the objective of the present study was to compare the effect of this PF strategy on productive and reproductive performances of gestating sows compared to the CF strategy. As the effects of such a strategy has not been reported yet on sows' feeding behavior (frequency of isits and time spent in the feeder), it constituted the second objective of this study. The experiment included 131 gestating sows divided into the two feeding strategies regarding their parity and body weight at insemination. Feed supply was similar for the two strategies. The results matched those from simulations as sows fed the PF strategy reduced their lysine ingestion of around 25%, which therefore reduced nitrogen excretion of 18.5%, and feed costs by 3.4 euros per gestation or 8 euros per ton of feed. Phosphorus intake and excretion were also reduced with PF compared to CF (around 8% and 9%, respectively).

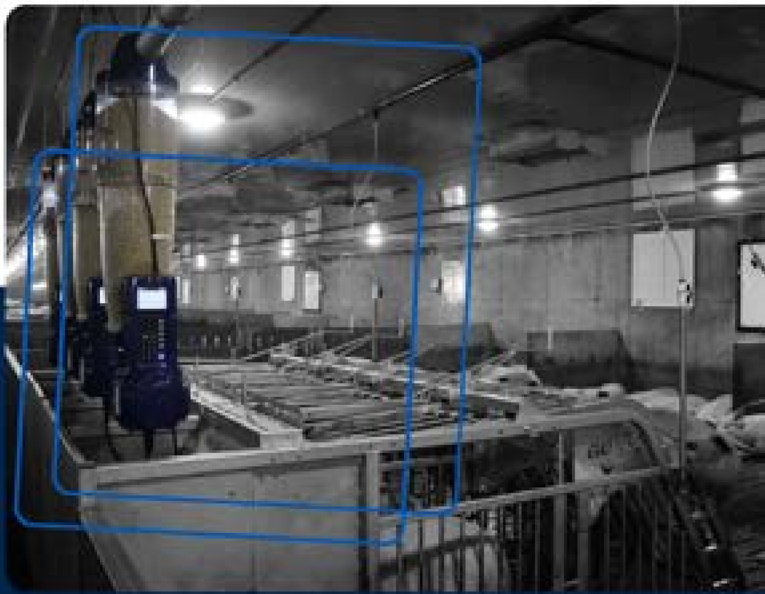
Reproductive performance, defined as the number of piglets per litter and the litter weight, was not affected by the feeding strategy. All sows usually ate their daily ration in one "feeding visit." The PF sows did a constant number of "non-feeding visits" to the feeder during gestation (on average 4.25 visits/d), while the CF sows did more non-feeding visits at the beginning of the gestation (on average 4.42 visits/d) and less at the end of the gestation (on average 3.69 visits/d) than the PF sows ($P < 0.01$). The sows spent 54% of their daily time in the feeder for feeding visits, and 46% for non-feeding visits. The PF sows spent more daily time for non-feeding visits than CF sows (32.4 vs. 29.7 min/d, respectively, $P < 0.01$). Time spent at the feeder for feeding visits or non-feeding visits was constant over the gestation for the CF sows (35.3 and 29.2 min/d, respectively) while for the PF sows it increased over gestation. In conclusion, the PF strategy can be used to reduce lysine intake without influencing reproductive performance while reducing protein intake and feed costs. Feeding behaviors were barely affected by the feeding strategies but may serve as management indicators to detect sick or injured animals.

INTRODUCTION

Gestating sows are often fed with the same standard diet during their gestation even though their nutrient requirements vary during gestation and among sows (McPherson et al., 2004, Dourmad et al., 2008, Gaillard et al., 2020). Only feed allowance is sometimes adjusted regarding the parity, gestation stage, and body condition (Young et al., 2004).In all cases, this group feeding strategy leads to protein and minerals under- or over-feeding situations which may result in a lack of performance and health issues on the one hand, and economic loss and environmental negative effects on the other. To reduce environmental load and feed costs, new feeding strategies have been developed in pig production (Dourmad et al., 2015, Andretta et al., 2016). Combined with improved nutritional models, smart feeders are now able to offer a daily amino acid (AA)-adjusted ration to each animal regarding its nutrient requirements. Using a simulation approach based on farm databases Gaillard et al. (2020) evaluated the potential of such a precision feeding (PF) strategy for gestating sows (individual and daily mixing of two diets with different AA content) compared to a conventional feeding (CF) strategy (a single diet with a fixed AA content). Simulations indicated that PF appeared to be relevant to better meet the AA requirement and that, compared to a CF strategy, it reduced feed costs by 3.6%, lysine intake by 30%, and nitrogen and phosphorus excretion by 17% and 15%, respectively (Gaillard et al., 2020). However, these simulations results have not been verified experimentally. Moreover, they do not allow to evaluate the effects of such a PF strategy on reproductive performance or feeding behaviors. Indeed, animals housed in group with feeding stations are subjected to feed competition. Due to physiological (i.e., hormonal circadian rhythm) or management (i.e., start of a new feeding day) factors, popularity of certain times for feeding can be increased, leading to an increased competition for feed and risks of conflicts between animals. The model of Boumans et al. (2018) showed that the pig and diet characteristics interact with the group size and affect daily feeding patterns (e.g., feed intake and feeding time) as well as the frequency of conflicts around the feeder. Moreover, variations of the time spent waiting in front of the feeder or visiting it will impact the sows' energy requirements, as time standing is considered to require twice more energy than lying (Noblet et al., 1993).



Therefore, the objectives of the present study were to evaluate experimentally the effects of a PF strategy on productive and reproductive performances of gestating sows, and to report any effect of such a strategy on feeding behaviors. We hypothesized that compared to a CF strategy, a PF strategy will reduce feed costs and nutrient excretion without affecting sows' reproductive performance, and might affect sows' feeding behavior as diet characteristics will vary over gestation.



MATERIALS AND METHODS

2.1 EXPERIMENTAL FACILITIES AND ANIMALS

The Ethics Committee in Animal Experimentation in Rennes, France, reviewed and approved the protocol for the experiment (reference APAFiS #20619). The experiment was carried out from June 2019 to June 2020, at the Pig Physiology and Phenotyping Experimental Facility, Saint-Gilles, France (doi: 10.15454/1.5573932732039927E12).

Initially, a total of 170 Landrace × Large White gestating sows were involved in the experiment and moved to gestation rooms 3–4 days after insemination. However, in early gestation, 37 sows were found out not pregnant at confirmation, and 2 sows were sick. Therefore, these 39 sows were taken out of their group pen when detected non-pregnant or sick. The sows were initially equally distributed between the two feeding strategies described below. Thus, finally 131 gestations from 97 multiparous and 34 primiparous were fully followed and their data analyzed. Each of the eight groups of gestating sows was housed in a pen of 7.5 × 8.0 m, with free acces to water (2 drinking troughs), and to 2 automatic feeders (GESTAL, Jyga Technologies, Québec, Canada) allowing the individual mixture of two diets. Every morning fresh straw was delivered in the resting areas of the pen.

2.2 EXPERIMENTAL DESIGN

As lysine is the first limiting AA in plant-based diets for sows, the two feeding strategies were based on the mixture of two diets with different standardized ileal digestible lysine (SID Lys) concentrations: a diet with a high lysine content (H diet, with 8.5 g SID Lys/kg of feed) and a diet with a low lysine content (L diet, with 3.3 g of SID Lys/kg of feed). For the CF strategy, the sows received a fixed mixture of the L and H diets (73% and 27%, respectively) during all the gestation, so a mixture with a fixed lysine content of 4.7 g SID Lys/kg of feed. For the PF strategy, the sows received an individualized mixture of L and H diets, varying over the gestation according to their requirements. Ingredients and composition of L and H diets are presented in Table 1.

Table 1. Ingredients and composition of the two diets used in the experiment as-fed basis, one with a low lysine content (L diet) and one with a higher lysine content (H diet).

Ingredients, g/kg	L Diet	H Diet
Barley	400	256
Wheat	255	257
Maize	100	120
Wheat bran	150	100
Soybean meal (45% CP)	-	180
Rapeseed oil	20,0	20,0
Sugar beet pulp	50,0	-
Molasses	-	30,0
Monocalcium phosphate	2,00	6,50
Calcium carbonate	11,5	15,5
Salt (sodium chloride)	4,50	4,50
Acidifying agent	1,00	1,00
L-Lysine HCl	0,70	2,50
DL-Methionine	-	0,40
L-Threonine	-	1,40
L-Valine	-	0,40
Trace elements and vitamins (1)	5,00	5,00

Analyzed Composition (g/kg)	L Diet	H Diet
Dry matter	904	896
CP (2)	108	182
Crude fat	42,3	39,9
Crude fiber	53,6	39,9
NDF	162	140
ADF	45,8	36,2
ADL	9,20	7,20
Lysine Content	4,74	9,18
Phosphorus content	4,87	6,24
Calculated composition, g/kg	**L Diet**	**H Diet**
Lysine Content	4,34	9,64
SID lysine	3,30	8,50
Total phosphorus	4,43	5,62
STTD-P	2,31	3,27
Total calcium	7,38	9,79
Energy, MJ/kg	**L Diet**	**H Diet**
Gross energy	16,5	16,3
Metabolizable energy	12,7	13,0

(1) Provided the following amounts of vitamins, trace elements and enzymes in units per kg: vitamins: A = 10,000 IU; D3 = 1500 IU; E = 45 IU; biotin = 0.2 mg; Oligo-elements: Cu (E4 sulfate) = 10 mg; Zn (E6 oxide) = 100 mg; Mn (E5 oxide) = 40 mg; Fe (E1 carnonate) = 24 mg; Fe (E1 hepta sulfate) = 28.2 mg; Fe (E1 mono sulfate) = 27.5 mg; I (E2 calcium iodate) = 0.60 mg; Se (E3 sodium selenite) = 0.25 mg; Enyme: phytase (E 1600) = 500 FTU.

(2) Abbreviations: CP, crude protein; NDF, Neutral Detergent Fiber; ADF, Acid Detergent Fiber; ADL, Acid Detergent Lignin; SID Lysine, standardized ileal digestible lysine; STTD-P, standardized total tract digestible phosphorus.

Calculations of individual feed allowance for all sows and diets proportions for the PF sows were done with an improved version of InraPorc model, previously evaluated by running simulations with PF strategy for gestating sows (Gaillard et al., 2020). The model first calculates the requirement estimates in energy, AA, and minerals of each animal and then determines the ration's quantity and composition to be distributed. These calculations take into account individual characteristics like sow's age, maternal (BW) and backfat thickness (BT) at insemination as well as their targets at farrowing. The same 19 mm BT target was used for all sows. Target of maternal BW at farrowing (BWt, in kg) was defined according to sows' age at farrowing (AF, in days) and a growth curve specific from the genotype and adjusted from historical data from the same herd. The detailed approach is described in Gaillard et al. (2019, 2020).

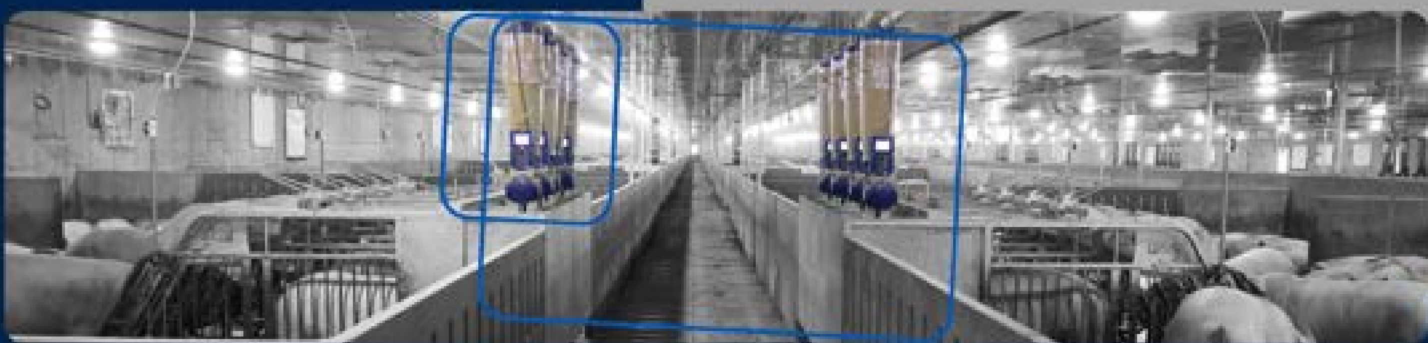
Expected litter size and litter weight at birth are also estimated according to the previous year average performance measured per parity in the same herd.

Furthermore, once the total gestation feed allowance had been calculated for each sow, a bump feeding strategy was applied to obtain a higher allowance of 500 g from 86 days until the end of gestation. The sows of the same group were allocated to one of the two feeding strategies according to parity, BW and BT at insemination.

2.3 RECORDINGS AND CALCULATIONS

The automatic feeders allow the identification of the sow entering the feeder and the recording of the time of each visit to the feeder, as well as the quantity of feed delivered during the visit. From these data, the daily number of visits per sow and the daily time spent at the feeder (in minutes) were calculated. Furthermore, the visits were distinguished between "feeding visits", when the sow received feed, and "non-feeding visits" when the sow did not received feed because she had already eaten her daily ration.

The BW (kg) and BT (mm) of each sow were measured, with a manual weighing scale and an ultrasound portable device respectively, at insemination, at around 63 days of gestation, before farrowing (around 110 days), and after farrowing (up to 48 h after farrowing). During these measurements each sow was removed from the group pen and walked by herself into the scale in which she stayed 2 or 3 min to record her BW and measure her BT. The BT was an average of two measurements taken on the right and left side, 65 mm from the midline, on the back of the animal, by the same person each time.



The reproductive performance (litter size and weight) was recorded for each sow at farrowing, differentiating the total number of piglets and the number of alive piglets. Each piglet was weighted within a few hours after birth and litter weight was calculated.

Lysine and phosphorus retentions and excretions have been calculated using the equations reported in Gaillard et al. (2019), and Bikker and Blok (2017), respectively. Estimated feed costs were based on average prices of feed ingredients observed in France over the first semester 2019 (IFIP, 2019), with the L diet cost being 259.05 €/ton and the H diet 294.25 €/ton.

2.4 LABORATORY ANALYSIS

Diets H and L were sampled every three weeks in the automatic feeders. The samples were stored at 5 °C during the experiment. At the end of the experiment, 230 g of each of the 18 samples were sampled and the 9 samples of each diet mixed before being analyzed. Feed samples were analyzed for dry matter (standard NF V18–109, October 1982), ash (incineration at 550 °C), nitrogen (Dumas method, standard NF EN ISO 16634–1, 2008), Weende crude fiber (AOAC, 1990), gross energy (IKA adiabatic calorimeter, standard ISO 9831:1998) and phosphorus (Standard NF EN 15621, 2017). Cell wall fractions (neutral detergent fiber, acid detergent fiber and acid detergent lignin) were determined according to the method of Van Soest and Wine (1967). Feed samples were also characterized for their fat content (Standard AFNOR NF V18–104; June 1980) using petroleum extraction with prior acid hydrolysis.

2.5 STATISTICAL ANALYSIS

A first linear mixed-effects model was applied to determine the influence of feeding strategy (PF

vs. CF), and parity (primiparous vs. multiparous) on sows' body characteristics (BW and BT), and reproductive parameters (litter size and weight). A second linear mixed-effects model, based on the first model but integrating the day of gestation as fixed effect, was used to evaluate the effects of the feeding strategy, parity, and the day of gestation on the intakes (feed, lysine, and phosphorus) and retentions for the entire gestation, and also on two restricted data set: over the beginning (≤ 85 d, early period), and the end (> 85 d, late period) of gestation as at 86 d all the sows received 500 g extra feed daily. This second model also took into account the correlations over days within each sow with the temporal corAR1 function, representing an autocorrelation structure of order 1 (Pinheiro and Bates, 2000). A third linear mixed-effects model was used to evaluate the effect of the feeding strategy, parity, and period on the feeding behaviors (number of visits to the feeder and daily time spent at the feeder). Finally, a last linear mixed-effects model was used to evaluate the effect of the feeding strategy, parity, and the hour of the day (from 0 to 24) on the hourly feeding behaviors. For all these models, the double interactions between each fixed effect were considered unless for the reproductive parameters for which the model was simplified as the interactions were never significant. These models were applied on R (version 3.4.2) using the LME function from the NLME package (Pinheiro et al., 2018). All these models took into account the random effect of the sow. The sow was the experimental unit. The results are presented below as means and standard errors for fixed effects, including P-values to indicate if the factors, and eventual interactions, were significant ($P < 0.05$) or tended to be ($0.05 \leq P < 0.10$).

To compare the measured values to the target values of sows' BW at farrowing, BT at farrowing, and reproductive performance, a Student test or a Welch test were used depending if the variances were equal or not, respectively.

RESULTS

3.1 INGESTIONS, COSTS AND EXCRETIONS

Table 2. Daily feed intake, proportion of low lysine content diet (L diet) in the ration, lysine intake, and gestation feed cost regarding feeding strategy (Str: CF vs. PF), parity (Par: Primiparous vs. Multiparous sows) and days of gestation (Day)

As planned, the daily feed intake was not influenced by the feeding strategy (Table 2). On average, primiparous sows ate 2.64 kg/d while multiparous sows ate 3.02 kg/d.

Table 2

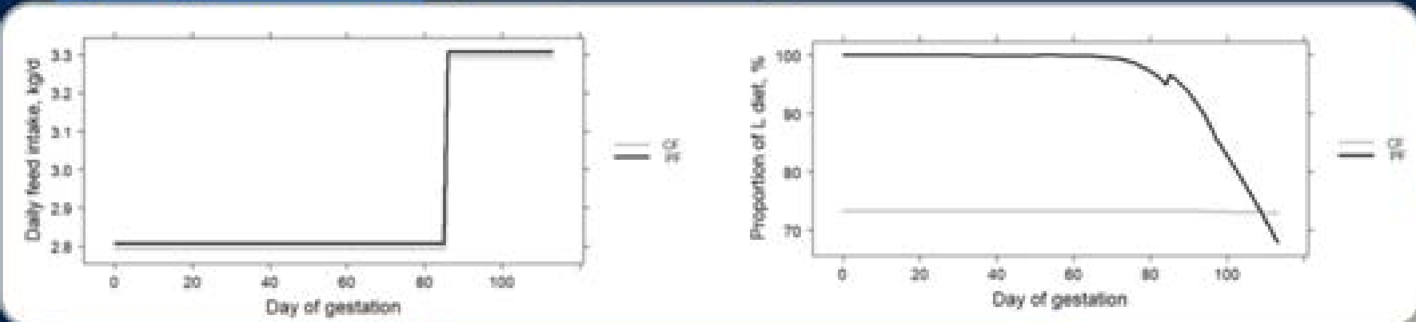
Daily feed intake, proportion of low lysine content diet (L diet) in the ration, lysine intake, and gestation feed cost regarding feeding strategy (Str: CF vs. PF), parity (Par: Primiparous vs. Multiparous sows) and days of gestation (Day).

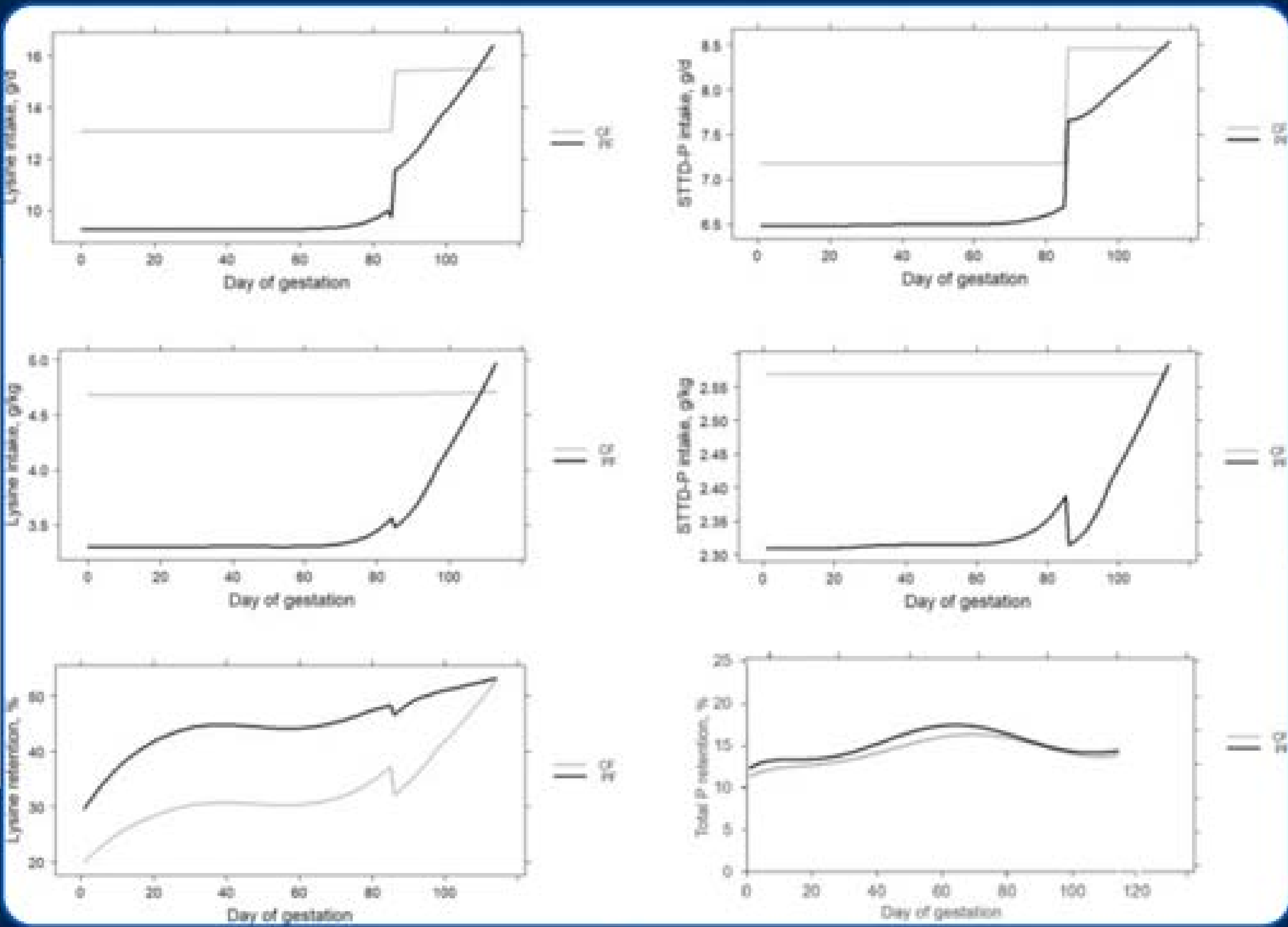
	All sows		Primi		Multi		SE	P-value					
Means	CF[1]	PF	CF	PF	CF	PF		Str	Par	Day	Str × Par	Str × Day	Par × Day
Number of sows	66	65	17	17	49	48							
Daily feed intake, kg/d													
Total over gestation	2.92	2.93	2.61	2.66	3.01	3.02	0.043	0.948	< 0.001	< 0.001	0.549	0.157	0.503
< 86 d	2.79	2.81	2.49	2.54	2.89	2.90	0.043	0.860	< 0.001	0.066	0.544	0.209	0.546
≥ 86 d	3.29	3.31	2.99	3.04	3.39	3.40	0.043	0.890	< 0.001	< 0.001	0.544	0.541	0.541
Proportion of L diet, %													
Total over gestation	73.3	95.5	73.0	93.8	73.0	96.1	0.43	< 0.001	0.217	0.034	0.004	< 0.001	< 0.001
< 86 d	73.4	99.5	73.0	99.0	73.0	99.7	0.32	< 0.001	0.068	< 0.001	0.318	< 0.001	< 0.001
≥ 86 d	73.2	83.0	73.0	78.0	73.0	84.8	0.75	< 0.001	0.011	0.291	< 0.001	< 0.001	< 0.001
SID Lysine, g/kg													
Total over gestation	4.69	3.53	4.70	3.62	4.70	3.50	0.02	< 0.001	0.217	0.034	0.004	< 0.001	< 0.001
< 86 d	4.68	3.32	4.70	3.31	4.70	3.35	0.01	< 0.001	0.068	< 0.001	0.318	< 0.001	< 0.001
≥ 86 d	4.69	4.18	4.70	4.45	4.70	4.09	0.04	< 0.001	0.011	0.291	< 0.001	< 0.001	< 0.001
SID Lysine, g/d													
Total over gestation	13.7	10.4	12.3	9.74	14.1	10.7	0.19	< 0.001	< 0.001	< 0.001	0.004	< 0.001	0.209
< 86 d	13.1	9.33	11.7	8.51	13.6	9.61	0.19	< 0.001	< 0.001	< 0.001	0.014	< 0.001	< 0.001
≥ 86 d	15.5	13.8	14.1	13.5	15.9	13.9	0.24	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Lysine retention, %													
Total over gestation	32.8	44.9	38.0	50.0	31.1	43.0	0.88	< 0.001	< 0.001	< 0.001	0.974	< 0.001	< 0.001
< 86 d	29.7	42.9	35.6	49.2	27.7	40.7	0.72	< 0.001	< 0.001	< 0.001	0.760	< 0.001	< 0.001
≥ 86 d	41.9	50.7	45.1	52.2	40.9	50.1	0.34	< 0.001	< 0.001	< 0.001	0.035	< 0.001	< 0.001
N excretion, kg/gestation	5.70	4.65	4.78	4.14	6.03	4.83	0.20	< 0.001	< 0.001	–	0.074	–	–
Feed cost													
€/gestation	91.9	88.5	80.0	79.3	96.1	91.7	3.63	0.150	< 0.001	–	0.528	–	–
€/ton	268	260	269	261	268	260	0.17	< 0.001	0.482	–	0.015	–	–

1 Abbreviations: CF, conventional feeding strategy; PF, precision feeding strategy; Primi, primiparous sows; Multi, multiparous sows; SID Lysine, standardized ileal digestible lysine; N, nitrogen; SE, standard error.

As planned, the daily feed intake was not influenced by the feeding strategy (Table 2). On average, primiparous sows ate 2.64 kg/d while multiparous sows ate 3.02 kg/d.

Fig. 1. Daily feed intake (kg/d), proportion (%) of the diet with a low lysine content (L diet) in the ration, lysine intake (g/kg and g/d), STTD-P intake (g/kg and g/d), lysine and phosphorus retentions over the gestation weeks for each feeding strategy (conventional feeding, CF vs. precision feeding, PF).





Over a 114 days gestation, there was a reduction of 398 g of SID lysine ingested by the PF sows, compared to the CF sows (P<0.001), corresponding to around 25% reduction. Therefore, feed costs were reduced for the PF sows compared to the CF sows (by 3.4 € per gestation or 8 € per ton of feed). Nitrogen excretion was reduced of 18.5% with the PF sows compared to the CF sows (Table 2; P<0.001). Phosphorus intake and excretion were also reduced with PF compared to CF of around 8% and 9%; respectively (Table 3; P<0.001).

Table 3. Calculated digestible and total phosphorus (P) intakes and excretions regarding feeding strategy (Str: CF vs. PF), parity (Par: Primiparous vs. Multiparous sows) and days of gestation (Day).

	All sows		Primi		Multi		SE	P-value					
Means	CF[1]	PF	CF	PF	CF	PF		Str	Par	Day	Str × Par	Str × Day	Par × Day
Number of sows	66	65	17	17	49	48							
STTD-P[1] *intake, g/d*													
Total over gestation	7.50	6.90	6.72	6.31	7.77	7.12	0.06	< 0.001	< 0.001	< 0.001	0.164	< 0.001	0.635
< 86 d	7.12	6.51	6.39	5.92	7.44	6.72	0.06	< 0.001	< 0.001	< 0.001	0.160	< 0.001	< 0.001
≥ 86 d	8.46	8.04	7.68	7.46	8.73	8.25	0.06	< 0.001	< 0.001	< 0.001	0.179	< 0.001	< 0.001
STTD-P intake, g/kg													
Total over gestation	2.57	2.35	2.57	2.36	2.57	2.34	0.01	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
< 86 d	2.57	2.32	2.57	2.33	2.57	2.31	0.01	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
≥ 86 d	2.57	2.43	2.57	2.45	2.57	2.43	0.01	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Total P intake, g/d													
Total over gestation	13.9	13.1	12.4	12.0	14.4	13.6	0.12	< 0.001	< 0.001	< 0.001	0.254	< 0.001	0.904
< 86 d	13.3	12.4	11.8	11.3	13.8	12.9	0.12	< 0.001	< 0.001	< 0.001	0.250	< 0.001	< 0.001
≥ 86 d	15.6	15.1	14.2	14.0	16.1	15.6	0.12	< 0.001	< 0.001	< 0.001	0.269	< 0.001	< 0.001
Total P intake, g/kg													
Total over gestation	4.75	4.48	4.75	4.50	4.75	4.47	0.01	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
< 86 d	4.75	4.44	4.75	4.46	4.75	4.44	0.01	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
≥ 86 d	4.75	4.58	4.75	4.61	4.75	4.57	0.01	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Total P retention, %													
Total over gestation	14.3	15.1	14.9	15.0	14.1	15.1	0.31	< 0.001	0.017	< 0.001	0.290	0.078	< 0.001
< 86 d	14.4	15.3	14.8	14.8	14.2	15.5	0.37	0.014	0.007	< 0.001	0.270	0.202	< 0.001
≥ 86 d	14.0	14.5	15.3	15.6	13.6	14.1	0.31	0.800	0.360	0.367	0.750	0.940	0.698
P excretion, kg/gestation	1.40	1.27	1.21	1.16	1.47	1.31	0.02	< 0.001	< 0.001	–	0.184	–	–

[1]Abbreviations: CF, conventional feeding strategy; PF, precision feeding strategy; Primi, primiparous sows; Multi, multiparous sows; STTD-P, standardized total tract digestible phosphorus; SE, standard error.

3.2 FEEDING BEHAVIOR

3.2.1. NUMBER OF VISITS TO THE FEEDER

On average, 21% of the sows' visits to the feeder were feeding visits while the 79% left were non-feeding visits (Table 4). There was no significant effect of the feeding strategy or the gestation period on the number of feeding visits. All the sows ate their full daily ration, usually in one visit to the feeder. Concerning the non-feeding visits to the feeder, a significant interaction was found between the feeding strategy and the gestation period (P<0.001). While the number of non-feeding visits for the PF sows stayed constant over the gestation (4.25 non-feeding visits/d on average), the CF sows did more non-feeding visits at the beginning of the gestation than at the end (4.43 vs. 3.70 non-feeding visits/d, respectively).

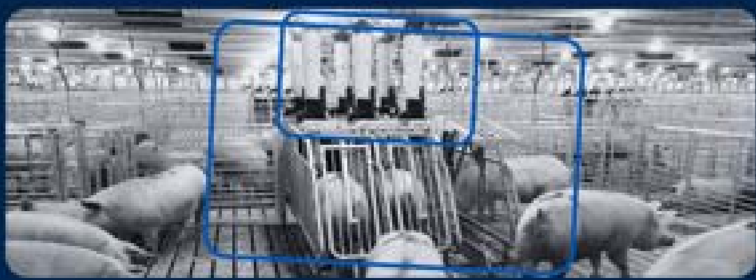


Table 4. Effects of the feeding strategy (Str: CF vs. PF), parity (Par: primiparous vs. Multiparous sows), and gestation period (Period: early vs. late) on feeding behavior (daily number of visits to the feeder, daily time spent at the feeder).

	Early Period				Late Period					P-value					
	CF[1]	PF	Primi	Multi	CF	PF	Primi	Multi	SE	Str	Par	Period[2]	Str × Par	Str × Period	Par × Period
Number of sows	66	65	34	97	66	65	34	97							
Number of daily visits to the feeder															
Total[3]	5.01^{a}	5.00^{a}	4.58	5.16	4.12^{b}	4.66^{a}	3.93	4.54	0.39	0.801	0.270	< 0.001	0.603	< 0.001	0.930
Feed[4]	1.08	1.08	1.01	1.11	1.08	1.08	1.01	1.10	0.02	0.820	0.010	0.691	0.752	0.951	0.863
No-feed[5]	4.42^{a}	4.26^{a}	3.80	4.54	3.69^{b}	4.24^{a}	3.58	4.09	0.37	0.556	0.176	< 0.001	0.470	< 0.001	0.222
Daily time spent in the feeder, min/d															
Total	62.1^{a}	65.8^{a}	51.7	68.2	57.5^{a}	69.2^{b}	58.4	65.0	6.63	0.788	0.141	< 0.001	0.772	< 0.001	< 0.001
Feed	35.2	37.1	32.8	37.3	35.6	38.7	36.0	37.5	2.46	0.712	0.249	0.273	0.772	0.070	< 0.001
No-feed	29.7^{a}	31.4^{a}	20.2	34.3	27.1^{a}	36.8^{b}	27.9	33.3	5.20	0.810	0.155	< 0.001	0.777	< 0.001	< 0.001

Different superscripts are used to compare the 4 means of the double interaction Str × Period when they are significantly different with a P-value < 0.05.
[1]Abbreviations: CF, conventional feeding strategy; PF, precision feeding strategy; Primi, primiparous sows; Multi, multiparous; SE, standard error
[2]Period, early period (≤ 85 d) vs. late period (> 85 d)
[3]Total, Total over the day
[4]Feed, daily feeding visits to the feeder
[5]No-feed, daily non-feeding visits to the feeder.

3.2.2. DAILY TIME SPENT IN THE FEEDER

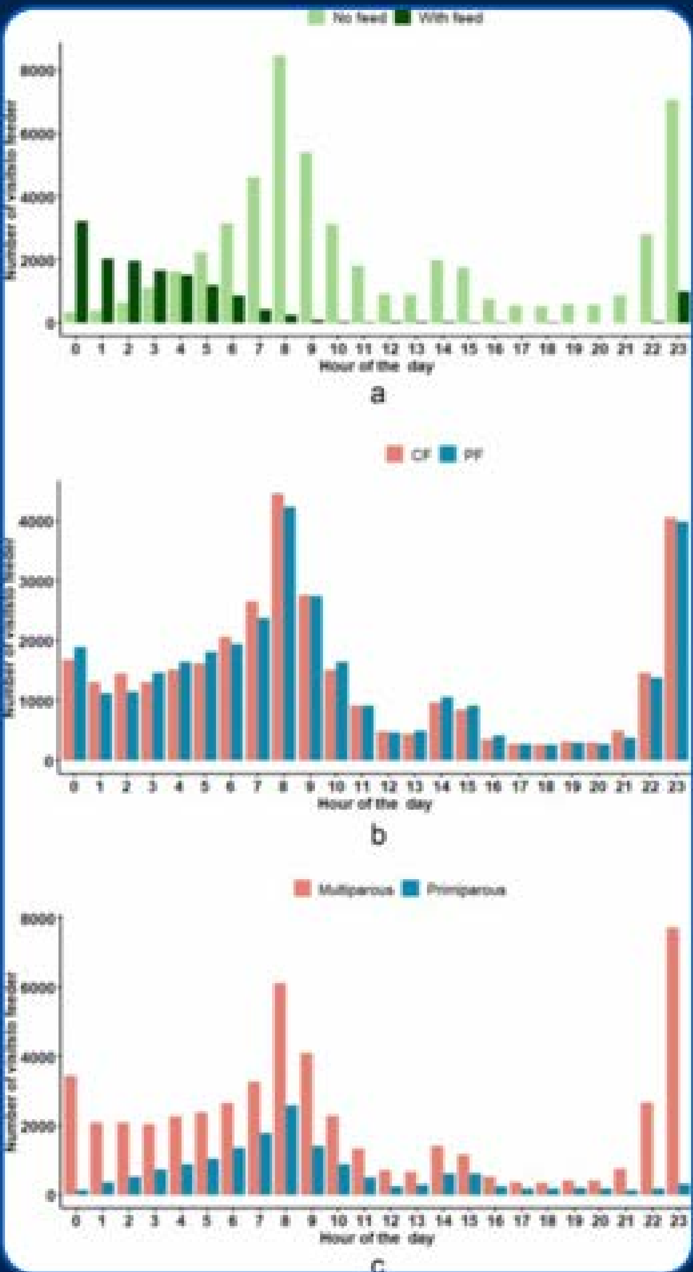
On average the sows spent 54% of their time at the feeder for feeding visits, and 46% for non-feeding visits (Table 4). There was a tendency for the feeding strategy to affect the daily time spent at the feeder for feeding visits regarding the gestation period (P=0.070). Indeed, PF sows slightly increased their time spent for feeding visits during the gestation, while it stayed relatively constant for the CF sows (35.3 min/d on average).

Similarly, the daily time spent for the non-feeding visits stayed stable over the gestation for the CF sows (29.2 min/d), but increased for the PF sows (strategy by period interaction P<0.001). Daily time spent at the feeder was also affected by the parity over gestation (interaction P<0.001): in the beginning of the gestation, the multiparous sows spent 16.5 min more per day in the feeder than the primiparous sows mainly due to non-feeding visits.

3.2.3. DAILY TIMETABLE

The sows did their feeding visits at the beginning of a new day (from 00h to 09h) which corresponds to the availability of their new daily ration as the feeding day started at 00h, while between 05h and 11h they did many non-feeding visits (Fig. 2a).

Fig. 2. Average distribution of a) the type of visits (with or without feed) to the feeder over a day, b) the number of visits regarding the feeding strategy (CF: Conventional Feeding vs. PF: Precision Feeding), and c) regarding parity (primiparous or multiparous).



Some hours of the day the CF sows tended (P=0.061) to visit more the feeder than the PF sows (i.e. from 01h to 03h, and from 06h to 08h), while some hours it was the opposite (i.e. from 10h to 15h, Fig. 2b). However, on average during the first 12h of the new feeding day, the PF sows spent more time in the feeder than the CF sows (P<0.001).

During the first 12h of the new feeding day, the primiparous sows visited less the feeder than the multiparous sows (P< 0.001). Moreover, the primiparous sows spent less time in the feeder from 19h to 00h, and more time from 11h and 14h, than the multiparous sows (P<0.001, Fig. 2c).

3.3 BODY WEIGHT AND BACKFAT THICKNESS

As reported in Table 5, there was no significant effect of the feeding strategy on the BW and BT at insemination, before and after farrowing. The primiparous sows had a lower BW than the multiparous sows (P<0.001) during all the gestation, and a higher BT but only at insemination (P=0.038).

The BW increased during gestation and the average BW before farrowing did not differ from the target BW at this stage. The BW after farrowing was heavier than the target used for the determination of feed requirements (260 vs. 250kg respectively; Welch t-test P=0.010).

The BT increased over gestation and reached on average 20.1mm at farrowing, which is higher than the objective of 19 mm used for the determination of feed requirements (Welch t-test P<0.001).

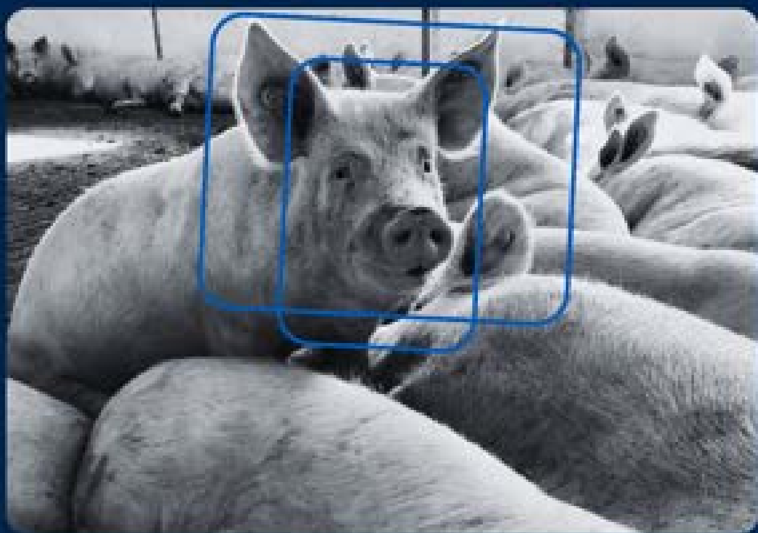


Table 5
Sows' body weight (BW) and backfat thickness (BT) over gestation regarding their parity (Par: Primiparous vs. Multiparous sows) and feeding strategy (Str: CF vs. PF).

	All sows		Primi		Multi			P-value		
Feeding strategy	CF[1]	PF	CF	PF	CF	PF	SE	Str	Par	Str × Par
Number of sows	66	65	17	17	49	48				
Body Weight (BW), kg										
At insemination	208	204	164	167	223	218	4.05	0.365	< 0.001	0.473
Mid-gestation (63 d)	252	247	208	208	267	261	4.13	0.223	< 0.001	0.550
Before farrowing (110 d)	283	277	239	236	298	291	3.62	0.121	< 0.001	0.671
After farrowing (118 d)	262	257	219	215	277	271	3.85	0.215	< 0.001	0.821
BW gain over gestation[2]	75.1	72.5	75.0	68.9	75.2	73.8	2.18	0.585	0.959	0.361
Net gestation BW gain[3]	54.3	52.3	55.3	48.7	54.0	53.6	2.04	0.876	0.695	0.191
BW loss from 110 to 118 d	-20.8	-20.2	-19.7	-20.2	-21.2	-20.2	1.20	0.550	0.533	0.645
Backfat Thickness (BT), mm										
At insemination	14.9	15.0	16.1	15.3	14.5	14.9	0.46	0.475	0.038	0.255
Mid-gestation (63 d)	18.3	18.6	18.9	19.2	18.1	18.4	0.48	0.558	0.299	0.987
Before farrowing (110 d)	20.2	20.9	20.8	21.3	20.1	20.8	0.49	0.284	0.469	0.884
After farrowing (118 d)	19.9	20.3	20.5	20.4	19.7	20.3	0.60	0.386	0.420	0.628
BT gain over gestation[2]	5.27	5.84	4.47	5.71	5.51	5.87	0.50	0.502	0.187	0.436
Net gestation BT gain[3]	4.89	5.27	4.13	5.00	5.12	5.35	0.49	0.669	0.211	0.569
BT loss from 110 to 118 d	-0.36	-0.55	-0.29	-0.62	-0.39	-0.52	0.12	0.348	0.633	0.482

[1]Abbreviations: CF, Conventional Feeding; PF, Precision Feeding; Primi, primiparous sows; Multi, multiparous sows; SE, standard error
[2] From insemination to 110 days of gestation
[3]From insemination to after farrowing (118 days of gestation).

On average, the sows gained 73.8±3.63kg over the gestation (from insemination to before farrowing), with an average BT gain of 5.55±0.55mm independently of the parity or feeding strategy. The net gestation maternal BW gain and the net maternal BT gain, from insemination to after farrowing, were also not affected by the feeding strategy or parity (Table 4).

3.3 REPRODUCTIVE PERFORMANCE

On average at birth a litter weighted 23.1±0.84 kg and was composed of 16.3±0.52 piglets including alive and dead (Table 6).

Litter weight at birth and total number of piglets were not affected by the feeding strategy. The multiparous sows had heavier litters at birth (23.7 vs. 21.0kg, P=0.028) and more piglets (16.7 vs. 14.9 piglets per litter, P=0.025) than the primiparous sows. On average, the number of piglets born alive was 15.1±0.66 and the number of stillborn 1.19±0.27 per litter, without any effect of feeding strategy. The multiparous sows gave birth to more alive piglets than the primiparous sows (15.5 vs. 13.8, P=0.030). The average number of weaned piglets was 11.1±0.48, without any significant effect of the parity or feeding strategy. On average, from birth to weaning, litter gained 71.8±2.79kg, without significant effect of the feeding strategy. Litter weight gain was lower for the primiparous sows than the multiparous sows (64.7 vs. 74.3kg, P=0.015).

Table 6
Reproductive results of the 131 gestating sows, regarding their parity (Par: Primiparous vs. Multiparous sows) and feeding strategy (Str: CF vs. PF).

	All sows		Primi		Multi			P-value		
Feeding strategy	CF[1]	PF	CF	PF	CF	PF	SE	Str	Par	Str × Par
Number of litters	66	65	17	17	49	48				
At birth										
Litter weight, kg	23.5	22.6	21.3	20.6	24.3	23.4	0.67	0.280	0.028	0.833
Total number of piglets	16.4	16.2	15.4	14.4	16.7	16.8	0.70	0.916	0.025	0.508
Number of alive piglets	15.1	15.1	14.4	13.3	15.3	15.7	0.65	0.672	0.030	0.342
Number of dead piglets	1.27	1.12	1.00	1.12	1.37	1.12	0.28	0.465	0.432	0.583
At weaning										
Litter weight, kg	94.8	95.0	84.2	87.2	98.4	97.7	2.91	0.832	0.003	0.580
Number of piglets	11.3	10.9	11.5	11.0	11.2	10.8	0.47	0.489	0.733	0.940
Litter weight gain from birth to weaning, kg	71.3	72.4	62.9	66.6	74.1	74.5	3.21	0.922	0.015	0.603

[1]Abbreviations: CF, Conventional Feeding; PF, Precision Feeding; Primi, primiparous sows; Multi, multiparous sows; SE, standard error

There was no significant difference between the litter weight at birth estimated for the calculation of the nutrient requirements and the measured weight (22.8 vs. 23.1kg), neither between the estimated and the measured number of alive piglets (15.0 vs. 15.1 alive piglets per litter).

DISCUSSIONS

4.1 PRECISION FEEDING, EFFECT ON PERFORMANCE

The increase of intake after 86 d compared to the previous period of gestation was due to the 500g added to the ration for all the sows. Performances (BW, BT, litter size, and weight) were not affected by the feeding strategies. This is in accordance with the results of Cloutier et al. (2019) who ran a similar experiment but with a higher number of sows (523 gestations followed) and reported no effect of the PF strategy on BW and BT. However, they found that, for the primiparous sows, the gestational muscle gain was higher for the PF sows compared to the CF sows (+2.03 vs. −0.51mm respectively), and that there was a tendency for the piglet survival rate to be higher for PF than CF. These results for the primiparous sows could be explained because the PF strategy covers better the requirements of the primiparous sows at the end of the gestation according to the simulations of Gaillard et al. (2020). Our results are in accordance with those of Buis (2016) who used the NRC model (2012) to evaluate the effects of PF on primiparous BW and BT changes during gestation and found no effect of the feeding strategy on these two variables. However, in his study the sows fed with PF tended to gain less BW during early gestation (from 4 to 33 gestation days) than the sows fed with CF (10.0 vs. 12.4kg) but gained more BW during late gestation (from 68 to 102 days; 29.2 vs. 23.9kg). Moreover, patterns of BW gain for the PF sows reflected more closely the gain of fetuses and reproductive tissues which could affect long term performance.

Finally, in the study of Hansen (2011), the litters produced by the sows fed with PF had a higher growth performance in the final nursery stage than those produced by sows fed with CF. These results indicate that PF might not have a direct effect on sows' BW and BT but also a potential long-term positive effect on piglets' performance. In the study of Stewart (2020) reporting the effect of PF on 105 gestating sows followed over 3 consecutive cycles, sow's longevity was not impacted by the feeding strategy.

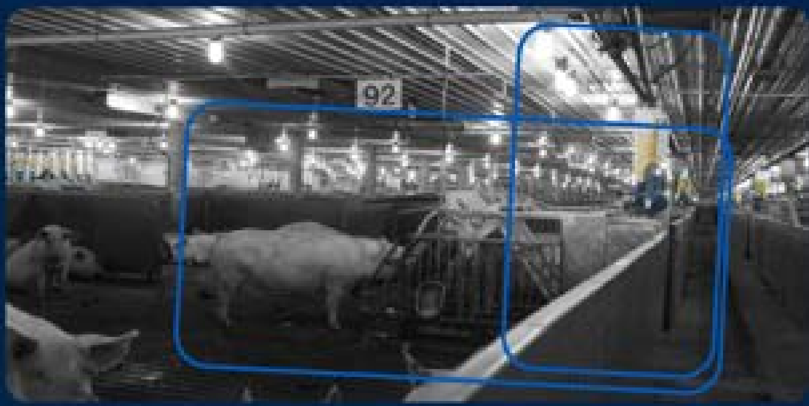
In the present study, total lysine intake over gestation was lowered by 25% with the PF strategy compared to the CF strategy, which is in accordance with previous simulations reporting a 27–32% reduction with PF compared to CF, depending on the farms (Gaillard et al., 2020). Feed costs were reduced by 3.7% with PF compared to CF, also in agreement with previous simulations on gestating sows (−3.6%; Gaillard et al., 2020) and a similar study performed in growing pigs (−4.0%; Pomar et al., 2009). Stewart (2020) also reported the potential financial advantage of PF over CF especially when protein become an expensive ingredient. Similarly phosphorus intake and excretion decreased with PF compared to CF as predicted in Gaillard et al. (2020). However, these differences were smaller in the present experiment than in the simulations (−8 vs. −14% for standardized total tract digestible phosphorus intake, and −9 vs. −15% for phosphorus excretion), probably due to differences in feed phosphorus content and sows' characteristics. The present experiment focused on one gestation cycle per sow only. It would be interesting to go further and follow the effects of PF on the sows' performances and feed costs over several consecutive cycles, in combination with the use of PF also during lactations. Indeed, a recent study showed that PF during lactation also reduced feed costs and lysine ingestion (Gauthier, 2021).

4.2 BODY WEIGHT AND BACKFAT THICKNESS

On average the estimated BW before farrowing was precise as no significant difference was found between the estimated and measured values. Conversely, average values of BW and BT measured after farrowing were slightly but significantly greater than the values used for the factorial calculation of requirements (Dourmad et al., 2008). The estimated litter weight was not different from the observed one so this does not explain the underestimation of the sow BW after farrowing, which might be linked to an underestimation of the placenta and fluids weight as well as mammary tissues weight (Close et al., 1984). The greater maternal gain than expected could also indicate that the efficiency of nutrient utilization, or the nutritional value of the diets, especially for energy, might be greater than the values used for the factorial calculation of requirements. Differences in sows' behavior that affect maintenance requirement could also be involved. This suggests that further development of the decision support system (e.g. real-time measurement of sows' BW and behavior) could improve the determination of nutrient requirement, and the real-time adjustment of supplies.

Young et al. (2004) compared different ways of attributing and calculating feeding allowance, based on a visual estimation (body condition score, BCS, grade from 1 – thin sow, to 5 – fat sow) or based on BT and BW measurements at weaning or service (for gilts). These BW and BT measurements were then used as inputs for equations calculating the energy requirements for maintenance, maternal gain, and uterus, similarly to our study. They reported that feeding gestating sows using their BW and BT resulted in lower proportion of fat sows at farrowing, and similar proportion of thin sows compared to the visual BCS strategy. Feed intake of sows fed with the BCS strategy was higher than the one of sows fed with the BW-BT strategy (+27 kg of feed throughout gestation). Thus, for a sow producing 2.3 litters per year, and for a gestation feed cost of 0.13 $/kg, the BT-BW strategy allows the saving of 8 $/sow yearly compared to the BCS strategy. Moreover, feeding strategy did not affect performance during lactation.

Therefore, using BT and BW at service to calculate feeding allowance is an inexpensive and relevant feeding method for gestating sows. It also makes sense as BT has been shown to be positively correlated with lifetime productivity (Gaughan et al., 1995).



4.3 FEEDING BEHAVIORS

4.3.1. GENERAL SOWS FEEDING BEHAVIORS

On average, the sows visited the feeders 5 times per day and spent 64 min per day in the feeders. They ate all their ration in one visit and a feeding visit lasted around 36 min, corresponding to an average feeding rate of 80 g/min. Marcon et al. (2020) reported a similar average of 6 visits per day with 48–72 sows for 2 feeders but shorter total time (27 min) and feeding time (13 min) in the feeders, that could be related to the greater number of sows per feeder in their study or to the fact that the feeders' doors were closed once all the sows had eaten their ration. Wavreille et al. (2009) reported a daily meal duration of 23 min per day, stating that it fits well with the feeding rate of 118 g/min measured by Cerneau et al. (1997). As shown by Ramonet et al. (1999) feeding rate varied with the fiber content of the diet, from 152 to 67 g/min when CF content varied from 3.3% to 18.1% of the diet. But this does not explain the rather low feeding rate found in the present study because dietary CF was rather low (about 4.5% on average). These results suggest that in the present study the sows spent more time in the feeder than required to eat their ration, taking the space of others that did not eat yet. A solution would be to motivate the sows to move out of the feeder as soon as they have eaten, for example adding water in the feed (e.g., 50 mL per 100 g) or going for a one-pass pen design that reduces feeding time (Stewart et al., 2008).

Reducing waiting time in front of the feeder will decrease the competition for feed and injuries; and might also avoid energy requirements to be affected by this extra physical activity.

4.3.2. PARITY, FEEDING AND TIME EFFECTS

There was no significant parity effect on the number of visits or time spent in the feeders even if, numerically, the primiparous sows spent around 16 min more per day in the feeder than the multiparous sows. This value is in agreement with Wavreille et al. (2009) reporting that the primiparous sows spent 10 min more per day in the feeder than the multiparous sows, although this result was also linked to a higher number of visits. In the present study, the sows spent more time at the feeder in the beginning of the new feeding day than later during the day even though it was during night time (midnight). Wavreille et al. (2009) also reported that the feeder was mainly occupied during the first 12 h of the feeding day, and that it was first occupied by the multiparous sows, in accordance with our results. As the sows were fed restrictively during gestation, the new feeding day to start at any time (day or night) and parity was clearly related to the hierarchical order of entrance in the feeder (Wavreille et al., 2009).

At the end of the gestation, the frequency of non-feeding visits and time spent in the feeder were higher for the PF sows compared to the CF sows. Buis (2016) did not find any effects of the feeding strategy on the number of visits to the feeder. These results are difficult to interpret but might indicate that the PF strategy may stimulates hunger somehow so the sows were visiting the feeder expecting more feed. It would be interesting to study these feeding behaviors during consecutive cycles to see if they keep stable or if the PF sows are behaving similarly to the CF sows after a while. Furthermore, the effect of the feeding strategy on feeding behaviors requires further investigation as feeding behaviors could be linked to the level of activity of the sows, and therefore to the energy requirements. They could also serve as management indicators to detect health troubles, as for example a reduction of the non-feeding visits to the feeder pointed out sick calves in the study of Weary et al. (2009). The use of these data should be investigated for gestating sows, for example to evaluate their ability to detect leg injuries but also their response to heat stress. Indeed, previous study showed that low-intensity heat stress altered duration and frequency of feeding (Anderson et al., 2020). The link should also be explored between feeding behavior and physical activity as it seems logical that these two variables would be positively correlated.

CONCLUSIONS

5

Compared to the CF strategy, the PF strategy reduced lysine intake, nitrogen excretion, phosphorus excretion, and feed costs per gestation of around 25%, 18.5%, 9%, and 3.7%, respectively. Reproductive performance and sow's body characteristics were not affected by the feeding strategy. The number of feeding visits to the feeder and the time spent for these visits were barely affected by feeding strategy. Only at the end of the gestation the frequency of non-feeding visits and the time spent in the feeder were higher for the PF sows compared to the CF sows. In conclusion, the PF strategy reduced lysine intake, protein intake and feed costs without influencing reproductive performance while reducing nitrogen and phosphorus excretion.

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