Impact of feed intake during late gestation on piglet birth weight and reproductive performance: a dose-response study performed in gilts

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ABSTRACT: The effects of increasing feed intake (1.8, 2.3, 2.8, and 3.3 kg/d) during late gestation of gilts on piglet birth weight and female reproductive performance were evaluated. A total of 977 gilts were fed a diet based on corn-soybean meal (3.29 Mcal ME per kg and 0.64% standardized ileal digestible lysine) from day 90 of gestation until farrowing. Gilts were weighed on days 90 and 112 of gestation, at farrowing and weaning. Born alive and stillborn piglets were weighed within 12 h of birth. Colostrum yield (**CY**), lactation feed intake, and litter growth rate were measured in a randomly selected subsample of 245 gilts. The data were analyzed using generalized linear mixed models. As expected, gains in body weight (**BW**) were different at day 112 ($P < 0.001$) with the greatest values observed in the 3.3 kg/d treatment. As feed intake increased during late gestation, BW, body condition score (**BCS**), backfat (**BF**), and Caliper unit also increased between day 112 and weaning ($P < 0.001$). No differences were found among treatments in total number of piglets born, mummified fetuses, sum of born alive and stillborn piglets, and within-litter birth weight CV ($P > 0.05$). Tendencies for quadratic effect of feed intake were observed for born alive piglets ($P = 0.079$), average birth weight of piglets ($P = 0.083$), and litter weight ($P = 0.059$). Gilts with lower feed intake during late gestation had reduced percentages of stillborn piglets than gilts with greater feed intakes. The CY decreased linearly ($P < 0.05$) as the feed intake was increased. No differences among treatments were found at weaning in individual piglet weight and litter weight, as well as in percentage of weaned piglets ($P > 0.05$). Lactation feed intake decreased as gestation feeding level increased ($P < 0.05$). No differences in the subsequent cycle were observed among treatments for farrowing rate, retention rate up to the next farrowing, number of total piglets born, born alive, stillborn piglets, and mummified fetuses ($P > 0.05$). In conclusion, increased feed intake from day 90 of gestation until farrowing resulted in increased maternal BW gain and stillborn rate, but reduced CY and lactation feed intake. A slight increase in birth weight was observed for the 2.3 kg/d treatment. Furthermore, litter growth and subsequent female reproductive performance were not affected by feed intake during late gestation.

Key words: birth weight, dose-response, feeding, gilts, late gestation, nutrition

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INTRODUCTION

The intense genetic improvement over the last years has resulted in increased litter size. However, as the number of piglets born has increased, the birth weight has decreased due to a greater competition for nutrients in the intrauterine environment (Town et al., 2005; Foxcroft et al., 2006). Low-birth-weight piglets have several negative implications during their lifetime, such as greater pre-weaning mortality (Quiniou et al., 2002), greater mortality during nursery period when associated with a reduced colostrum intake (Ferrari et al., 2014), reduced weaning weight and subsequent market weight (Quiniou et al., 2002; Fix et al., 2010; Alvarenga et al., 2012), and decreased reproductive performance (Magnabosco et al., 2016).

There are several nutritional strategies to improve the birth weight of piglets such as the supplementation of L-carnitine at early gestation (Ramanau et al., 2008), L-arginine throughout the gestational period (Mateo et al., 2008; Quesnel et al., 2014), and lysine or energy levels during late gestation (Gonçalves et al., 2016b). Another strategy is called "bump feeding" and involves increased daily feed intake during the late gestational period (Cromwell et al., 1989; Shelton et al., 2009; Soto et al., 2011; Mallmann et al., 2018). In general, feeding during the early gestational period is focused on the recovery of body condition score (**BCS**), whereas at late gestation it is focused on exponential development of the fetus (NRC, 2012). However, studies have failed to demonstrate great improvement in birth weight, or have found results that are controversial, indicating how difficult it is to manipulate the birth weight of piglets through maternal nutritional intervention.

The benefits or the real necessity of the bump feeding practice during late gestation have not been elucidated. Generally, results were controversial and did not show benefits with this strategy (Campos et al., 2012; Gonçalves et al., 2016a). When studies were conducted with sows, no increase in the birth weight was found (Shelton et al., 2009; Soto et al., 2011, Greiner et al., 2016). However, some researchers have found better results when the study was conducted with gilts (Shelton et al., 2009; Soto et al., 2011). Although Gonçalves et al. (2016b) reported a moderate improvement in piglet birth weight associated with the increase in energy intake, in our previous study (Mallmann et al., 2018) the increase in feed intake had no improved the birth weight, regardless of the female category (sows or gilts).

A greater feed intake during gestation represents a challenge for sows because those achieving greater body weight (**BW**) may experience negative implications during the subsequent lactational period, mainly a reduction in voluntary feed intake (Eissen et al., 2000; Shelton et al., 2009; Mallmann et al., 2018). Lower feed intake and consequent greater BW loss impair the subsequent reproductive performance (Koketsu et al., 1996, 2017), although few studies regarding bump feeding have considered this effect. It has also been reported that females submitted to a bump feeding practice exhibit greater stillborn rates (Gonçalves et al., 2016b), and show no benefits on lactation performance and retention rate on the subsequent cycle (Gonçalves et al., 2016b; Mallmann et al., 2018).

The main aim of this study was to verify if the bump feeding practice is necessary for hyper-prolific gilts, establishing the maximum daily feed intake to improve the birth weight. Another objective was to identify the effects of feed intake on colostrum yield (**CY**), voluntary feed intake during lactation, growth performance of litters, and subsequent female reproductive performance. A dose-response study might elucidate the benefits of this practice, not only for piglet birth weight but also for female reproductive performance.

MATERIALS AND METHODS

The protocol used in this study was approved by the Ethics Committee of Animal Utilization (CEUA) of the Federal University of Rio Grande do Sul (UFRGS), under the process no. 31653.

Location

The study was conducted in a pig farm with 2,200 females, in the Midwest of Santa Catarina State (27°00′15″S, 51°14′32″W), Brazil, between January and April, which corresponds to summer and early fall in the southern hemisphere. The average, minimum, and maximum temperatures in the region, during the period of study, were 21.0, 11.1, and 35.6 °C, respectively, and the average relative humidity was 86.3%.

Animals and Diets

The gilts were individually housed (2.20 × 0.60 m), with automatic feeders, and ad libitum access to water. During all the stages of gestation, the diet was a corn-soybean-based meal with 3.29 Mcal ME per kg, 13.4% crude protein (**CP**), and 0.64%

standardized ileal digestible lysine (**SID Lys**). From day 0 to day 4 of gestation, the gilts were fed 1.8 kg/d of the feed. According to the methodology proposed by Young et al. (2004), from day 5 to day 35, gilts with the BCS (1 to 5 scale) of 2 and 3 were fed 2.7 and 2.1 kg/d of the diet, respectively. From day 36 to day 89 of gestation, all gilts received 1.8 kg/d of the diet.

Dietary samples were collected weekly for 16 wk and analyzed in triplicates for CP, total AA, and dry matter (Methods described in CBAA, 2017 which is based on **AOAC**—Official Methods of Analysis of AOAC International methodologies, 19th edition, 2012). Samples were also analyzed for crude fiber, ash, ether extract, calcium, and phosphorus (AOAC Int., 2012; CBAA, 2017). The analyzed diet was considered consistent with formulated values based on analytic variability (Table 1).

Experimental and Treatment Design

On day 89 of gestation, a total of 977 gilts (Landrace × Large White) were selected according to the following characteristics: general health status; BCS between 2.5 and 4.5 (1 to 5 scale; Young et al., 2004), and age >190 d at first service. The selected females were weighed individually and randomly assigned, according to their BW, into 4 feed amounts, to be fed from day 90 of gestation to farrowing: 1.8 kg/d (5.9 Mcal ME per day and 11.5 g/d SID Lys); 2.3 kg/d (7.6 Mcal ME per day and 14.7 g/d SID Lys); 2.8 kg/d (9.2 Mcal ME per day and 17.9 g/d SID Lys), and 3.3 kg/d (10.9 Mcal ME per day and 21.1 g/d SID Lys) of a corn-soybean-based diet (Table 2; 3.29 Mcal ME per day, 13.4% CP, and 0.64% SID Lys). The NRC (2012)

Table 1. Chemical analysis of the diets (as-fed basis)[1]

Ingredient	Gestation	Lactation
Proximate analysis, %		
DM	89.10 (88.87)	89.50 (86.58)
CP	12.79 (13.39)	20.20 (21.68)
Crude Fiber	1.89 (2.17)	2.56 (2.51)
Fat	3.42 (3.11)	7.55 (5.54)
Ash	5.31 (1.91)	5.64 (2.91)
Ca	1.02 (0.82)	1.20 (0.89)
P	0.51 (0.50)	0.65 (0.56)
Total AA, %		
Lys	0.72 (0.74)	1.27 (1.42)
Ile	0.55 (0.51)	0.85 (0.90)
Leu	1.36 (1.28)	1.66 (1.81)
Met	0.28 (0.28)	0.28 (0.43)
Met and Cys	0.44 (0.58)	0.49 (0.75)
Thr	0.60 (0.57)	0.90 (0.94)
Trp	0.12 (0.14)	0.22 (0.26)
Val	0.71 (0.61)	0.97 (0.99)
His	0.36 (0.37)	0.46 (0.58)
Phe	0.69 (0.64)	1.03 (1.05)

[1]Values in parentheses indicate those calculated from diet formulation and are based on the values from the NRC (2012).

Table 2. Composition of the experimental diets (as-fed basis)

Ingredient	Gestation[1]	Lactation[2]
Corn	82.69	58.56
Soybean meal	12.87	33.66
Vitamin and mineral premix[3]	1.00	1.00
Dicalcium phosphate	1.00	0.86
Limestone	1.31	1.39
Salt	0.50	0.50
L-Lys	0.18	0.33
DL-Met	0.04	0.10
L-Thr	0.09	0.14
Soybean oil		3.00
Phytase	0.01	
Others	0.31	0.46
Total	100.00	100.00
Calculated analysis		
SID[4] Lys, %	0.64	1.27
SID Met: Lys, %	38	31
SID Met and Cys: Lys, %	70	54
SID Thr: Lys, %	74	64
SID Trp: Lys, %	18	18
SID Val: Lys, %	80	67
CP, %	13.39	21.68
Ca, %	0.82	0.89
STTD P[5], %	0.50	0.56
Na, %	0.23	0.24
Cl, %	0.46	0.60
ME, Mcal/kg	3,288	3,429
NE, Mcal/kg	2,521	2,550

[1]Diet was fed from day 90 of gestation to farrowing.

[2]Diet was fed during the lactation period.

[3]*Vitamin composition per kg of diet—Gestation*: vitamin A: 13,800 IU/kg; vitamin D_3: 2,760 IU/kg; vitamin E: 92 IU/kg; vitamin K_3: 3,082 ppm; vitamin B_1: 2,300 ppm; riboflavin (B_2): 5,060 ppm; pyridoxine (B_6): 2,760 ppm; vitamin B_{12}: 30.82 ppb; niacin: 30.82 ppm; pantothenic acid: 13.800 ppm; folic acid: 1.932 ppm; biotin: 0.97 mg/kg; choline: 1.800 ppm. *Mineral composition—Gestation*: selenium: 0.480 ppm; iron: 135.945 ppm; copper: 75.0 ppm; manganese: 49.765 ppm; zinc: 158.073 ppm; iodine: 1.520 ppm; fluorine: 34.855 ppm; cobalt: 0.600 ppm. *Vitamin composition per kg of diet—Lactation*: vitamin A: 12,000 IU/kg; vitamin D_3: 2,400 IU/kg; vitamin E: 80 UI/kg; vitamin K_3: 2.680 ppm; vitamin B_1: 2.00 ppm; riboflavin (B_2): 4.4 ppm; pyridoxine (B_6): 2.4 ppm; vitamin B_{12}: 26.8 ppb; niacin: 26.8 ppm; pantothenic acid: 12.0 ppm; folic acid: 1.680 ppm; biotin: 0.970 mg/kg; choline: 1.800 ppm. *Mineral composition—Lactation*: selenium: 0.400 ppm; iron: 113.416 ppm; copper: 50.0 ppm; manganese: 42.371 ppm; zinc: 131.672 ppm; iodine: 1.260 ppm; fluorine: 28.125 ppm; cobalt: 0.500 ppm.

[4]SID = standardized ileal digestible.

[5]STTD = standardized total tract digestible.

recommendation for gilts from day 90 of gestation to farrowing is a feed amount of 2.53 kg/d (3.3 Mcal ME per day, 0.69% SID Lys), which corresponds to an effective daily energy intake of 7.9 Mcal ME per day. In a dose-response arrangement, our study intended to have lower and greater levels, ranging from 5.9 to 10.9 Mcal ME per day. All females were fed manually twice a day, at 0700 and 1500 h. Feed wastage during the treatment period was recorded daily after the meal. The females that did not consume the total amount of daily feed offered (31 gilts from 3.3 kg/d and 7 gilts from 2.8 kg/d levels) over the treatment period were excluded from the study.

Females were moved on day 112 to the farrowing room where they kept on receiving the gestation diet until farrowing. Females were individually switched to the lactation diet as they farrowed. All gilts were weighed and submitted to BCS, backfat thickness (**BF**), and Caliper evaluations on day 89 (before the onset of the experimental period), day 112 of gestation (moving from gestation to farrowing), and at weaning. All weighing was performed with a 500 g precision scale (EW6, Tru Test, Auckland, New Zealand). The measurements of BF were performed in the P2 point (6.5 cm away from the midline of the vertebral column at the last rib level) with A-mode ultrasonography (Renco Lean Meter–Renco Corporation, Minneapolis, MN) within a range of 2 mm. Caliper unit was measured at the same BF point with the Caliper equipment in a unit range from 1 to 25 (Knauer and Baitinger, 2015). The birth weight of the born alive and stillborn piglets was recorded within 12 h of birth, using a scale with a resolution of 1 g. The mummified fetuses were not weighed; however, the number was recorded to be included in total number of piglets born.

Lactation Performance

A random subsample of 245 gilts was used to evaluate CY, voluntary feed intake during lactation, and performance of females and their litters. All farrowings were followed to ensure all the procedures were performed adequately and that both oxytocin and obstetric manual intervention were not used. Females subjected to these interventions were removed from the subsample evaluation.

The CY was calculated as the sum of colostrum intake by each piglet within a litter. Colostrum intake was estimated using the equation described by Devillers et al. (2004), based on piglet weight difference between the weight at 24 h after birth and the weight at birth, before the first colostrum intake. Colostrum intake period and the time to first suckling were used as fixed times, 1,440 and 30 min, respectively. In our study, piglets that died within 24 h of birth were not included in the evaluation, and piglets that had lost weight during the 24 h were considered as having had no colostrum intake. A drying powder was used to dry the body, the umbilical cord was not shortened, and each piglet was identified with a numerical ear tag.

The cross-fostering of piglets was performed within 24 h of birth after having been recorded and weighed. Each piglet was fostered according to the dietary treatment of the respective dam. Few changes were performed because Mac Rebel practices were adopted by the farm: only piglets weighing less than 900 g were excluded and piglets were included to equalize the litter numerically. After cross-fostering, no piglets were added to the litters, and deaths and removals were recorded. All the piglets were weighed at weaning.

The post-farrowing weight of females was recorded within 12 h after the last piglet was born to evaluate the effects of the feed intake on weight loss of the females during lactation.

Females were individually housed (2.20 × 0.70 m) during lactation with ad libitum access to water. The lactation diet (3.43 Mcal ME per kg, 21.7% CP, and 1.27% SID Lys; Table 2) was provided 4 times a day from farrowing until weaning, through the manual filling of the feed box. However, if they showed more appetite, more feed was added into the feed box. The maximum daily feed amount was 9 kg. The feed wastage was weighed and recorded every day to measure the average lactation feed intake. Four-day intervals were used for analyses (day 0 to 3, 4 to 7, 8 to 11, and 12 to 15 of lactation), except for the last interval (16 to 20 d) with 5 d, because the duration of lactation was 20.1 ± 1.5 d.

Subsequent Female Reproductive Performance

Estrus detection was performed once a day after weaning, and weaning-to-estrus interval (**WEI**) was recorded after estrus confirmation by female standing reflex in the presence of a boar. Born alive piglets, stillborn piglets, and mummified fetuses in the subsequent farrowing were recorded. Data concerning the litter size of females that returned to estrus after post-weaning insemination were not included in the statistical analyses.

Statistical Analysis

The Statistical Analysis System software, version 9.3 (SAS Inst. Inc., Cary, NC), was used to perform the statistical analysis. All models included dietary treatment as a fixed effect. The week of onset of the feed treatment was included as a random effect, except in the nonparametric models. Polynomial contrasts were used to evaluate the linear and quadratic effects of the dose-response (different feed amounts offered daily).

The following variables were analyzed using the GLIMMIX procedure fitted assuming a normal distribution: BW; BF; Caliper unit at different time periods, and the respective gains and losses; total number of piglets born; born alive piglets; sum of born alive and stillborn piglets; CY; WEI; litter weight, and individual piglet weight at birth, cross-fostering, and weaning. The results of differences in body measures (i.e., gain or loss) are presented in 3 periods: period 1 (from day 90 to day 112 of gestation) and period 2 (from day 112 of gestation to weaning), and overall period (from day 90 of gestation to weaning).

A model with repeated measures was used for the analysis of voluntary feed intake during lactation. Treatments (gestation feed level), time (lactation interval), and the interaction between these 2 factors were included as fixed effects in the model.

The percentage of stillborn and mummified fetuses, and the percentage of piglets weighing less than 1,000 g were analyzed as nonparametric distributions using the NPAR1WAY procedure. The comparison among treatments was performed using the Kruskal–Wallis test. The percentage of females bred until day 7 after weaning, farrowing rate, and retention rate until second parity were analyzed as binary distributions using the GLIMMIX procedure.

The results were considered significant at $P \leq 0.05$, and the tendency at $0.05 < P \leq 0.10$. Each female was considered as an experimental unit in all the analyses.

RESULTS

BW, BCS, BF, and Caliper Unit Gain During Late Gestation

No differences were found among treatments at the onset of the experiment ($P > 0.428$) for age at insemination (229.5 ± 0.63), BW (185.8 ± 0.44), BCS (3.52 ± 0.01), BF (13.21 ± 0.08 mm), and Caliper unit (14.96 ± 0.75).

During period 1 (day 90 to day 112 of gestation), changes in BW, BCS, BF, and Caliper unit increased linearly with the increase in feed intake (Table 3; $P < 0.001$). Gilts from 1.8 kg/d treatment lost BCS, BF, and Caliper unit. During the period 2 (from day 112 to weaning), all the treatments resulted in BW, BCS, BF, and Caliper losses (linear; $P < 0.001$); greater feed intake during late gestation resulted in greater body reserve losses. Losses of BW, BCS, BF, and Caliper unit were also observed in all treatments during overall period (day 90 to weaning). The losses reduced as the feed intake during late gestation increased (linear; $P < 0.001$).

Litter Size and Piglet Birth Weight

No effect of feed intake during late gestation was found on total number of piglets born, mummified fetuses, sum of born alive and stillborn piglets, and within-litter birth weight CV (Table 3; $P > 0.05$), whereas a tendency of quadratic effect was observed on the number of born alive piglets ($P = 0.079$). Furthermore, females fed 1.8 kg/d had a lower percentage of stillborn piglets than those of other treatments, which were not different from each other. Individual piglet birth weight and litter weight tended (Table 3; quadratic effect) to increase in gilts fed 2.3 kg/d ($P = 0.083$ and $P = 0.059$, respectively).

Colostrum Yield, Voluntary Feed Intake, and Lactational Performance

The number of piglets weighed after birth (13.5 ± 0.36) and at 24 h post-farrowing (13.0 ± 0.35), considered in the measurement of CY, exhibited similar values among treatments ($P > 0.05$). Likewise, the mortality of piglets during the first 24 h was also similar among treatments (2.86 ± 0.55%; $P > 0.05$). Other subsample results are shown in Table 4. As feed intake increased during late gestation, CY decreased linearly ($P < 0.05$; Table 4). Maternal BW at post-farrowing increased with increase in feed intake during late gestation (linear; $P < 0.001$). Voluntary feed intake during lactation decreased linearly with the increase in feed intake during late gestation ($P < 0.05$); consequently, the BW loss at first lactation increased (linear; $P < 0.001$). No differences among treatments were found at weaning for individual piglet weight, litter weight, and the percentage of weaned piglets (Table 4; $P > 0.05$).

Subsequent Reproductive Performance

Among the 977 gilts analyzed at the first farrowing, 16 were removed due to sickness or death during lactation and were not considered for the

Table 3. Effects of feed intake in the last third of gestation on maternal body weight, farrowing performance, and characteristics related to the offspring of gilts under commercial conditions[1]

	Feed intake, kg[2]					Probability, $P <$	
	1.8	2.3	2.8	3.3			
Item	$n = 244$	$n = 242$	$n = 241$	$n = 250$	SEM	Linear	Quadratic
Body weight (BW), kg							
Day 90	186.6	187.3	187.1	187.2	2.79	0.668	0.714
Day 112	200.7	204.6	210.0	213.1	0.58	<0.001	0.200
Weaning	167.8	170.7	171.6	173.9	3.45	<0.001	0.748
Body condition score (BCS)							
Day 90	3.6	3.5	3.5	3.5	0.27	0.140	0.352
Day 112	3.5	3.5	3.6	3.7	0.03	<0.001	0.385
Weaning	3.0	3.0	3.0	3.1	0.03	<0.001	0.615
Backfat (BF), mm							
Day 90	13.4	13.4	13.5	13.4	0.58	0.772	0.768
Day 112	13.2	13.6	14.3	14.6	0.12	<0.001	0.381
Weaning	11.8	12.2	12.7	12.9	0.72	<0.001	0.776
Caliper unit							
Day 90	15.0	14.8	14.9	14.8	0.79	0.280	0.988
Day 112	14.2	14.6	15.2	15.8	0.22	<0.001	0.470
Weaning	11.2	11.4	11.9	12.1	0.84	0.002	0.331
Changes in period 1, day 90 to 112							
BW, kg	15.0	18.8	24.2	27.4	0.58	<0.001	0.200
BW, %	8.1	10.1	13.1	14.7	0.49	<0.001	0.230
BCS	−0.1	0.0	0.1	0.2	0.02	<0.001	0.707
BF, mm	−0.1	0.4	1.1	1.4	0.12	<0.001	0.381
Caliper unit	−0.8	−0.4	0.3	0.8	0.22	<0.001	0.470
Changes in period 2, day 112 to weaning							
BW, kg	−33.4	−35.1	−39.2	−40.2	1.87	<0.001	0.596
BW, %	−16.7	−17.2	−18.7	−18.9	0.88	<0.001	0.625
BCS	−0.5	−0.5	−0.6	−0.6	0.02	<0.001	0.480
BF, mm	−1.5	−1.5	−1.8	−1.9	0.33	0.008	0.988
Caliper unit	−3.1	−3.4	−3.6	−3.7	0.32	0.001	0.672
Overall changes, day 90 to weaning							
BW, kg	−18.7	−16.7	−15.4	−13.3	1.44	<0.001	0.991
BW, %	−10.0	−8.9	−8.1	−7.0	0.83	<0.001	0.923
BCS	−0.6	−0.5	−0.5	−0.4	0.04	<0.0001	0.484
BF, mm	−1.6	−1.2	−0.8	−0.5	0.27	<0.0001	0.553
Caliper unit	−4	−3.7	−3.3	−2.9	0.36	<0.0001	0.577
Litter size							
Total born, *n*	14.5	14.1	14.3	14.3	0.29	0.600	0.333
Born alive, *n*	13.8	13.2	13.3	13.4	0.23	0.208	0.079
Born alive + stillborn, *n*	14.2	13.8	14.0	14.0	0.27	0.590	0.277
Stillborn, %[3]	3.4[a]	4.6[b]	5.5[b]	4.2[b]	0.52	–	–
Mummified fetuses, %[3]	2.0	2.1	1.8	1.9	0.33	–	–
Piglet weight							
Average piglet birth weight, g[4]	1300	1327	1298	1289	14.15	0.193	0.083
Total litter weight, kg[4]	18.0	18.3	18.0	17.8	0.20	0.109	0.059
Birth weight CV, %	18.7	18.7	18.8	19.3	0.39	0.256	0.621
Piglets weighing <1,000 g, %[3]	16.6[a]	14.2[b]	17.1[a]	17.9[a]	1.06	–	–
Subsequent performance							
Weaning-to-estrus interval, d[5]	4.9	4.9	4.8	4.7	0.09	0.082	0.228
Bred up to 7 d after weaning, %	85.7	84.2	86.4	87.5	2.3	0.462	0.584
Farrowing rate, %	91.7	93.2	94.1	95.2	1.6	0.135	0.993

Table 3. Continued

	Feed intake, kg[2]					Probability, $P <$	
	1.8	2.3	2.8	3.3			
Item	$n = 244$	$n = 242$	$n = 241$	$n = 250$	SEM	Linear	Quadratic
Retention rate, %	88.2	86.0	88.2	89.3	2.1	0.565	0.442
Total piglets born, *n*	13.9	13.8	13.7	13.4	0.26	0.163	0.682
Born alive, *n*	13.0	12.9	13.0	12.6	0.25	0.379	0.523

[1]A total of 977 females (Landrace × Large White) were used, with 244, 242, 241, and 250 females for the treatments 1.8, 2.3, 2.8, and 3.3 kg/d, respectively.

[2]Feed intake: 1.8, 2.3, 2.8, and 3.3 kg/d from day 90 of gestation until farrowing.

[3]Submitted to a nonparametric analysis.

[4]Calculated considering the number of born alive + stillborn.

[5]Analyzed considering females in estrus until day 10 after weaning.

[a,b]Means in the row with 1 letter in common are not significantly different ($P > 0.05$).

Table 4. Effects of feed intake in the last third of gestation on the performance of sows and piglets during the lactation period[1]

	Feed intake, kg[2]					Probability, $P <$	
	1.8	2.3	2.8	3.3			
Item	$n = 61$	$n = 66$	$n = 55$	$n = 63$	SEM	Linear	Quadratic
Colostrum yield, kg	3.6	3.5	3.3	3.2	0.26	0.016	0.703
Post-farrowing weight, kg	176.8	180.8	185.3	188.5	1.32	<0.001	0.668
Voluntary feed intake, kg	4.2	4.1	3.8	3.9	0.23	0.001	0.165
Lactation weight change, kg	−14.3	−16.8	−20.8	−19.2	1.31	<0.001	0.058
Lactation weight change, %	−8.1	−9.3	−11.3	−10.4	0.75	<0.001	0.169
Litter size after cross-fostering, *n*	13.6	13.7	13.5	13.6	0.20	0.815	0.818
Piglets weight after cross-fostering, g	1411	1450	1411	1388	26.86	0.339	0.225
Litter weight after cross-fostering, kg	19.2	19.7	19.1	18.9	0.37	0.332	0.292
Weaned piglets, %	87.9	86.8	87.5	86.9	1.18	0.677	0.854
Litter weight on day 19, kg	59.2	58.2	59.2	59.9	2.08	0.494	0.401
Individual weaning weight on day 19, kg	4.9	4.9	5.0	5.1	0.16	0.196	0.489

[1]A total of 245 females (Landrace × Large White) were used, with 61, 66, 55, and 63 females for the treatments 1.8, 2.3, 2.8, and 3.3 kg/d, respectively.

[2]Feed intake: 1.8, 2.3, 2.8, and 3.3 kg/d from day 90 of gestation until farrowing.

subsequent farrowing rate. A tendency of a significant decrease was observed for WEI (linear; $P = 0.082$, Table 3) as the gestation feed intake increased. The percentage of females bred up to 7 d after weaning, farrowing rate, and retention rate until the next farrowing were not affected by the feed intake ($P > 0.05$). There were also no differences among treatments for total number of piglets born and born alive piglets in the subsequent cycle ($P > 0.05$).

DISCUSSION

Changes in Body Measures

The current study demonstrated that the increase in the feed intake during late gestation (day 90 to 112) resulted in a linear increase in BW, BCS, BF, and Caliper unit. All the levels of feed intake resulted in BW gain. However, the females fed 1.8 kg/d (5.9 Mcal/d) exhibited reduced BCS, BF, and Caliper unit, whereas females fed 2.3 kg/d (7.6 Mcal/d) showed reduced Caliper units. The requirements for maintenance during late gestation show little change in comparison with increments necessary to support the growth of fetal tissue, mammary tissue, placenta, and fluids (NRC, 2012). The fetal growth rate changes from a 0.25 g/d before day 69 to 4.63 g/d after day 69 of gestation (Mcpherson et al., 2004), and mammary gland growth rate changes from 0.08 g/d before day 75 to 1.5 g/d after the day 75 of gestation (Ji et al., 2005). Considering the 6 pools proposed by the NRC (2012), the requirements for gilts in late gestation increase from approximately 7.0 Mcal/d on day 90 of gestation to 8.5 Mcal/d before farrowing. Goodband et al. (2013)

suggested that the energy requirements to avoid maternal tissue catabolism in late gestation must increase by 1.5 to 2.3 Mcal/d, which is equivalent to an incremental feed intake increase of around 0.5 to 0.75 kg/d. Thus, the results of our study confirm that 1.8 kg/d (5.9 Mcal/d) was insufficient because the values of BCS, BF, and Caliper unit for females of this treatment reduced from day 90 to day 112 of gestation. The fact that gilts fed 2.3 kg/d (7.6 Mcal/d) did not lose BF in late gestation, with an energy intake slightly lower than requirements for this phase (NRC, 2012), suggests that there might be an overestimation for gilts requirements during late gestation. Nonetheless, it is important to consider that gilts are still growing and their lower BW gain until farrowing or greater body reserve losses for the overall period might have negative consequences for their lifetime performance. The farrowing rate after first weaning and retention rate until third parity have been negatively affected in females that gained less weight between mating and first weaning (Lesskiu et al., 2015). The importance of an adequate body weight at first farrowing for the lifetime performance was pointed out by Kim et al. (2016) who reported greater retention rate and number of piglets born alive over 6 parities in females with 210 kg (among groups ranging from 190 to 240 kg) at day 109 of first gestation.

Greater BW gain during late gestation was linearly associated with body reserve losses during lactation. Although the BW at weaning was still linearly affected by gestation feeding level, the negative correlation between gain during gestation and loss during lactation affected the magnitude of difference among treatments. The difference of 12.4 kg between the 2 extreme treatments (3.3 and 1.8 kg/d) on day 112 was reduced to 6.1 kg at weaning. In other studies, gilts with greater feed intake during late gestation were also found to lose more weight during lactation (Amdi et al., 2013; Mallmann et al., 2018). Amdi et al. (2013) reported that gilts fed 1.8 kg/d during gestation did not lose weight during lactation, whereas gilts fed 2.5 or 3.5 kg/d lost weight. Likewise, Kim et al. (2016) showed greater BW and BF losses during lactation when gilts had greater pre-farrowing BW. In our study, females were found to lose 0.54 kg BW during lactation per 1 kg of gain during gestation, when 2.3, 2.8, and 3.3 kg/d feed intakes were compared with 1.8 kg/d.

Female Performance at Farrowing

Although the stillborn rate is not always affected by feed intake during late gestation of gilts (Gonçalves et al., 2016b; Mallmann et al., 2018), more stillborn piglets were reported in sows receiving greater energy levels (Gonçalves et al., 2016b). The negative effect of excessive body condition on the survival of piglets at birth is already known because overweight gilts (Amaral Filha et al., 2010) and sows that were too fat (Oliviero et al., 2010) before farrowing showed a greater rate of stillborn piglets. Similarly, Lavery et al. (2018) associated the high BF with a reduction in born alive piglets. In the present study, the farrowing length was not measured. However, females that are too fat have prolonged parturitions and greater rates of stillborn piglets (Oliviero et al., 2010), suggesting that females fed 1.8 kg/d might have had lower percentages of stillborn piglets because they were lighter and leaner before farrowing, hence found to be less prone to farrowing problems.

Contrarily to the results of other studies (Cromwell et al., 1989; Shelton et al., 2009; Gonçalves et al., 2016b), only marginal increases in the average piglet birth weight and total litter weight were observed in gilts that received 2.3 kg/d. Recently, in a study with 2 different feed intakes, 1.8 and 2.2 kg/d from day 90 to farrowing, in sows and gilts, no increase in piglet birth weight was observed (Mallmann et al., 2018). However, the increase in daily feed intake during other gestational periods has resulted in increased birth weight in gilts (Amdi et al., 2013) and sows (Ren et al., 2017). It is important to mention that in those studies the treatments were performed during other gestational periods, with females of different parities or with few females in each treatment, compared with the present study. No improvement in the piglet birth weight was achieved with greater feed intakes (2.8 and 3.3 kg/d), in our study, indicating that the crowding of embryos in hyper-prolific females can establish the programming of a low-birth-weight phenotype as suggested by Foxcroft (2012). As insulinemia is lower in sows with more fetuses (Père and Etienne, 2018), our results reinforce the previous assumption that the transfer of nutrient to fetuses in hyper-prolific females can be reduced because they develop a limited insulin resistance (Mallmann et al., 2018); a limited nutrient transfer to growing fetuses seems to occur even in females with greater feed intake.

Colostrum Yield

Our study demonstrated average values of CY similar to those reported in other studies (Devillers et al., 2007; Foisnet et al., 2010; Quesnel 2011).

Foisnet et al. (2010) reported a CY of 3.2 kg (range of 0.8 to 4.8 kg) for the first-parity sows. Similarly, Decaluwé et al. (2013) reported a CY of 3.2 kg (range of 1.6 to 5.0 kg) in sows of parities 1 to 7. Colostrum yield is extremely variable and influenced by some factors of different origins, such as environmental factors and characteristics of piglets and sows (Devillers et al., 2007; Foisnet et al., 2010; Quesnel 2011). The association between the mobilization of body reserves during late gestation and CY has not been confirmed to be consistent. Sows (parities 1 to 7) with BF loss between days 85 and 109 of gestation produced 113 g more colostrum for each 1 mm of extra BF loss (Decaluwé et al., 2013). However, in the same study, females that exhibited BF loss between day 109 of gestation and day 1 after farrowing had lower CY, mainly for parities 4 to 7. The authors suggested that the high catabolic state in older sows likely inhibited the colostrum production at a full potential. Contrarily, in the present study, the CY was greater for females receiving 1.8 kg/d, which we consider was the only treatment that did not fulfill the requirements for gilts, based on their BF deposition (NRC, 2012). It seems that the mobilization of body reserves compensated for the deficiency in daily feed intake of gilts fed 1.8 kg/d during their first gestation. Loisel et al. (2014) showed a positive correlation between CY and free fatty acids measured before parturition, which suggests that a low or negative energy balance can enhance the CY to a certain extent, mainly for young sows. The fact that females fed 1.8 kg/d lost BF may indicate that this fat mobilization was prioritized for CY, because colostrum synthesis occurs mainly during the last week of gestation (Devillers et al., 2006).

Not only fatty acids but also greater levels of plasma creatinine and urea before farrowing are associated with greater CY (Loisel et al., 2014). Yet, the mobilized protein can be used by mammary glands as a source of amino acids or glucogenic substrates (Theil et al., 2012). Thus, we infer that a greater protein mobilization around parturition may be associated with an increased CY.

Performance During the Lactation Period

As previously reported (Amdi et al., 2013; Ren et al., 2017; Mallmann et al., 2018), the performance of piglets until weaning was not affected by feed intake during late gestation, even with a greater colostrum intake by piglets of gilts fed 1.8 kg/d. Voluntary feed intake was lower for females with greater feed intake during late gestation, as already reported (Shelton et al., 2009; Mallmann et al., 2018). Voluntary feed intake is mainly controlled by the metabolic condition before farrowing and driven by the central nervous system (Eissen et al., 2000). Thus, heavier females with more BF are prone to have a lower feed intake, and consequently more body reserve loss during the lactation period. The capacity to compensate the lower feed intake during gestation by the mobilization of the body reserves during lactation (King and Dunkin, 1986; Mallmann et al., 2018) was indeed expressed by greater loss of BW and BF between the post-farrowing and weaning periods. Furthermore, only a severe reduction in the daily feed intake affects the performance of piglets (King and Dunkin, 1986; Sulabo et al., 2010). Therefore, it is likely that the difference of 0.3 kg in daily feed intake (4.2 and 3.9 kg for 1.8 and 3.3 kg/d treatments, respectively) between the 2 extreme feed intakes during late gestation was easily counteracted by the greater mobilization of body reserves in gilts fed 3.3 kg/d.

Subsequent Performance

The increase in WEI observed in females of lower feed intake during late gestation (1.8 and 2.3 kg/d) was too small and not enough to reduce the farrowing rate and subsequent litter size. In recent studies, no negative effects on subsequent performance were observed with bump feeding during late gestation (Gonçalves et al., 2016b; Mallmann et al., 2018) or with different feed intake levels during different gestational periods (Ren et al., 2017). In a previous study, the subsequent litter size decreased when the BW loss was greater than 10% (Schenkel et al., 2010). However, although gilts fed 2.8 and 3.3 kg/d lost more than 10% of BW during lactation, their subsequent litter size was not reduced. Taken together, these findings confirm that contemporary females can have less adverse effects driven by metabolic changes during lactation (Patterson et al., 2011).

CONCLUSION

In gilts with suitable body condition, the BW, BCS, and BF gains increased as the feed intake during the last third of the gestational period increased from 1.8 to 3.3 kg/d; however, only a marginal increase in piglet birth weight was achieved. Increased feed intake during late gestation increased the stillborn rate, whereas CY and voluntary feed intake during lactation were reduced. The litter growth and subsequent female reproductive performance were not affected by feed intake during late gestation.

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