Journal of Agricultural and Crop Research
Vol. 7(8), pp. 137-147, August 2019
doi: 10.33495/jacr_v7i8.19.134
ISSN: 2384-731X
Research Paper

The effects of dietary replacement with extruded whole plant forage corn silage on gestation and lactation performances of sow and litter

Ruey-Chee Weng

Department of Animal Science, National Pingtung University of Science and Technology, Neipu Pingtung 91201, Taiwan, Republic of China.
ORCID No: https://orcid.org/0000-0001-5631-0567

E-mail: rcweng@mail.npust.edu.tw. Tel: +886-8-7703202-6287.

Accepted 4th July, 2019.

Abstract. The search for useful resources locally produced for livestock is an attempt of urgency, particularly in the wake of high grain price and high demands of reducing global warming potential. Despite its negative impact on performances, increasing attention has been paid to dietary fiber in monogastric animals' nutrition due to its multiple functionalities, especially in sow diets. In the experiment, a total of 48 Yorkshire cross with Landrace (YL) hybrid sows were fed with dry matter base of 0, 15, 30 and 50% extruded whole-plant forage corn silage (52.5% DM and 8.4% CP) replacement experimental diets during gestation and lactation. Sows were weighed, the backfat thickness was measured ultrasonically and jugular blood samples were collected from all sows. The results show that sows fed with corn silage replacer loss more body weight (P=0.015) and backfat thickness (p=0.024) during lactation. The 50% replacement sows took an average of 230.52 kg experimental rations during lactation (p<0.001). As can be seen, 50% replacement sows had a higher average daily feed intake of 8.23 kg during lactation. Although not significant statistically, it seemed that control, 15% and 30% replacement sows had better litter weight gain than 50% replacement sows. Sows fed with corn silage replacer tend to have lower total USFA before farrowing (P=0.044) but lower total SFA at weaning (P=0.004) whereas the control sows had the opposite condition. Serums C20:1, C22:1, C24:1 and C20:4 were not detected in late pregnancy for sows fed with corn silage replacer. However, they tend to have increasing concentrations of C22:5 and C22:6 as the replacement rate increases in late pregnancy and convert more body reserve to higher milk lipid contents. In conclusion, 30% sows' dry matter replacement ration had the highest margins with extruded corn silage. This local resource is an effective approach to reduce feed cost significantly as well as to minimize carbon-foot prints of rations for pig production and increase voluntary feed intake in lactation sows.

Keywords: Dietary fiber, gestation, lactation, sow and litter performance, corn silage, extruder.

INTRODUCTION

Using local resources is an effective approach to reduce feed cost as well as to minimize carbon-foot prints of rations for livestock and poultry. Pig production mostly relies on imported grains in Taiwan; thus, the search for useful resources locally produced for livestock is an attempt of urgency, particularly in the wake of high grain price and high demands of reducing global warming potential. Despite its negative impact on performances, increasing attention has been paid to dietary fiber in monogastric animals' nutrition due to its multiple functionalities, especially in sow diets.

Intensive production systems generally provide sows with restricted feed during gestation and fed ad libitum during lactation. However, the voluntary feed intake of modern sows is too low to meet their increased energy requirements during lactation (Noblet *et al.*, 1990), especially in young sows (Eissen *et al.*, 2000). A reduction in voluntary feed intake during lactation occurs when the intake during first and second parity sows rose above 1.93 kg/day (Close and Cole, 2000). Therefore, it is usually recommended that feed intake be restricted during pregnancy to avoid low appetite in lactation. However, different feeding practices are often found in pig operations, with the lactation diet being offered more often 30 days before rather than a few days after parturition. Supplying high-fiber diets during pregnancy has been shown to improve the welfare of sows (Meunier-Salaün *et al*., 2001) and increase feed intake over the subsequent lactation period (Farmer *et al*., 1996; van der Peet-Schewering *et al.*, 2003; Guillemet *et al.*, 2006). Moreover, sows fed with a high-fiber diet during gestation, manage their own feed transition, choosing the lactation diet spontaneously on the week preceding parturition (Guillemet *et al*., 2010). This indicates that a high-fiber gestation diet promotes early intake of the lactation diet. When energy intake per sow was equalized among the gestation treatments, a higher percentage of the sows fed a diet containing 50% alfalfa hay had a greater piglet survival rate (Pollmann *et al*., 1980). However, fiber multiple functionalities also depend on the types of fiber, animal's gastric adaption and other additional requirements during metabolism process. Inclusion of increased amounts of dietary fiber may reduce hunger of restricted-fed pregnant sows due to a reduced assimilation of energy derived from starch at the expense of greater amounts of energy derived from short-chain fatty acid due to microbial fermentation of non-starch polysaccharides in the large Intestine (Serena *et al*., 2009; Jensen *et al*., 2012).

The addition of approximately 6.8% ground wheat straw as a source of fiber to a gestation diet that was fed for 5 successive parities increased overall litter size and total litter weight at weaning, when basal diet intake was equalized among treatments (Everts, 1991). The additional 13.35% ground wheat straw to the gestation diet improved sow and litter performance, with increases in litter size and total litter weight at birth and weaning compared with control sows and litters (Veum et. al., 2009). Recently, Meunier-Salaün and Bolhuis (2015) summarized and concluded that provided dietary fibers during gestation generally have a beneficial effect on the behavior and welfare of sows which were restricted-fed.

As can be seen from the above studies, fiber does have significant effects on sow nutrition and welfare. For traditional corn-soybean diets, wheat brane used to be the fiber source in sow diet formulation, however, those materials are not readily available in Taiwan. Using local resources to alter traditional corn-soybean diet composition and feeding management simultaneously may improve sow performance and reduce feed cost.

Therefore, the purpose of this study was to investigate the effects of feeding sows with a partial extruded whole-plant forage corn silage during gestation and lactation on their physiological and metabolic adaptations during the pre-partum period, and to determine how these effects may carry on to lactation period and relate to sow and piglet performances.

MATERIALS AND METHODS

Methodology

The experiment was carried out at the agriculture college practical farm in National Pingtung University of Science and Technology, Taiwan, R.O.C. The Practical Farm of the Animal Production Division consists of pig, dairy, poultry, feeds and waste treatment units. The Pig Unit was established for training and research purposes, and is managed by the animal nutrition and energy resource management laboratory.

Animals and housing

48 sows (Yorkshire × Landrace) of 3rd or 4t^{h} parity after weaning were housed in 4 groups and fed with experimental diets. All sows were given daily boar contact for 15 min in the early morning and late afternoon. When signs of estrus were seen, the sows received two inseminations at 12 and 24 hours after stable reaction to "back press". The fresh semen was mixed from different Duroc boars and diluted to 50×10^{8} sperm per 100 ml dose. At 21 and 30 days after insemination, the ultrasonic pregnancy detector PREG-TONE (RENCO CORPORATION, Inc. Minneapolis, USA) was used to test each sow for pregnancy. Keeping conception failures in mind, 40 gestating sows were used as experimental animals in each replicate for the whole duration. All the experimental sows were moved to individual stalls and received experimental diets. 109 days after insemination, all gestating sows were moved to farrowing house for 28 days of nursing and then moved back to the previous dry sow accommodation after weanling. No hormone treatments were allowed for parturition. No piglet fostering was allowed for experimental animals; other sows were made available to take piglets if necessary. All sows were fed diets corresponding to their physiological stages. There was only one type of feed fed during the pregnancy stage and lactating stage for each treatment. The composition and chemical characteristics of the experimental diets are described in Table 1. Tainan No. 19 forage corn plant was the main species for the corn silage and this was used in the experiment. Normally, fresh plant was harvested at around 70 to 80 days old, and then the immature plants would be machinery

Table 1. Ingredient composition (%) of gestation and lactation diets[4].

Items	CTL[1]	15%[2]	30%[2]	50%[2]
Extruded corn silage[2]	0	30	60	100
Yellow corn	53.2	45.22	37.24	26.6
Soybean seed dehulled	16	13.6	11.2	8
Soybean meal dehulled, 47% CP	6	5.1	4.2	3
Wheat bran	20	17	14	10
Dicalcium phosphate	1.2	1.02	0.84	0.6
Limestone, pulverized	1.7	1.445	1.19	0.85
Salt	0.4	0.34	0.28	0.2
Vitamin premix [3]	0.2	0.17	0.14	0.1
Mineral premix [3]	0.2	0.17	0.14	0.1
Choline chloride (50%)	0.1	0.085	0.07	0.05
Lard	1	0.85	0.7	0.5

[1]: Control group
[2]: The replacer was analyzed for 52.5% dry matter, 8.4% crude protein, 1.7% crude fat, 6.3% crude fiber, 2.9% ash, 0.45% calcium, 0.4% total phosphate and 1800 Kcal/kg. Replacement percentage was based on ration's dry matter.
[3]: Vitamin and trace mineral premix (China Chemical & Pharmaceutical Co., Ltd., Taiwan, R.O.C.) provided, per kilogram of control diet or diet containing corn silage: 6,600 IU of vitamin A acetate; 1,210 IU of vitamin D_3; 22.0 IU of vitamin E from dl-α-tocopheryl acetate; 3.5 mg of vitamin K from menadione sodium dimethylprimidinol bisulfite; 22.0 mg of pantothenic acid as d-calcium pantothenate; 33.2 mg of niacin; 2.0 mg of folic acid; 5.5 mg of riboflavin; 27.6 µg of vitamin B12; 330 µg of biotin from d-biotin; 575 mg of choline from choline chloride; 125 mg of Zn as $ZnSO_4$; 126 mg of Fe as $FeSO_4$; 60 mg of Mn as $MnSO_4$; 0.55 mg of I as $Ca(IO_3)_2$; and 0.35 mg of Se as Na_2SeO_3.
[4]: The rations were fed to sows from gestation to lactation in each treatment.

Table 2. Calculated chemical concentrations (%) as fed basis of gestation and lactation diets[3].

Items	CTL[1]	15%[2]	30%[2]	50%[2]
Dry matter %	87.5	74.375	61.25	43.75
Crude protein %	16.0	16.1	16.3	16.4
Crude fat %	6.9	6.4	5.9	5.2
Crude fiber %	4.5	5.7	6.9	8.6
ADF %	5.7	10.3	14.8	20.9
NDF %	16.3	24.0	31.7	42.0
Calcium %	0.9	0.9	0.9	0.9
Total phosphate %	0.8	0.8	0.8	0.8
Ash %	6.0	6.0	5.9	5.9
Energy DE Kcal/Kg	3300	3345	3390	3450

[1]: Control group
[2]:The replacer was analyzed for 52.5% dry matter, 8.4% crude protein, 1.7% crude fat, 6.3% crude fiber, 2.9% ash, 0.45% calcium, 0.4% total phosphate and 1800 Kcal/kg. Replacement percentage was based on ration's dry matter.
[3]: The rations were fed to sows from gestation to lactation in each treatment.

chopped to 5 to 10 mm in length and ensilaged for 45 to 60 day. The chemical compositions of corn silage were analyzed for 29% dry matter (CNS2770-3), 2.7% crude protein (CNS2770-5), 1.1% crude fat (CNS2770-4), 7.8% crude fiber (CNS2770-8) and 1.5% crude ash (CNS2770-9).

In this experiment, high fiber replacer was made up of 425 kg corn silage, 75 kg dehulled soybean meal, 2.5 kg dicalcium phosphate, 3.5 kg limestone and 6 kg lard. The formula was extruded after mixing by using dry type single screw extruder K28000 (KUO HUI HIN ENTERPRISE Co. Ltd., Kaohsiung, Taiwan R. O. C.). The chemical compositions of the high fiber replacer were analyzed for 52.5% dry matter (CNS2770-3), 8.4% crude protein (CNS2770-5), 1.7% crude fat (CNS2770-4), 6.3% crude fiber (CNS2770-8), 2.9% crude ash (CNS2770-9), 0.45% calcium, 0.4% total phosphate and 1800 Kcal/kg. The composition and chemical characteristics of the experimental diets are described in Tables 1 and 2.

The sows were fed ad libitum with experimental diets before mating. After mating, the sows were kept in stalls and were fed twice a day. The amount was reduced to 2.0 kg DM per day per sow from mating until 80 days after service. The diet was increased to 2.2 kg DM per day per sow from 80 days after service to 110 days of pregnancy. Five days before the expected farrowing date (114 days), the sows were moved to the farrowing house. The diet was reduced to 2.0 kg DM per day per sow and experimental diets were continued being fed. The sows that did not give birth by 114 days of pregnancy continued to be fed 2.0 kg DM per day. Any uneaten feed was cleaned out before the next feeding, and it was not returned to the experimental animals. All feed refusals were recorded on the datasheets and corrected to dry matter (determined by drying at 60ºC). From the initial day of pregnancy until parturition, sows had no feed refusals. The daily feed allowances and, thus, feed intakes of control, 15%, 30% and 50% replacement sows were, respectively, 2.20, 2.43, 2.65 and 2.95 kg of experimental rations from 1 to 80 days of pregnancy, 2.40, 2.65, 2.89 and 3.22 kg of experimental rations from 81 days of pregnancy until 110 days of pregnancy. The feed was increased postpartum by 0.5 kg DM per day till sows reached ad libitum ration. The feed amount was divided into three meals and fed to sows three times a day. After weaning, the feed amount was reduced to 3.2 DM kg per sow per day and fed to sows twice a day until rebreeding.

Creep feed was given to piglets from one week postpartum and was increased by 100 gm per day, using a 20% CP (corn-soybean meal) broken pellet commercial concentrate. However, there was some difficulty in measuring the creep feed consumption due to wastage. This feed was cleaned out every day and troughs kept half full all the time. The health of the animals was checked daily and, if necessary, ill animals were treated by the veterinarian. The piglets received Hog cholera and Swine erysipelas vaccination injections at day 21. The teeth clipping, tail docking and castration were not performed.

Data collection

Sows were weighed and backfat thickness was measured ultrasonically (Preg-Alert Pro, Renco Corporation, Minneapolis, USA) at the last rib 6.5 cm from the midline on each side at mating, 30, 80,110 days after insemination and weaning. Piglets were weighed within 24 h after birth (day 0), and then at day 7, day 14, day 21 and weaning at day 28.

Blood and milk sampling

Jugular blood samples were collected from all sows at 06:00 AM (before feeding) on day 80 and 108 of gestation and weanling. Blood samples (10 ml) were collected in vacutainer tubes containing EDTA (Becton Dickinson and Co., Rutherford, NJ). They were put on ice and centrifuged within 60 min at 4°C for 30 min at 3,000 × g, and plasma was immediately recovered and frozen at −20°C until further analyses. Concentrations of fatty acid profiles in sow plasma were measured in all samples.

Milk was collected at day 7 ± 1 and day 17 ± 1 of lactation after an injection of Cloprostenol sodium (450 μg i.m.; REGUBIRTH INJECTION, YUNGSHIN PHARM Ind. Co. Ltd., Taiwan, ROC). The milk samples were immediately filtered through gauze, aliquoted, and stored at −20°C until further analyses.

Statistical analysis

The GLM (general linear mode) procedure was used with SAS to perform the analysis (SAS, 1989). Comparison between treatments was done by calculating the standard error of difference (S.E.D.) and least significant difference (LSD). Analysis of variance was also used to compare the characteristics of sow and piglet performance, serum biochemical parameters, and fatty acid profiles in sow plasma for each factor. The factors included in the analysis were sow dietary treatments and physiological stages. For investigation of the effects of treatment, comparison of piglet performance was analyzed by analysis of variance with litters as the experiment unit.

RESULTS

Results of sow performance

There were 48 sows throughout the whole experiment without any losses or replacements. There was an average of 113.4 ± 0.21 days for pregnancy, and 3.28 ± 0.26 hours for farrowing. The sows spent an average of 4.9 ± 1.11 days before coming into heat after weaning, however only 43 sows (92.5%) were seen in heat for subsequent reproduction cycle.

Treatment effects on sow performance

Table 3 shows the treatment effects on body weight and backfat thickness changes. In this section, there was no distinction of treatment effects in the initial body weight (p=0.197). With the increase days of pregnancy, control sows tend to have higher body weight at 30 days of pregnancy (p=0.043) and at 80 days of pregnancy (p=0.027). There was no difference between 15, 30 and 50% replacement groups in these stages. At 110 days of pregnancy, there were no significant treatment effects on body weight and backfat thickness, however, sows fed

Table 3. The effects of dietary partial replacement with extruded whole plant corn silage in gestation and lactation on sow body weight and backfat thickness changes.

Items	CTL[1]	15%[2]	30%[2]	50%[2]	SEM	*P*-value
Initial body weight (kg)	211.7	209.7	202.7	207.6	8.57	0.197
Body weight at 30 days pregnancy (kg)	223.0[a]	216.8[ab]	208.0[b]	213.6[ab]	10.68	0.043
Body weight at 80 days pregnancy (kg)	236.9[a]	228.1[ab]	216.8[b]	223.7[ab]	13.65	0.027
Body weight at 110 days pregnancy (kg)	248.5	242.4	233.5	244.8	14.39	0.223
Body weight at weaning (kg)	242.3[a]	221.0[b]	206.5[b]	213.3[b]	19.25	0.001
Backfat thickness at 30 days pregnancy (mm)	14.6	15.0	13.9	13.7	1.32	0.158
Backfat thickness at 80 days pregnancy (mm)	15.6	15.7	14.9	14.3	1.44	0.249
Backfat thickness at 110 days pregnancy (mm)	17.3	17.0	16.1	15.3	2.36	0.422
Backfat thickness at weaning (mm)	17.6[a]	15.3[ab]	14.1[b]	13.7[b]	2.69	0.020
Body weight changes at middle pregnancy (kg)	25.2[a]	18.5[b]	14.0[b]	16.1[b]	7.18	0.012
Body weight changes at late pregnancy (kg)	11.6	14.3	16.7	21.1	8.10	0.182
Body weight changes at lactation (kg)	6.2[b]	21.5[a]	27.0[a]	31.5[a]	16.22	0.015
Backfat changes at middle pregnancy (mm)	1.0	0.7	1.0	0.7	0.46	0.279
Backfat changes at late pregnancy (mm)	1.6	1.3	1.2	1.0	1.28	0.842
Backfat changes at lactation (mm)	-0.4[b]	1.7[a]	1.9[a]	1.7[a]	1.68	0.024

[1]: Control group
[2]:The replacer was analyzed for 52.5% dry matter, 8.4% crude protein, 1.7% crude fat, 6.3% crude fiber, 2.9% crude ash, 0.45% calcium, 0.4% total phosphate and 1800 Kcal/kg. Replacement percentage was based on ration's dry matter.
[ab]: Means with the same letter are not significantly different.
SEM: Standard error of the difference between two means.

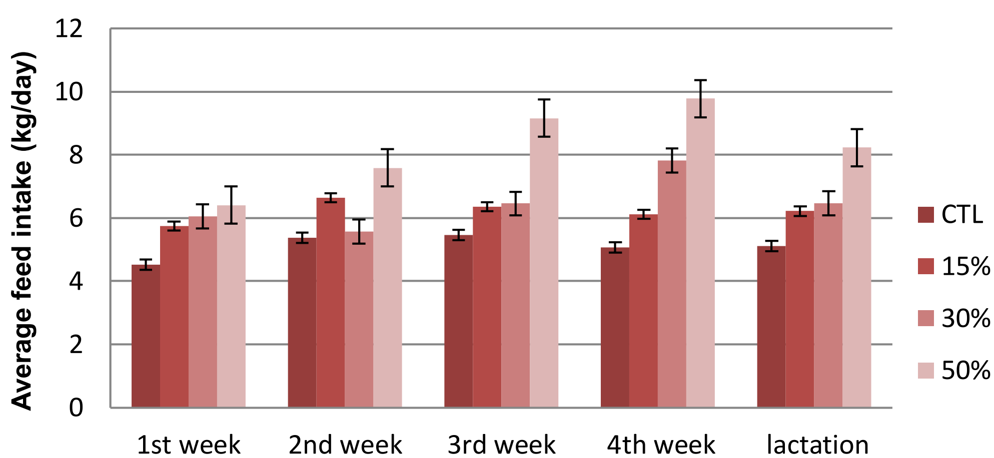

Figure 1. The effects of dietary partial replacement with extruded corn plant silage in gestation and lactation on sow feed intake during lactation.

with corn silage replacer loss more body weight (P=0.015) and backfat thickness (p=0.024) during lactation. The control, 15%, 30% and 50% replacement sows lost 6.2, 21.5, 27 and 31.5 kg body weight and 0.4, 1.7, 1.9 and 1.7 mm backfat thickness, respectively, during lactation. From 30 days of pregnancy until parturition, sows had no feed refusals. The daily feed allowances and, thus, feed intakes of control, 15%, 30% and 50% replacement sows were, respectively, 2.20, 2.43, 2.65 and 2.95 kg of experimental rations from 1 to 80 days of pregnancy, 2.40, 2.65, 2.89 and 3.22 kg of experimental rations from 81 days of pregnancy until the day of parturition. The experimental rations were increased postpartum by 0.5 kg DM per day accordingly till sows reached ad libitum ration.

With the increase of lactation, 30 and 50% replacement sows gradually increasing daily feed intake, however, control and 15% replacement sows reduced feed intake in the fourth week of lactation (Figure 1). The 50% replacement sows took significant high amounts of experimental rations in different weeks of the lactation (Table 4). The 50% sows took average 230.5 kg experimental rations during lactation, other sows took 143.1, 174.1 and 181.3 kg (for control, 15% and 30%,

Table 4. The effects of dietary partial replacement with extruded whole plant corn silage in gestation and lactation on sow feed intake during lactation.

Items	CTL[1]	15%[2]	30%[2]	50%[2]	SEM	*P-value*
Feed intake of 1st week (kg)	31.68	40.24	42.34	44.85	2.059	0.173
Feed intake of 2nd week (kg)	37.68	46.52	39.01	53.12	2.158	0.08
Feed intake of 3rd week (kg)	38.23^{b}	44.50^{b}	45.23^{b}	64.13^{a}	1.701	<0.001
Feed intake of 4th week (kg)	35.50^{c}	42.83^{c}	54.71^{b}	68.42^{a}	1.823	<0.001
Total feed intake at lactation (kg)	143.1^{c}	174.1^{bc}	181.3^{ab}	230.5^{a}	5.352	<0.001
Crude fat intake of 1st week (kg)	2.19	2.58	2.46	2.33	0.124	0.704
Crude fat intake of 2nd week (kg)	2.60	2.98	2.34	2.76	0.132	0.318
Crude fat intake of 3rd week (kg)	2.64	2.85	2.67	3.34	0.102	0.117
Crude fat intake of 4th week (kg)	2.45^{c}	2.74^{bc}	3.30^{ab}	3.56^{a}	0.108	0.006
Total crude fat intake at lactation (kg)	9.87	11.14	10.76	11.99	0.325	0.215
Crude fiber intake of 1st week (kg)	1.42^{c}	2.29^{b}	2.87^{b}	3.86^{a}	0.126	<0.001
Crude fiber intake of 2nd week (kg)	1.70^{c}	2.65^{b}	2.73^{b}	4.57^{a}	0.128	<0.001
Crude fiber intake of 3rd week (kg)	1.72^{c}	2.54^{b}	3.12^{b}	5.52^{a}	0.105	<0.001
Crude fiber intake of 4th week (kg)	1.60^{d}	2.44^{c}	3.86^{b}	5.88^{a}	0.124	<0.001
Total crude fiber intake at lactation (kg)	6.44^{d}	9.92^{c}	12.59^{b}	19.83^{a}	0.321	<0.001

[1] : Control group
[2] :The replacer was analyzed for 52.5% dry matter, 8.4% crude protein, 1.7% crude fat, 6.3% crude fiber, 2.9% crude ash, 0.45% calcium, 0.4% total phosphate and 1800 Kcal/kg. Replacement percentage was based on ration's dry matter.
[a~d] : Means with the same letter are not significantly different.
SEM : Standard error of the difference between two means.

respectively; p<0.001). When comparing the effect of the treatment by dry matter intake amounts, it is seen that the sows that took corn silage replacer tend to take more dry matter but there was no statistically significant difference (Table 5). The 50% sows took an average of 100.9 kg of dry matter during lactation, other sows took 125.2, 129.5 and 111.29 kg (for control, 15% and 30%, respectively; p=0.048). Their litters gained similar body weights, of which 51.31, 50.22, 51.04 and 47.25 kg for control, 15, 30 and 50% treatments, respectively; p=0.842). The 50% replacement sows had the better dry matter feed conversion efficiency to litter body weight gain at the first (p=0.024) and the second (p=0.008) week of lactation. The control, 15% and 30% sows tend to have similar dry matter feed conversion efficiency to litter body weight gain. They were recorded to have 2.49, 2.63, 2.20 and 2.16 dry matter feed conversion efficiency to litter body weight gain at lactation for control, 15, 30 and 50% treatments, respectively (p=0.108).

Treatment effects on piglet performance

The average numbers of piglets (born alive) per litter were 10.43, 11.22, 11.50 and 10.83 for control, 15, 30 and 50% replacement sows, respectively (p=0.586). There were no treatment effects on the average of piglets' birth weight and total body weight of piglets born alive (Table 6). There were no treatment effects on the percentage of piglets that survived after 5 days and 28 days. However, sows fed with corn silage replacer tend to keep more piglets at day 5 of lactation and weaned more piglets. The piglets from control sows tend to have heavier body weights at 21 days old (p=0.029) and at 28 days old (p=0.046). They also gained more body weight at third weeks of age (p=0.009). The piglets were weaned at 28 days old with the average body weight of 7.8, 6.78, 6.68 and 6.51 kg for control, 15, 30 and 50% replacement treatment, respectively. The body weight gains for the first two weeks were similar (p=0.276). However, during the last two weeks of lactation, control group piglets gained the most followed by 15% and 30% replacement groups, and with 50% replacement group coming in last (p=0.039).

Fatty acid profiles in sow plasma and milk quality

The dietary treatment had a significant influence on the concentrations of SFA and USFA, and was significant for most of the dependent variables at 108 days of pregnancy and at weaning (Tables 7 and 8). Sows fed with corn silage replacer tend to have lower Total USFA concentrations before farrowing (P=0.044, Table 7) but lower Total SFA concentrations at weaning (P=0.0014, Table 8) whereas the control sows had the opposite condition. Sows fed with corn silage replacer tend to have higher Total SFA concentrations before farrowing (P=0.0668, Table 7), especially C14:0, C16:0 and C20:0. However, C16:0 concentrations dramatically dropped at weaning in these sows. The control sows again had the opposite condition for C16:0 concentrations (p=0.0008,

Table 5. The effects of dietary partial replacement with extruded whole plant corn silage in gestation and lactation on sow performances during lactation.

Items	CTL[1]	15%[2]	30%[2]	50%[2]	SEM	*P-value*
Total dry matter intake of 1st week (kg)	27.72	29.93	25.93	19.62	1.439	0.112
Total dry matter intake of 2nd week (kg)	32.97[a]	34.60[a]	23.90[b]	23.24[b]	1.547	0.022
Total dry matter intake of 3rd week (kg)	33.45	33.10	27.71	28.05	1.188	0.180
Total dry matter intake of 4th week (kg)	31.06	31.86	33.51	29.94	1.182	0.761
Total dry matter intake at lactation (kg)	125.2[a]	129.5[a]	111.0[ab]	100.9[b]	3.798	0.048
Litter size at 5-day-old (live piglets)	8.43	9.67	10.00	9.83	0.252	0.146
Litter size at weaning (piglets)	7.71	8.89	9.25	8.50	0.227	0.121
Litter weight at birth(kg)	15.51	19.29	16.32	14.80	0.943	0.332
Litter weight gain at 1st week (kg)	10.15	9.87	9.84	10.94	0.508	0.876
Litter weight gain at 2nd week (kg)	13.96	13.72	14.13	13.83	0.761	0.998
Litter weight gain at 3rd week (kg)	15.07	13.93	12.51	12.46	0.528	0.280
Litter weight gain at 4th week (kg)	12.14	12.70	14.93	10.03	0.734	0.174
Total litter weight gain at lactation (kg)	51.31	50.22	51.40	47.25	1.729	0.842
Feed conversion efficiency at 1st week	2.73[a]	3.21[a]	2.85[a]	1.83[b]	0.147	0.024
Feed conversion efficiency at 2nd week	2.59[a]	2.64[a]	1.72[b]	1.69[b]	0.120	0.008
Feed conversion efficiency at 3rd week	2.27	2.40	2.24	2.35	0.087	0.896
Feed conversion efficiency at 4th week	2.83	2.61	2.40	3.24	0.160	0.346
Feed conversion efficiency at lactation	2.49	2.63	2.20	2.16	0.078	0.108

[1]: Control group
[2] :The replacer was analyzed for 52.5% dry matter, 8.4% crude protein, 1.7% crude fat, 6.3% crude fiber, 2.9% crude ash, 0.45% calcium, 0.4% total phosphate and 1800 Kcal/kg. Replacement percentage was based on ration's dry matter.
[ab]: Means with the same letter are not significantly different.
SEM: Standard error of the difference between two means.

Table 7 and p=0.0002, Table 8). Surprisingly, the serum C20:1, C22:1, C24:1 and C20:4 were not detected in late pregnancy (Table 7) for sows fed with corn silage replacer. However, they tend to have increasing concentrations of C22:5 and C22:6 as the replacement rate increased in late pregnancy (Table 7). Serum C22:1 (P<0.0001, Table 8) were not detected in the control sows, but they tend to have higher levels of C20:4, C20:5, C22:5 and, the lowest levels of C22:6 at weaning (Table 8).

Measurement of the interactions between lactation day and dietary replacement rate on sow milk quality (Table 9) showed that the later the lactation, the lower the percentage of dry matter, lipid and energy density. However, the percentage of ash and lactose increased with lactation. There were also significant interactions among lactation day and dietary replacement rate on lipid and lactose contents. Sows fed with higher replacement diet ratio had higher lipid content in their milk, which increased with lactation days. In contrast, higher replacement diet ratio leads to lower lactose content, which increased with lactation days.

DISCUSSION

The levels of performance recorded in this experiment were similar to typical commercial performance in Taiwan. There were no significant differences in initial body weight and P_2 backfat thickness. This indicates an unbiased allocation that should be expected since animals were genetically similar and had been maintained under standard conditions until this time. In the following stages, all sows gained similar body weight and backfat thickness but the control sows had a higher body weight gain at 80 days of pregnancy. These differences maybe because of the different fiber contained and utilized by the animals. Bindelle and colleagues (2008) reviewed that the presence of dietary fiber lowers the apparent fecal digestibility of the crude protein and possibly the ileac digestibility, but not necessarily the efficiency of nitrogen retention by the animal. In this study, sows fed with extruded corn silage replacer tend to gain more body weight at late pregnancy. This may be caused by the pig's adaptation to dietary fiber digestion, which is a long process that requires 5 weeks (Martinez-Puig *et al.*, 2003); but energy digestibility is always higher with sows, due to their higher transition time consecutive to their higher gastrointestinal tract volume combined to lower feed intake per live weight (Le Goff *et al.*, 2002). Besides the lower efficiency in the utilization of corn silage energy compared to grain, the low digestibility of some fiber sources contribute to their negative impact on the density content of the ration. Sows fed with 50% replacer had the worse ratio of rations of dry matter convert to litter weight gain at the 3rd and the 4th week of lactation, and had great

Table 6. The effects of dietary partial replacement with extruded whole plant corn silage in gestation and lactation on piglet performances during lactation.

Items	CTL[1]	15%[2]	30%[2]	50%[2]	SEM	*P-value*
Litter size at birth (live piglets)	10.43	11.22	11.50	10.83	1.542	0.586
Litter size at 5 days old (live piglets)	8.43	9.67	10.00	9.83	1.432	0.146
Litter size at weaning (piglets)	7.71	8.89	9.25	8.50	1.299	0.121
Molarity at 5 days old (%)	16.33	13.63	12.60	9.55	11.586	0.786
Live piglet at weaning (%)	76.71	79.91	80.74	79.18	12.497	0.942
Litter weight at birth(kg)	15.51	19.29	16.32	14.90	5.142	0.342
Body weight at birth (kg)	1.54	1.50	1.43	1.39	0.211	0.584
Body weight at 7-day-old (kg)	2.74	2.51	2.40	2.54	0.384	0.398
Body weight at 14-day-old (kg)	4.39	3.92	3.82	3.99	0.604	0.308
Body weight at 21-day-old (kg)	6.20^{a}	5.35^{b}	5.08^{b}	5.32^{b}	0.789	0.029
Body weight at 28-day-old (kg)	7.80^{a}	6.78^{b}	6.68^{b}	6.51^{b}	0.964	0.046
Body weight gain at 1st week (kg)	1.21	1.01	0.97	1.15	0.252	0.242
Body weight gain at 2nd week (kg)	1.64	1.40	1.42	1.45	0.385	0.640
Body weight gain at 3rd week (kg)	1.81^{a}	1.44^{b}	1.25^{b}	1.33^{b}	0.360	0.009
Body weight gain at 4th week (kg)	1.60	1.42	1.61	1.19	0.429	0.257
Body weight gain at first two weeks (kg)	2.85	2.42	2.40	2.60	0.500	0.276
Body weight gain at last two weeks (kg)	3.41^{a}	2.86^{ab}	2.86^{ab}	2.51^{b}	0.591	0.039
Total body weight gain at suckling (kg)	6.26^{a}	5.28^{b}	5.26^{b}	5.12^{b}	0.884	0.049

[1]: Control group
[2]:The replacer was analyzed for 52.5% dry matter, 8.4% crude protein, 1.7% crude fat, 6.3% crude fiber, 2.9% crude ash, 0.45% calcium, 0.4% total phosphate and 1800 Kcal/kg. Replacement percentage was based on ration's dry matter.
[ab]: Means with the same letter are not significantly different.
SEM: Standard error of the difference between two means.

amount of dry matter during lactation stage. These results might be because of high moisture content of the replacer and too much fluffiness for 50% dry matter replacement. As can be seen, 50% replacement sows had a higher average daily feed intake of 8.23 kg during lactation. Although not significant statistically, it seemed that control, 15% and 30% replacement sows raised better litter weight gain than 50% replacement sows. This may imply that 30% sows' dry matter replacement ration has the highest margins with extruded corn silage. In other experiments which the daily energy intake per sow was equalized among the gestation treatments, a greater percentage of the sows, which were fed a diet containing 50% alfalfa hay, completed 3 reproductive cycles with a greater pig survival rate than control sows (Pollmann *et al*., 1980). However, the performance of sows fed a diet containing 46% of an alfalfa-orchardgrass hay mix was equal to that of control sows (Holzgraefe *et al*., 1986). Additions of sugar beet pulp to the gestation diet that ranged from 25% to 50% did not improve sow performance compared with control sows when daily energy intake was equalized among treatments (Vestergaard and Danielsen, 1998; McGlone and Fullwood, 2001; van der Peet-Schwering *et al*., 2003). The addition of approximately 6.8% (Everts, 1991) or 13.35% (Veum *et al*., 2009) ground wheat straw as a source of fiber to a gestation diet that were fed for respectively 5 and 3 successive parities increased overall litter size and total litter weight at weaning compared with sows fed the control diet when basal diets intake were equalized among treatments.

In the lactation stage, sows fed with extruded corn silage replacer had a similar higher body weight loss and mobilized more backfat. In comparison, control sows lost 6.2 kg bodyweight and gained 0.4 mm backfat thickness. The litter performance and the experimental feeding regime may explain this. There is only one type of feeds for both pregnancy and lactation in each treatment. On the other hand, the voluntary feed intake of sows during lactation will not affect the role of previous feeding experience. The role of previous feeding experience in the development of feeding behavior is well documented in lactating sows (Guillemet *et al*., 2006). Sows chose the lactation diet spontaneously on the week preceding parturition when they were fed a fibrous gestation diet and to promote early intake of the lactation diet (Guillemet *et al*., 2010). However, sows fed with extruded corn silage still need time to adapt to dietary fiber. As can be seen, they were gaining less body weight at early two-thirds of pregnancy.

There were no significant treatment differences in the average body weight at birth and the average live piglet body weight. This may be because the mothers had a similar body weight gain in pregnancy. By 21 days old, piglets from control sows had higher body weight and were still significantly heavier at weaning. Piglets from 15,

Table 7. Plasma fatty acid composition (%) at 110 days of pregnancy in sows fed one of four diets from breeding till 28 days of lactation.

Items	CTL[1]	15%[2]	30%[2]	50%[2]	SEM	*P-value*
Lauric acid (C12:0)	0.12[a]	0.00[b]	0.00[b]	0.00[b]	0.016	<.0001
Myristic acid (C14:0)	0.31[b]	0.68[a]	0.61[a]	0.784[a]	0.145	0.0037
Palmitic acid (C16:0)	14.77[b]	22.30[a]	21.94[a]	24.43[a]	2.506	0.0008
Stearic acid (C18:0)	10.33	14.12	12.56	14.09	2.503	0.1577
Arachidic acid (C20:0)	0.00[b]	0.42[a]	0.44[a]	0.48[a]	0.184	0.0090
Benenic acid (C22:0)	4.35[a]	0.58[b]	1.08[b]	0.66[b]	1.129	0.0009
Tetracosanoic acid (C24:0)	0.06	0.00	0.16	0.00	0.197	0.5875
Total saturated fatty acids	29.93[b]	38.08[a]	36.78[a]	40.45[a]	5.023	0.0668
Palmtoleic acid (C16:1)	0.37[b]	0.81[ab]	1.05[a]	0.87[ab]	0.379	0.1070
Oleic acid (C18:1)	17.43	15.24	15.57	17.78	8.239	0.2677
Eicosenoic acid (C20:1)	0.38[a]	0.00[b]	0.00[b]	0.00[b]	0.019	<.0001
Docosaenoic acid (C22:1ω9)	23.66[a]	0.00[b]	0.00[b]	0.00[b]	2.345	<.0001
Tetracosaenoic acid (C24:1)	0.36[a]	0.00[b]	0.00[b]	0.00[b]	0.036	<.0001
Linoleic acid (C18:2ω6)	25.80[b]	37.53[a]	27.96[b]	31.12[b]	4.106	0.0042
Linolenic acid (γ-C18:3ω6)	0.995	1.041	0.722	0.921	0.4288	0.6703
Arachidonic acid (C20:4ω6)	0.452[a]	0.000[b]	0.000[b]	0.000[b]	0.0378	<.0001
Eicosapentaenoic acid (C20:5ω3)	0.000	0.000	0.207	0.033	0.1634	0.2021
Docosapentaenoic acid (C22:5ω6)	0.000[b]	0.0372[ab]	0.098[a]	0.110[a]	0.0600	0.0728
Docosahexaenoic acid (C22:6ω3)	0.628[c]	6.550[b]	6.819[b]	8.165[a]	0.8188	<.0001
Total unsaturated fatty acids	70.068[a]	61.213[b]	62.421[b]	59.002[b]	4.9584	0.0438

[1] : Control group

[2] :The replacer was analyzed for 52.5% dry matter, 8.4% crude protein, 1.7% crude fat, 6.3% crude fiber, 2.9% crude ash, 0.45% calcium, 0.4% total phosphate and 1800 Kcal/kg. Replacement percentage was based on ration's dry matter.

[ab] : Means with the same letter are not significantly different.

SEM : Standard error of the difference between two means.

30 and 50% replacement sows gained less weight at the last two weeks of lactation, although in the first two weeks of lactation, there were no differences in the body weight gain. This suggests that the lower nursing frequency recorded in extruded corn silage replacement groups adversely affected milk intake. Once piglets were older and able to utilize creep feed, they were able to compensate for the lower milk intake, but could not recover their growth check. To sum up, the total bodyweight gain of piglets that were born from the control sows tend to be better than piglets that were born from extruded corn silage replacement groups. This may be a disadvantage of extruded corn silage replacement for piglets, which could be balanced by improving the digestibility of extruded corn silage replacer for the sow.

Sows are restrictively fed during gestation to prevent excessive body weight gain and, in contrast, are allowed to consume feed ad libitum during lactation to cover nutrient requirements for milk production and limit mobilization of sow body reserves (Dourmad *et al.*, 1996). Nevertheless, voluntary feed intake of highly prolific sows is generally insufficient to cover the nutrient demands for milk production and maintain body condition. Feeding sows a higher ratio of fiber replacement diets without altering the daily energy supply during gestation resulted in a greater feed intake during lactation, which is in agreement with previous researches (Matte *et al.*, 1994; Vestergaard and Danielsen, 1998; Courboulay and Gaudré, 2002). Interestingly, the sows fed with higher dietary fiber were found to convert more body reserve to higher milk lipid content in this study. The mechanisms underlying the effect of bulky dietary fiber on the milk quality of sows during lactation have not yet been fully elucidated.

CONCLUSIONS

During pregnancy, sows were genetically similar and had been maintained under standard conditions and gained similar body weight and backfat thickness. Besides the lower efficiency in the utilization of corn silage energy compared to grain, the low digestibility of some fiber sources contribute to their negative impact on the density content of the ration. Sows fed with 50% corn silage replacer loss more body weight and backfat thickness during lactation, but they took an average of 230.52 kg experimental rations during lactation and had a higher average daily feed intake (8.23 kg) during lactation. Although not significant statistically, it seemed that control, 15% and 30% replacement sows raised better litter weight gain than 50% replacement sows. Sows fed

Table 8. Plasma fatty acid composition (%) at 14 days of lactation in sows fed one of four diets from breeding till 28 days of lactation.

Items	CTL[1]	15%[2]	30%[2]	50%[2]	SEM	*P-value*
Lauric acid (C12:0)	0.00c	0.09[b]	0.19[a]	0.11[ab]	0.0428	0.0021
Myristic acid (C14:0)	0.32	0.36	0.41	0.32	0.1571	0.8535
Palmitic acid (C16:0)	20.17[a]	14.94[b]	16.09[b]	15.39[b]	1.0002	0.0002
Stearic acid (C18:0)	15.24[a]	11.30[b]	10.55[bc]	9.50[c]	0.9175	<.0001
Arachidic acid (C20:0)	0.00	0.02	0.00	0.00	0.0129	0.3795
Benenic acid (C22:0)	0.00[c]	5.00[a]	5.19[a]	3.97[b]	0.3036	<.0001
Tetracosanoic acid (C24:0)	0.00	0.05	0.05	0.05	0.0288	0.1113
Total saturated fatty acids	35.73[a]	31.75[bc]	32.47[b]	29.35[c]	1.3815	0.0014
Palmtoleic acid (C16:1)	0.36[b]	0.55[ab]	0.58[a]	0.60[a]	0.1040	0.0434
Oleic acid (C18:1)	25.49[a]	19.99[b]	19.81[b]	19.37[b]	1.8236	0.0040
Eicosenoic acid (C20:1)	0.46	0.44	0.43	0.43	0.0808	0.9438
Docosaenoic acid (C22:1ω9)	0.00[b]	24.84[a]	24.94[a]	24.71[a]	4.3122	<.0001
Tetracosaenoic acid (C24:1)	0.32	0.38	0.39	0.37	0.0989	0.8012
Linoleic acid (C18:2ω6)	30.99[a]	20.27[b]	19.64[b]	23.52[ab]	5.3136	0.0638
Linolenic acid (γ-C18:3ω6)	0.85	0.72	0.69	0.76	0.0859	0.1488
Arachidonic acid (C20:4ω6)	5.31[a]	0.46[b]	0.45[b]	0.45[b]	0.3749	<.0001
Eicosapentaenoic acid (C20:5ω3)	0.17[a]	0.00[b]	0.00[b]	0.00[b]	0.0212	<.0001
Docosapentaenoic acid (C22:5ω6)	0.28[a]	0.00[b]	0.00[b]	0.00[b]	0.0287	<.0001
Docosahexaenoic acid (C22:6ω3)	0.04[c]	0.60[a]	0.61[a]	0.45[b]	0.0714	<.0001
Total unsaturated fatty acids	64.27[c]	68.25[ab]	67.53[b]	70.65[a]	1.3815	0.0014

[1] : Control group
[2] :The replacer was analyzed for 52.5% dry matter, 8.4% crude protein, 1.7% crude fat, 6.3% crude fiber, 2.9% crude ash, 0.45% calcium, 0.4% total phosphate and 1800 Kcal/kg. Replacement percentage was based on ration's dry matter.
[ab] : Means with the same letter are not significantly different.
SEM : Standard error of the difference between two means.

Table 9. Composition of milk at 7 and 17 days of lactation in sows fed one of four diets from breeding till 28 days of lactation.

Treatment	Day[3]	DM[4] %	Ash %	Lipid %	Protein %	Lactose %	Energy MJ/kg
CTL[1]	7	19.45	0.80	8.15	5.34	4.87	5.16
	17	19.43	0.88	7.25	5.60	5.45	5.17
15%[2]	7	19.76	0.80	8.12	5.53	5.02	5.17
	17	19.11	0.88	7.55	5.42	5.02	5.07
30%[2]	7	19.56	0.81	8.19	5.50	4.77	5.20
	17	19.21	0.85	7.68	5.42	5.02	5.11
50%[2]	7	19.61	0.81	8.31	5.53	4.66	5.17
	17	19.29	0.86	8.21	5.17	4.81	5.08
SEM		0.042	0.003	0.019	0.027	0.019	0.015
Treatment		0.956	0.701	<0.001	0.326	<0.001	0.631
Day[3]		0.001	<0.001	<0.001	0.171	<0.001	0.025
Treatment × Day[3]		0.094	0.196	<0.001	0.003	<0.001	0.544

[1]: Control group
[2]: The replacer was analyzed for 52.5% dry matter, 8.4% crude protein, 1.7% crude fat, 6.3% crude fiber, 2.9% crude ash, 0.45% calcium, 0.4% total phosphate and 1800 Kcal/kg. Replacement percentage was based on ration's dry matter.
[3]: Days of lactation.
[4]: Dry matter
SEM: Standard error of the difference between two means

with corn silage replacer tend to have lower total USFA before farrowing but lower total SFA at weaning whereas the control sows had the opposite condition. The serum C20:1, C22:1, C24:1 and C20:4 were not detected in late pregnancy for sows fed with corn silage replacer. However, they tend to have increasing concentrations of C22:5 and C22:6 as the replacement rate increased in late pregnancy. The sow fed with higher dietary fiber was found to convert more body reserve to higher milk lipid contain. The 30% sows' dry matter replacement ration has the highest margins with extruded corn silage. This local resource is an effective approach to reduce feed cost potentially as well as to minimize carbon-foot prints of rations for pig production and increase voluntary feed intake in lactation sows.

Conflict of interest

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

ACKNOWLEDGEMENTS

This work was carried out with the support of the Laboratory of Animal Nutrition and Energy Resource Management, Animal Science Department, National Pingtung University of Science and Technology and FORMOSA FORTUNE GROUP for supporting experimental animals and having hosted this study in their facilities. We would especially like to thank Professor Sandra Edwards from School of Agriculture, Food & Rural Development, Newcastle University for providing us with a lot great deal of suggestions and enthusiasm throughout the discussion.

REFERENCES

Bindelle J, Leterme P, Buldgen A (2008). Nutritional and environmental consequences of dietary fibre in pig nutrition: a review. Biotechnol. Agron. Soc. Environ. 12(1):69-80.

Close WH, Cole DJA (2000). Nutrition of Sows and Boars. Nottingham University Press, Nottingham. UK. pp. 181-204.

Courboulay V, Gaudré D (2002). Is it necessary to give fibrous diets to group-housed sows? J. Rech. Porcine. 34:225-232.

Dourmad JY, Etienne M, Noblet J (1996). Reconstitution of body reserves in multiparous sows during pregnancy: Effect of energy intake during pregnancy and mobilization during the previous lactation. J. Anim. Sci. 74:2211-2219.

Eissen JJ, Kanis E, Kemp B (2000). Sow factors affecting voluntary feed intake during lactation. Livest. Prod. Sci. 64:147-165.

Everts H (1991). The effect of feeding different sources of crude fiber during pregnancy on the reproductive performance of sows. Anim. Prod. 52:175-184.

Farmer C, Robert S, Matte JJ (1996). Lactation performance of sows fed a bulky diet during gestation and receiving growth hormone-releasing factor during lactation. J. Anim. Sci. 74:1298-1306.

Guillemet R, Guérin C, Richard F, Dourmad JY, Meunier-Salaün MC (2010). Feed transition between gestation and lactation is exhibited earlier in sows fed a high-fiber diet during gestation. J. Anim. Sci. 88:2637-2647.

Guillemet R, Dourmad JY, Meunier-Salaün MC (2006). Feeding behavior in primiparous lactating sows: Impact of a high-fiber diet during pregnancy. J. Anim. Sci. 84:2474-2481.

Holzgraefe DP, Jensen AH, Fahey Jr GC, and Grummer RR (1986). Effects of dietary alfalfa-orchard grass hay and lasalocid on sow reproductive performance. J. Anim. Sci. 62:1145-1153.

Jensen MB, Pedersen LJ, Theil PK, Yde CC, Bach Knudsen KE (2012). Feeding motivation and plasma metabolites in pregnant sows fed diets rich in dietary fiber either once or twice daily. J. Anim. Sci. 90:1910-1919.

Le Goff G, van Milgen J, Noblet J (2002). Influence of dietary fibre on digestive utilization and rate of passage in growing pigs, finishing pigs, and adult sows. Anim. Sci. 74:503-515.

Martinez-Puig D, Pérez JF, Castillo M, Andaluz A, Anguita M, Morales J, Gasa J (2003). Consumption of raw potato starch increases colon length and fecal excretion of purine bases in growing pigs. J. Nutr. 133 (1): 134-139.

Matte JJ, Robert S, Girard C L, Farmer C, Martineau GP (1994). Effect of bulky diets based on wheat bran or oat hulls on reproductive performance of sows during their first two parities. J. Anim. Sci. 72:1754-1760.

McGlone JJ, Fullwood SD (2001). Behavior, reproduction and immunity of crated pregnant gilts: Effects of high dietary fiber and rearing environment. J. Anim. Sci. 79:1466-1474.

Meunier-Salaün MC, Edwards SA, Robert S (2001). Effect of fibre on the behaviour and health of the restricted fed sow. Anim. Feed Sci. Technol. 90:53-69.

Meunier-Salaün MC, Bolhuis JE (2015). Hiber-Fiber feeding in gestation. In: The Gestation and Lactating Sow. Chantal Farmer (Eds.), Wageningen, Netherlands: Wageningen Academic Publishers. pp. 95-116.

Noblet J, Dourmad JY, Etienne M (1990). Energy utilization in pregnant and lactating sows: Modeling of energy requirements. J. Anim. Sci. 68:562-572.

Pollmann DS, Danielson DM, Crenshaw MA, Peo Jr ER (1980). Long-term effects of dietary additions of alfalfa and tallow on sow reproductive performance. J. Anim. Sci. 51:294-299.

SAS (1989). SAS/STAT User's Guide: Version 6. 4th edn. SAS Institute Inc., Cary, NC, USA.

Serena A, Jørgensen H, Bach Knudsen KE (2009). Absorption of carbohydrate-derived nutrients in sows as influenced by types and contents of dietary fiber. J. Anim. Sci. 87:136-147.

van der Peet-Schwering CMC, Kemp B, Binnendijk GP, den Hartog LA, Spoolder HAM, Verstegen MWA (2003). Performance of sows fed high levels of non-starch polysaccharides during gestation and lactation over three parities. J. Anim. Sci. 81:2247-2258.

Vestergaard EM, Danielsen V (1998). Dietary fiber for sows: Effects of large amounts of soluble and insoluble fibers in the pregnancy period on the performance of sows during three reproductive cycles. Anim. Sci. 68:355-362.

Veum TL, Crenshaw JD, Crenshaw TD, Cromwell GL, Easter RA, Ewan RC, Nelssen JL, Miller ER, Pettigrew JE, Ellersieck MR (2009). The addition of ground wheat straw as a fiber source in the gestation diet of sows and the effect on sow and litter performance for three successive parities. J. Anim. Sci. 87:1003-1012.