Long-term performance and behavior of sows fed high levels of non-starch polysaccharides

Promotoren:	Prof. dr. ir. M. W. A. Verstegen Hoogleraar Diervoeding, Wageningen Universiteit
	Prof. dr. ir. B. Kemp Hoogleraar Adaptatiefysiologie, Wageningen Universiteit
Co-promotor:	Prof. dr. ir. L. A. den Hartog Hoogleraar Bedrijfsontwikkeling in de Veehouderij, Wageningen Universiteit

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Prof. dr. G. Janssens	Universiteit Gent, België
Dr. ir. E. D. Ekkel	Wageningen Universiteit

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Carola van der Peet-Schwering

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Abstract

The main objective of this thesis was to investigate the long-term effects of feeding sows high levels of dietary fermentable non-starch polysaccharides (NSP) (i.e., NSP from sugar beet pulp) restrictedly or ad libitum during gestation or ad libitum during lactation on behavior, reproductive performance, and development in body weight and backfat thickness. During gestation, sows were group-housed. Feeding gestating sows a high level of dietary fermentable NSP restrictedly reduced the frequency of total non-feeding oral activities in gestation compared with a starch diet. Feeding sows a high level of dietary fermentable NSP during lactation reduced the frequency of total non-feeding oral activities during subsequent gestation compared with a starch diet. Body weight and backfat gains during gestation were lower in sows fed a high level of dietary fermentable NSP restrictedly during gestation over three successive parities than in sows fed a starch diet restrictedly. These results indicate an overestimation of the energy value of fermentable NSP. Body weight and backfat losses during lactation were less in sows fed a high level of dietary fermentable NSP during gestation than in sows fed a starch diet. Sows fed a high level of dietary fermentable NSP during lactation lost more backfat during lactation than sows fed a starch diet. The number of live born piglets was 0.5 piglet higher in sows fed a high level of dietary fermentable NSP from weaning until mating and during subsequent gestation than in sows fed a starch diet. It may be that this effect can be attributed to feeding sows a high level of dietary fermentable NSP from weaning until mating. Lactation diet did not affect the number of live born piglets in the following parity. Gestating sows that were fed a high level of dietary fermentable NSP ad libitum during three successive parities ate 1.3 kg/d more during gestation than sows that were fed a starch diet restrictedly (4.2 versus 2.9 kg/d), resulting in higher body weight and backfat gains during gestation and greater losses in body weight and backfat during lactation. Feed intake during lactation was similar in sows that were fed restrictedly or ad libitum during gestation. Reproductive performance was not affected by feeding gestating sows a high level of dietary fermentable NSP ad libitum. Ad libitum fed sows spent 90 min/d eating whereas restrictedly fed sows spent 24 min/d eating. An increase in time spent eating is associated with a reduction in feeding motivation and in stereotypic behaviors. In conclusion, feeding gestating sows a high level of dietary fermentable NSP reduces the level of stereotypic behavior in gestation compared to a starch diet. Feeding sows a diet with a high level of fermentable NSP during lactation has an additional reducing effect on the development of stereotypic behavior in subsequent gestation. Reproductive performance is not negatively affected by feeding gestating sows a diet with a high level of fermentable NSP (i.e. NSP from sugar beet pulp) restrictedly or ad libitum during three successive parities compared to feeding gestating sows a starch diet restrictedly.

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Chapter 1

General introduction

Introduction

In practice, gestating sows are fed at a restricted level to maintain optimal body condition and productivity. Food restriction, however, is identified as one of the major factors associated with the development of stereotypic behavior (Terlouw et al., 1991; Spoolder et al., 1995). Stereotypies are behaviors that are relatively invariant, are repeated frequently and serve no obvious function (Ödberg, 1978). It is assumed that stereotypies are an indicator of poor welfare of animals (Broom, 1983). Brouns et al. (1994) suggested that the development of stereotypic behavior in sows is related to a combination of a lack of a sufficient amount of feed to induce satiety and to a frustration due to lack of foraging and/or feeding behavior. A high feed intake level (Terlouw et al., 1991) or offering a high fiber diet can reduce the frequency of stereotypic behavior and improve the welfare of gestating sows (Robert et al., 1993, 1997, 2002; Vestergaard, 1997; Ramonet et al., 1999). A high feed intake level or ad libitum feeding reduces feeding motivation because sows are more satiated (Bergeron et al., 2000). Ad libitum feeding with a conventional low fiber diet, however, is not a viable option because of the high feed intake capacity of sows and its concomitant obesity. High fiber diets increase feeding time and satisfy the sow's motivation for feed, without providing her with too much energy (Brouns et al., 1994; Bergeron et al., 2000). There are some indications that fermentable non-starch polysaccharides (NSP) in the diet are more involved in the feeling of satiety and in reducing stereotypic behavior than crude fiber or non fermentable NSP (Brouns et al., 1995; Vestergaard, 1997). Fermentable NSP (i.e., fermentable NSP from sugar beet pulp) changes the postprandial glucose response inducing long lasting effects on satiety (Vestergaard, 1997). Moreover, diets with a high level of fermentable NSP can limit ad libitum feed intake of gestating sows to an acceptable level (Brouns et al., 1995). It might be that stereotypic behavior during gestation can be further reduced by feeding a diet with a high level of fermentable NSP during both gestation and lactation. The effects of feeding diets with a high level of fermentable NSP during both gestation and lactation on stereotypic behavior during gestation and lactation is not known.

Reproductive performance seems unaffected when gestating sows are fed a diet with a high level of fermentable NSP restrictedly or ad libitum compared with feeding a low fiber diet restrictedly (Vestergaard and Danielsen, 1998; Whittaker et al., 2000). There are some indications of two Danish field studies (Sørensen, 1992, 1994) that litter size may be improved when sows are fed diets with a high level of fermentable NSP during both gestation and lactation. Moreover, Ferguson et al. (2003) concluded that litter size may be increased when sows are fed a diet with a high level of fermentable NSP during late lactation and prior to insemination. Information on long term consequences and carry-over effects of feeding high levels of dietary fermentable NSP restrictedly or ad libitum during gestation, during lactation or during both gestation and lactation on reproductive performance and body composition of the sows is lacking.

In high NSP diets, the starch content is generally low. Starch provides glucogenic energy. For fetal development sufficient glucose is required (Père et al., 2000). High NSP diets may provide insufficient glucogenic energy to sustain optimal growth at the end of gestation resulting in lower birth weight of the piglets and in lower liver glycogen reserves in the piglets before birth. Fetal liver glycogen is crucial for the survival of the neonates (Père, 2003). Feeding additional energy to the sow in the last month of gestation may improve birth weight of the piglets but it also may induce glucose intolerance in sows which can result in greater piglet mortality (Kemp et al., 1996).

In most of the studies with high NSP diets, gestating sows were housed individually or in very small groups. Confinement and restriction of movement seems to induce stereotypic behavior (Stolba et al., 1983). Stereotypic behavior occurs less in group-housed gestating sows than in individually housed gestating sows but is still existing (Terlouw et al., 1991; Backus et al., 1997). Moreover, the type of housing system may influence reproductive performance and body composition of sows (Backus et al., 1997). As recent European legislation makes group housing of gestating sows compulsory from 2013 onwards, we conducted our experiments with group-housed gestating sows.

Thesis outline

The currently used feed evaluation system in the Netherlands is based on fecal digestibility trials with individually housed growing pigs (CVB, 2000). However, several authors reported that fecal digestibilities of dietary energy and nutrients are higher for sows than for growing pigs especially in diets with a high level of NSP. The time required for sows to adapt to an NSP diet is not known. Therefore, we studied the adaptation in nutrient digestibility to a starch-rich diet and a diet with a high level of fermentable NSP in group-housed gestating sows during a time period of 6 weeks. The results of the digestibility trial are described in chapter 2.

In several studies, it is shown that feeding gestating sows a high level of dietary fermentable NSP reduces stereotypic behavior whereas reproductive performance seems unaffected. It might be that stereotypic behavior during gestation can be further reduced and reproductive performance can be improved (Sørensen, 1992, 1994) by feeding diets with a high level of fermentable NSP during both gestation and lactation. Therefore, the long-term effects and carry-over effects of feeding sows high levels of dietary starch or dietary fermentable NSP during gestation, during lactation or during both gestation and lactation on reproductive performance and development in stereotypic behavior were studied. In chapter 3, the effects of feeding sows a starch diet or a diet with a high level of fermentable NSP during gestation, lactation or both gestation and lactation during the first three parities on reproductive performance, body weight, backfat thickness and feed intake during gestation and lactation are described. The experiment was conducted in two group-housing systems for gestating sows: free access stalls or electronic sow feeding system. In chapter 4, the effects of feeding sows a starch diet or a diet with a high level of fermentable NSP during gestation, lactation or both gestation and lactation on the development in stereotypic behavior during the first two parities are described.

In high NSP diets, the starch content is generally low. A deficiency in glucogenic energy at the end of gestation may reduce birth weight of the piglets. It was hypothesized that in case of a shortage of glucogenic energy, feeding sows additional starch at the end of gestation may increase the birth weight of the piglets while feeding sows additional fat will not affect birth weight. Feeding sows additional energy at the end of gestation, however, may induce glucose intolerance in sows (Kemp et al., 1996). Therefore, the effect of feeding additional starch or additional fat from day 85 of gestation on litter performance and glucose tolerance was studied in sows that were fed a high NSP diet. The results of this experiment are described in chapter 5.

The objective of the last experiment was to determine the effects of feeding group-housed gestating sows a high level of dietary fermentable NSP diet ad libitum compared with feeding a conventional diet restrictedly on reproductive performance, development in body weight and backfat thickness and feed intake during gestation and lactation during three successive reproduction cycles. Also the development in individual feed intake characteristics of the gestating sows that were fed the high NSP diet ad libitum was studied during three reproduction cycles. The results of this experiment are described in chapter 6.

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Chapter 2

Adaptation to the digestion of nutrients of a starch diet or a non-starch polysaccharides diet in group-housed pregnant sows

C.M.C. van der Peet-Schwering[§], B. Kemp[†], L.A. den Hartog[‡], J.W. Schrama[†], and M.W.A. Verstegen[†]

[§] Applied Research Division of Animal Sciences Group, Wageningen UR
P.O. Box 2176, 8203 AD Lelystad, The Netherlands

[†] Wageningen Institute of Animal Sciences, Wageningen UR
P.O. Box 338, 6700 AH Wageningen, The Netherlands

[‡] Nutreco Agriculture Research and Development
P.O. Box 220, 5830 AE Boxmeer, The Netherlands

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Abstract

A trial was conducted with twenty group-housed pregnant sows to study the adaptation in nutrient digestibility to a starch rich diet or a diet with a high level of fermentable non-starch polysaccharides (NSP) during a time period of six weeks. The starch rich diet was primarily composed from wheat, peas, and tapioca, whereas soybean hulls and sugar beet pulp, which both are highly fermentable NSP-sources, were used to formulate the NSP-rich diet. The starch rich diet and the NSP-rich diet were formulated to contain different levels of starch (298 vs. 78 g/kg) and fermentable NSP (100 vs. 300 g/kg), but a similar level of net energy (NE) (8.36 MJ/kg). The trial consisted of a 1-week adaptation period followed by a 5-week collection period. Weekly apparent fecal digestibilities of dry matter (DM), crude protein (CP), crude fat, ash and NSP were measured by using the acid-insoluble ash marker method. Apparent fecal digestibilities of DM and organic matter (OM) of both diets were similar. Fecal digestibility of CP and crude fat was lower ($P < 0.001$) whereas that of NSP was higher ($P < 0.001$) for sows that received the NSP-rich diet. Calculated NE values of both diets were similar. Sows fed the NSP-rich diet produced feces that contained a lower ($P < 0.001$) DM content compared with sows that were fed the starch rich diet. The quantity of dry feces was the same on both diets, therefore total feces production (as-is basis) was higher ($P < 0.01$) for the sows fed the NSP-rich diet. During the 5-week collection period, no changes were observed in the digestibility of DM, OM, and NSP and in the NE value of the diets. Digestibilities of crude protein and fat, however, were lower in week 1 ($P < 0.05$) compared with weeks 2 to 5 for both diets. The DM content of the feces and the quantity of dry feces did not change from weeks 1 to 5. Diet by time interaction was not observed for any of the response variables indicating that sows adapt as quickly to a diet with a high level of fermentable NSP as to a starch rich diet. The present trial shows that with regard to digestibility of nutrients pregnant sows completely adapt to a NSP-rich diet (i.e., NSP from sugar beet pulp) in two weeks and that the time period necessary to adapt to a starch rich diet or a diet with a high level of fermentable NSP is similar.

Introduction

For animal welfare reasons there is a growing interest in feeding high fiber diets to pregnant sows. For example, in Dutch pig husbandry it is mandatory that sows without piglets receive a diet with at least 14% crude fiber or at least 34% non-starch polysaccharides (NSP) and that sows without piglets are group housed. Total tract digestibility coefficients of energy and nutrients decrease as NSP increase in the diet (Etienne 1987; Le Goff and Noblet 2001). Moreover, pigs may require more time to adapt to a NSP-rich diet than to a starch rich diet with regard to the digestibility of nutrients due to the time required for the micro flora and for the gastrointestinal tract itself to adapt to the new substrates and the new absorbable products (Bakker, 1996). In the trials of Le Goff and Noblet (2001) pigs were adapted to the diets for 10 days before collection of feces started. Longland et al. (1993) concluded that adaptation to NSP diets in terms of nitrogen and energy may be complete after 1 week, but 3 to 5 weeks may be necessary before stability of measurement of digestibility of NSP can be obtained in growing pigs. From studies in adult rats it is clear that adaptation to diets with supplementary NSP may be up to 4 weeks (Walter et al. 1986). We did not find studies in literature, which evaluated the time required for sows to adapt to a NSP diet.

The currently used feed evaluation system (a net energy value system) in the Netherlands is based on digestibility trials with individually housed growing pigs (CVB 2000). However, digestibility coefficients of energy and nutrients are higher for sows than for growing pigs (Shi and Noblet 1993; Le Goff and Noblet 2001). The difference in digestibility of nutrients between sows and growing pigs increases with increasing NSP content (Le Goff and Noblet 2001). As a consequence energy value for growing pigs and sows will be different. Moreover, Bakker (1996) concluded that, due to a decreased retention time of digesta in the gut, apparent fecal digestibilities are lower in group housed growing pigs than in individually housed growing pigs especially when pigs receive a high fiber diet. It seems logical that this also applies to sows. Therefore, the objective of this trial was to determine the adaptation in nutrient digestibility to a starch rich diet or diet with a high level of fermentable NSP and its possible consequences for the energy value of both diets in group-housed pregnant sows in a time period of six weeks.

Materials and methods

Animals and housing

Twenty (eleven parity 1 and nine parity 2) mid-pregnant rotational-bred sows were used. The rotational-bred sows involved three breeds: Dutch Landrace, Finnish Landrace and Dutch Large White. The trial consisted of a 1-week adaptation period followed by a 5-week collection period. Based on body weight, parity number and genotype, the sows were randomly assigned to one of the two experimental diets. At the start of the adaptation period sows weighed on average 153.5 kg (SEM = 6.9). Sows were housed in free access stalls in two groups of ten animals each. The two experimental diets were randomly assigned to the groups. During feeding sows were locked up in a box for one hour so they could be fed individually. Boxes in the free access stalls were 2.30 x 0.63 m and had partly slatted floors that consisted of 2.00-m concrete solid floor and 0.30-m concrete slatted floor. The communal area per group of 10 sows was 3.25 x 3.15 m. Stalls were equipped with computer-controlled heating and mechanical ventilation systems. Environmental temperature in the stalls was on average 20^0 C.

Feeding

Two experimental diets (Table 1) differing in the level of starch and fermentable NSP were formulated. The starch rich and NSP-rich diets were formulated to contain 298 and 78 g/kg starch and 100 and 300 g/kg fermentable NSP, respectively. The level of other nutrients such as fecal digestible crude protein (CP) (85 g/kg), fecal digestible crude fat (39 g/kg), non-fermentable NSP (200 g/kg), ileal digestible lysine (4.4 g/kg) and net energy (8.36 MJ/kg) were formulated to be the same in both diets. The starch rich diet was primarily composed of wheat, peas and tapioca, whereas NSP in the NSP-rich diet was derived from dried sugar beet pulp and soybean hulls. Dried sugar beet pulp and soybean hulls both have a high level of fermentable NSP. To comply with the Dutch law that says that pregnant sows should receive 14% crude fiber in their diet, 13.9 and 10.9% straw was added to the starch rich and the NSP-rich diet, respectively. Straw has a high level of crude fiber but a low level of fermentable NSP. Before the start of the trial all sows were fed the same commercial diet. The level of CP, crude fat, crude fiber, fermentable NSP and net energy in this commercial diet were 135 g/kg, 66 g/kg, 111 g/kg, 200 g/kg and 8.96 MJ/kg, respectively. Sows were fed twice a day at 08.00 h and at 15.00-h. Feeding level was 2.9 kg of feed per day. Diets were given as pellets. Feed refusals were collected 45 min after feeding in order to record daily feed intake. Sows were given free access to drinking water.

Table 1. Composition of experimental diets (as-fed basis)

Item	Starch rich diet	NSP-rich diet
Ingredients, g/kg		
Wheat	112.0	31.0
Peas	100.0	-
Tapioca	270.0	69.0
Soybeans, extracted	10.0	38.0
Soybean hulls	-	55.0
Sunflower seed, extracted	177.0	177.0
Sugar beet pulp	-	378.0
Lucerne	74.0	33.0
Molasses, cane	42.5	39.5
Straw	139.0	109.0
Fat	39.5	42.0
Limestone	4.8	-
Monocalcium phosphate	5.3	4.1
Salt	3.7	2.6
Phytase	0.2	0.5
Premix[a]	4.9	4.9
Lysine-50%	1.7	1.0
Threonine-10%	0.4	0.4
Diamol[b]	15.0	15.0
Chemical analysis, g/kg		
Dry matter	889	891
Crude protein	128	137
Crude fat	54	56
Starch	298	109
Sugar	44	72
Non-starch polysaccharides[c]	283	435
Ash	82	82
Crude fibre[d]	140	186

[a] Provided the following nutrients per kg of experimental diet: vitamin A, 7,000 IU; vitamin D3, 1,400 IU; vitamin E, 17 mg; riboflavin, 4 mg; niacinamide, 18 mg; d-panthothenic acid, 7 mg; choline chloride, 250 mg; vitamin B12, 15 mcg; folic acid, 2.4 mg; biotin, 0.1 mg; cobalt, 0.25 mg (as $CoSO_4.7H_2O$); copper,10 mg (as $CuSO_4.5H_2O$); manganese, 24 mg (as MnO_2); iron, 80 mg (as $FeSO_4.7H_2O$); zinc, 54 mg (as $ZnSO_4$); iodine, 0.4 mg (as KI); selenium, 0.15 mg (as $Na_2SeO_3.5H_2O$)
[b] Diamol is diatomaceous shell powder (HCl insoluble ash, apparent digestibility marker)
[c] Non-starch polysaccharide content was calculated as dry matter content minus ash, crude protein, crude fat, starch and sugar content
[d] Calculated content

Measurements

Individual body weight of the sows was measured at the start and at the end of the trial. Apparent fecal digestibilities of dry matter (DM), CP, crude fat and ash were measured by using the acid-insoluble ash (AIA) marker method. To increase dietary AIA level 1.5% Diamol was added to the experimental diets. During the 1-week adaptation period sows received the experimental diets but feed and feces were not sampled. During the following 5-week collection period, experimental diets were sampled daily. The daily samples were pooled per week. Fresh feces were collected daily from each sow from Monday till Thursday in the communal area after each feeding and were stored at –18 ^{0}C. Feces collected per sow were pooled per week.

Feed and feces were analyzed weekly for DM, ash, CP, crude fat and AIA. Feed was also analyzed for starch and sugars. DM and CP were determined in fresh feces. Ash, crude fat and AIA were determined in air-dried feces. Starch and sugars were assumed to be 100% digestible at fecal level (Le Goff and Noblet 2001; Rijnen et al. 2001). All samples were analyzed in duplicate.

DM, ash, nitrogen (N), crude fat and AIA content were determined according to standard methods ISO 6496 (ISO 1999b), ISO 5984 (ISO 1978a), ISO 5983 (ISO 1979), ISO 6492 procedure B (ISO 1999a) and ISO 5985 (ISO 1978b), respectively. CP content was calculated as N x 6.25. Starch content was analyzed enzymatically as described by Brunt (2000) and sugar content was analyzed by the method of Luff Schoorl (EG 1971). Organic matter (OM) content was calculated as DM minus ash. Dietary NSP was calculated as dietary DM minus dietary ash, CP, crude fat, starch and sugars. Fecal NSP was calculated as fecal DM minus faecal ash, CP and crude fat.

Calculations

Based on the apparent fecal digestibilities measured in this experiment and based on estimated net energy values of digestible nutrients (CVB 2000), the net energy (NE) value of the experimental diets was calculated according to CVB (2000). However, the estimated NE value of fermentable NSP was assumed to be similar to that of digested starch (13.5 MJ/kg) based on the results of Rijnen et al. (2001). They showed that group-housed sows are capable of using energy from fermentable NSP as efficiently as energy from digested starch.

NSP-diets may increase the feces production, therefore the feces production on DM basis and on as-is basis were calculated as follows:

Feces production (DM basis) (kg/d) = DM intake (kg/d) x (100 – DC_{DM}) / 100 (1)

Feces production (as-is basis) (kg/d) = feces production (DM basis) (kg/d) / DM content in the feces (kg/kg) (2)

where DC_{DM} = apparent fecal digestibility coefficient of DM (%).

Statistical analyses

Apparent fecal digestibility coefficients per week of DM, OM, CP, crude fat and NSP as well as NE values per week and feces production per week were analyzed for the effect of diet and time (week) with the GLM procedures of SAS (1994) by means of *F*-tests using a split-plot model, with weekly values within sows taken as repeated measurements:

$$Y_{ijk} = \mu + diet_i + e_{1,ij} + week_k + (diet \times week)_{ik} + e_{2,ijk} \qquad (3)$$

where Y_{ijk} = dependent variable; μ = overall mean; $diet_i$ = fixed effect of diet i (i = 2); $e_{1,ij}$ = error term 1, representing the random effect of sow j within diet i; $week_k$ = fixed effect of week k (k = 1, 2, 3, 4, 5); $e_{2,ijk}$ = error term 2, representing the random effect within sows between weeks. The effect of diet was tested against error term 1. The effect of week and the interaction between diet and week were tested against error term 2.

Results

General

All sows completed the trial. Bodyweight gains from the start of the 1-week adaptation period to the end of the 5-week collection period were 30.9 and 34.7 kg (SEM = 1.8) in sows that were fed the starch rich diet and the NSP-rich diet, respectively. In week 5 of the collection period one sow that received the starch rich diet refused 0.06 kg of her feed on one day. One sow that received the NSP-rich diet refused on average 0.40, 0.42, 0.26 and 0.13 kg of feed per day in week 1, 2, 3 and 4 of the collection period, respectively.

Apparent fecal digestibility coefficients and NE

Diet by time interaction was not observed for any of the response variables. The mean apparent fecal digestibility coefficients of DM and OM were not affected by experimental diet ($P > 0.1$; Table 2). The mean apparent fecal digestibility coefficients of CP and crude fat were lower ($P < 0.001$ and $P < 0.001$, respectively) whereas that of NSP was higher ($P < 0.001$) for sows fed the NSP-rich diet compared with sows fed the starch diet. The calculated NE-value was not affected by experimental diet. The mean apparent fecal digestibility coefficients of DM, OM and NSP did not change with time during the 5-week collection period ($P > 0.1$; Table 2). The mean apparent fecal digestibility coefficient of CP was lower in week 1 of the collection period ($P < 0.05$) whereas it was similar from weeks 2 to 5. The mean apparent fecal digestibility coefficient of crude fat was lower in week 1 as well as in week 4 of the collection period ($P < 0.05$) whereas it was equal in weeks 2, 3 and 5 of the collection period. NE-value was numerically lower in week 1 of the collection period ($P = 0.07$) but it was not affected by time from weeks 2 to 5.

Table 2. Mean apparent fecal digestibility coefficients and mean net energy value (NE) for group-housed pregnant sows as affected by experimental diet and week of collection period

	Experimental diet			Week of collection period					
	Starch rich diet	NSP-rich diet	SEM	1	2	3	4	5	SEM
Digestibility coefficients									
Dry matter, %	68.6	68.8	0.16	68.2	68.9	69.0	68.6	68.9	0.25
Organic matter, %	72.5	72.8	0.16	72.1	72.8	73.0	72.6	72.8	0.26
Crude protein, %	70.9[a]	66.1[b]	0.21	67.4[e]	68.8[f]	68.9[f]	68.6[f]	68.5[f]	0.33
Crude fat, %	77.5[a]	73.8[b]	0.24	74.7[e]	76.4[f]	76.2[f]	74.8[e]	76.0[f]	0.38
NSP, %[1]	39.1[a]	63.5[b]	0.32	50.5	51.5	51.7	51.2	51.5	0.51
NE, MJ/kg	8.55	8.56	0.02	8.49	8.58	8.59	8.53	8.58	0.03

[1] Non-starch polysaccharide content was calculated as dry matter content minus ash, crude protein, crude fat, starch and sugar content assuming an apparent digestibility coefficient of 100% for starch and sugar.

[a,b] Means within a row and within a main treatment comparison with different superscript are significantly different: $P < 0.001$

[e,f] Means within a row and within a main treatment comparison with different superscript are significantly different: $P < 0.05$

Table 3. Mean dry matter content in the feces and mean daily feces production for group-housed pregnant sows as affected by experimental diet and week of collection period

	Experimental diet			Week of collection period					
	Starch rich diet	NSP-rich diet	SEM	1	2	3	4	5	SEM
DM content in feces, %	30.9^{a}	26.7^{b}	1.04	28.6	28.9	29.1	28.7	28.7	1.65
Feces production, kg DM	0.810	0.806	0.004	0.821	0.803	0.800	0.810	0.804	0.007
Feces production, kg	2.639^{e}	3.028^{f}	0.019	2.904^{x}	2.810^{y}	2.776^{y}	2.851^{xy}	2.828^{xy}	0.030

^{a,b} Means within a row and within a main treatment comparison with different superscript are significantly different: $P < 0.001$

^{e,,f} Means within a row and within a main treatment comparison with different superscript are significantly different: $P < 0.01$

^{x,y} Means within a row and within a main treatment comparison with different superscript are significantly different: $P < 0.05$

Feces production

The DM content in the feces was lower for sows that received the NSP-rich diet ($P < 0.001$; Table 3). The feces production on DM basis was not affected by experimental diet whereas the feces production on as-is basis was higher for sows that received the NSP-rich diet ($P < 0.01$). The DM content in the feces and the feces production on DM basis did not change with time during the 5-week collection period (Table 3). The feces production on as-is basis was higher in week 1 of the collection period than in weeks 2 and 3 ($P < 0.05$). The feces production in weeks 4 and 5 was in between.

Discussion

A high level of NSP (44%) in the diet for pregnant sows did not affect the apparent fecal digestibility of DM and OM in this study compared to a level of 28% NSP. These results are in contrast to previous studies where the addition of alfalfa meal, straw, or oat hulls to the diet for sows reduced the digestibility of DM and OM (Etienne 1987). However, in our study highly fermentable NSP sources were used whereas in the study of Etienne (1987) poorly fermentable NSP sources were used.

The addition of NSP to the diet reduced the digestibility of CP and crude fat, which is consistent with results of Etienne (1987) and Rijnen et al. (2001). The decrease in digestibility of CP is mainly due to higher endogenous losses (Le Goff and Noblet, 2001). The decrease in fat digestibility can be explained by endogenous secretions and (or) a greater bacterial fat synthesis in the hindgut (Le Goff and Noblet, 2001). The measured digestibility coefficients are in line with the digestibility coefficients calculated in advance on basis of feedstuff tables (CVB 2000). The digestibilities calculated in advance of both CP and crude fat of the starch rich diet and NSP-rich diet were 70.8 and 65.4%, and 78.0 and 73.6%, respectively. Thus, the calculated digestibilities based on digestibility experiments with individually housed growing pigs are very similar to the measured values in group-housed pregnant sows in this trial.

Although the apparent fecal digestibility of fibrous components can be reduced by NSP addition to the diet (Etienne 1987), we observed that the apparent digestibility of NSP was 24 percentage units higher in the NSP-rich diet compared to the starch rich diet. Rijnen et al. (2001) also reported an increase in the digestibility of NSP with increasing levels (0 to 300 g/kg) of sugar beet pulp in the diet of sows. Kornegay (1981) observed an increase in the digestibility of acid detergent fiber and hemicellulose when the level of soybean hulls in the diet of pregnant sows was increased from

0 to 300 g/kg. In our study, soybean hulls (56 g/kg) and sugar beet pulp (382 g/kg) were used to formulate the NSP-rich diet. These ingredients contain a high level of pectin or water-soluble fiber and are therefore more digestible than ingredients that contain a high level of lignin or water-insoluble fiber (Noblet and Le Goff 2001). Thus, the botanical origin of dietary fiber is an important factor influencing the effect of fiber on NSP digestibility.

The measured digestibility coefficients of NSP of the starch rich and the NSP-rich diet were 5.8 and 3.5% percentage units higher than those calculated in advance on basis of feedstuff tables (CVB 2000). Therefore, for both diets the calculated NE value based on the measured digestibilities was slightly higher than that based on digestibility coefficients in feedstuff tables (8.55 vs. 8.36 MJ/kg for both diets).

The sows completely adapted to the experimental diets within two weeks. For both diets, the digestibility coefficients of CP and crude fat and the calculated net energy values increased slightly from week 1 to week 2 of the collection period whereas the digestibility coefficients of DM, OM and NSP were stable from week 1 onwards. The period in which the gastrointestinal processes in growing pigs are completely adapted to a new diet is usually longer for a high fiber diet than for a low fiber diet (Bakker, 1996), but this was not confirmed in our research. The time necessary for the sows to adapt to either the starch rich diet or the diet with a high level of fermentable NSP was similar. The relatively short adaptation period for the NSP-rich diet is in agreement with the results of Longland et al. (1993). They evaluated sugar beet pulp in 25 to 45 kg pigs that were fed cereal-based diets containing 139, or 244 g/kg sugar beet pulp. They concluded that adaptation to the sugar beet pulp diets in terms of digestibility of nitrogen and NSP may be complete after 7 d. Consistent with our finding, Longland et al. (1994) observed that adaptation to NSP-rich diets in terms of nitrogen digestibility required a longer time period than adaptation in terms of NSP digestibility. The results of Longland et al. (1993, 1994) and our results suggest that in terms of digestibility pigs adapt very quickly to NSP-rich diets that contain high levels of sugar beet pulp. To our knowledge there are no studies in published literature, that evaluated the time required for sows to adapt to NSP-rich diets that contain fibrous ingredients other than sugar beet pulp.

The lower DM content in the feces from sows fed the NSP-rich diet is in agreement with results of Low (1985) and Etienne (1987). According to Bertin et al. (1988) sugar beet pulp has a high water holding capacity. This effect is presumably still present in the large intestine and is responsible for the lower DM content in the feces. The feces production (DM basis) was similar for both diets. This is not surprising considering the minor differences observed between the diets in DM digestibility and considering the same daily feed intake of the sows on both diets. Total feces production (as-is basis) was higher for the sows that received the NPS-rich diet, because the feces of the sows on these diets contained more water. Lee and Close (1987) reported that feeding high fiber diets to pigs, results in more feces containing a higher DM content. They stated that this might be a problem in manure management systems designed to handle liquid manure. While this may be true for many highly indigestible sources of NSP, it appears much less of an issue for the NSP-rich diet used in our study.

Sow reproductive performance seems to be improved when NSP-rich diets are fed during gestation (Reese 1997). However, as shown clearly by Matte et al. (1994) there is a risk when the digestibility and metabolic availability of nutrients from NSP-rich dietary ingredients are not well known. In that case they reported severe consequences for sow reproductive performance. We established that the calculated NE- value of the NSP-rich diet we formulated is similar to that of the starch-rich diet. Future investigations on the effect of this NSP-rich diet on sow performance can be carried out while avoiding confounding effects of energy intake.

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Chapter 3

Performance of sows fed high levels of non-starch polysaccharides during gestation and lactation over three parities

C. M. C. van der Peet-Schwering[§], B. Kemp[†], G. P. Binnendijk[§], L. A. den Hartog[‡], H. A. M. Spoolder[§], and M. W. A. Verstegen[†]

[§] Applied Research Division of the Animal Sciences Group, Wageningen UR
P.O. Box 2176, 8203 AD Lelystad, The Netherlands

[†] Wageningen Institute of Animal Sciences, Wageningen UR
P.O. Box 338, 6700 AH Wageningen, The Netherlands

[‡] Nutreco Agriculture Research and Development
P.O. Box 220, 5830 AE Boxmeer, The Netherlands

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Abstract

The effect of feeding sows a starch diet or a diet with a high level of non-starch polysaccharides (NSP) during gestation, lactation or both gestation and lactation during the first three parities on reproductive performance, body weight and backfat was studied. Fourhundred and forty-four postpuberal gilts were allotted to a 2 x 2 x 2 factorial experiment. Treatments were diet composition during gestation (including weaning-to-estrus interval) (**G-Starch**: 274 g/kg of starch and 123 g/kg of fermentable NSP or **G-NSP**: 86 g/kg of starch and 300 g/kg of fermentable NSP), diet composition during lactation (**L-Starch**: 293 g/kg of starch and 113 g/kg of fermentable NSP or **L-NSP**: 189 g/kg of starch and 216 g/kg of fermentable NSP) and group-housing system during gestation (free access stalls or electronic feeding). Both gestation diets were formulated to be isoenergetic. During lactation, sows were given free access to the lactation diets from d 6 after parturition onwards. Body weight and backfat gains during gestation were lower in sows fed the G-NSP diet than in those fed the G-starch diet ($P < 0.001$). The effects were more pronounced in the electronic feeding system than in the free access stalls. These results indicate an overestimation of the energy value of fermentable NSP. Body weight and backfat losses during lactation were less in sows fed the G-NSP diet during gestation than in those fed the G-starch diet ($P < 0.05$). This can be explained by a 0.4 kg/d higher ($P < 0.001$) feed intake during lactation of the sows fed the G-NSP diet. Sows fed the L-NSP diet lost more backfat during lactation than sows fed the L-starch diet ($P < 0.05$). The number of total piglets born and live born piglets was 0.5 piglet higher in sows fed the G-NSP diet than in those fed the G-starch diet ($P < 0.05$). Lactation diet did not affect the number of total piglets born or live born piglets. This study shows that, although high NSP diets negatively influence BW and backfat thickness of the sows, it is possible to feed sows a diet with a high level of fermentable NSP diet during both gestation and lactation without negative effects on reproductive performance. Under the conditions of this study, feeding sows a diet with a high level of fermentable NSP during gestation and a high level of starch during lactation seems the most favorable feeding strategy.

Introduction

Gestating sows are restricted in feed intake to maintain optimal body composition and productivity. Food restriction, however, is identified as one of the major factors associated with the development of stereotypic behavior in sows (Terlouw et al., 1991). High levels of fermentable non-starch polysaccharides (NSP) in diets for gestating sows reduce stereotypic behavior due to reduced hunger (Vestergaard, 1997). Reproductive performance seems unaffected when gestating sows are fed a diet with a high level of fermentable NSP (Vestergaard and Danielsen, 1998). However, there are some indications from two Danish field studies (Sørensen, 1992, 1994) that reproductive performance (in terms of subsequent litter size) may be improved when sows are fed diets with a high level of fermentable NSP during both gestation and lactation. Information on the long-term effects and carry-over effects of feeding high levels of dietary fermentable NSP during gestation, during lactation or during both gestation and lactation on reproductive performance and body composition of the sows is lacking. Group housing of gestating sows in countries within the European Community will be compulsory in the future. The type of group-housing system may influence reproductive performance and body composition of sows (Backus et al., 1997).

Therefore, this experiment was conducted to determine the effects on reproductive performance, body weight and backfat thickness in sows that are fed a starch diet or a diet high in fermentable NSP during gestation, lactation or both gestation and lactation during the first three parities. The experiment was conducted in two group-housing systems for gestating sows: free access stalls or electronic feeding.

Materials and Methods

Animals and Experimental Design

During a 15-month period, 444 (21 batches of 20 and 1 batch of 24) rotational-bred postpuberal gilts (involving the breeds: Dutch Landrace, Finnish Landrace and Dutch Large White) with an average age of 218 d (SD = 6.1) were allotted to a 2 x 2 x 2 factorial experiment. Treatments were diet composition during gestation (including weaning-to-estrus interval) (**G-Starch**: 274 g/kg of starch and 123 g/kg of fermentable NSP or **G-NSP**: 86 g/kg of starch and 300 g/kg of fermentable NSP), diet composition during lactation (including 10 days prior to parturition) (**L-Starch**: 293 g/kg of starch and 113 g/kg of fermentable NSP or **L-NSP**: 189 g/kg of starch and 216 g/kg of fermentable NSP) and group-housing system during gestation (free access stalls or electronic feeding). Within each batch, gilts were blocked by body weight, backfat thickness and genotype and allotted to one of the eight experimental treatments. Gilts were followed over three parities. The same treatment was applied over the successive parities. At the first estrus after assignment to the treatments, gilts were inseminated with a commercial dose of semen (3 x 10^9 sperm cells) of a Dutch Large White boar. Estrus was checked twice a day in the presence of a mature boar, using the back pressure test. Gilts and sows that showed estrus were inseminated each day of standing estrus. Gilts that did not show estrus within three weeks after assignment to the experiment and sows that did not show estrus within three weeks after weaning were treated with PG600 (200 IU HCG and 400 IU PMSG, Intervet BV, Boxmeer, The Netherlands) to induce estrus. Gilts and sows that returned to estrus after first insemination were rebred. The care and treatment of the sows were according to Dutch animal welfare legislation. The Institutional Animal Care and Use Committee of the Wageningen University approved all experimental protocols.

Diets

The pelleted diets for the gestating sows (Table 1) differed mainly in starch and fermentable NSP content. To feed the gestating sows iso-energetic, a digestibility trial was conducted with both gestation diets (Van der Peet-Schwering et al., 2002). The level of fecal digestible CP, fecal digestible crude fat, non-fermentable NSP and NE in the starch and NSP gestation diets were 93 and 90 g/kg, 42 and 40 g/kg, 191 and 172 g/kg, and 8.52 and 8.59 MJ/kg, respectively. Net energy of the diets was calculated according to CVB (2000). However, based on the results of Rijnen et al. (2001) the estimated net energy value of fermentable NSP was assumed to be similar to that of digested starch (13.5 MJ/kg). Starch in the starch diet was primarily derived from wheat, peas and tapioca, whereas NSP in the NSP diet was derived from dried sugar beet pulp and soybean hulls, both of which are highly fermentable NSP sources. To comply with the Dutch law (National Reference Center, 1998) that says that gestating sows should receive 14% crude fiber in their diet, 14.1% and 11.1% straw was added to the starch diet and the NSP diet, respectively. Straw has a high level of crude fiber but a low level of fermentable NSP. The pelleted diets for the lactating sows (Table 1) also differed mainly in starch and fermentable NSP content. The level of fecal digestible CP (120 g/kg), fecal digestible crude fat (48 g/kg), non-fermentable NSP (120 g/kg) and NE (9.42 MJ/kg) were formulated to be the same in both diets (CVB, 2000). The net energy value of fermentable NSP was assumed to be similar to that of digested starch. Starch in the starch diet was primarily derived from tapioca, whereas NSP in the NSP diet was derived from dried sugar beet pulp.

Table 1. Composition of experimental diets (as-fed basis)

	Gestation diet		Lactation diet	
Item	G-Starch	G-NSP	L-Starch	L-NSP
Ingredient, g/kg				
Wheat	114.0	32.0	-	-
Peas	102.0	-	105.0	129.0
Tapioca	274.0	70.0	367.0	168.0
Soybean meal (extracted)	10.0	38.0	97.0	81.0
Soybean hulls	-	56.0	-	-
Sunflower meal (extracted)	180.0	180.0	185.0	150.0
Wheat middlings	-	-	80.0	100.0
Sugar beet pulp	-	383.0	-	206.0
Lucerne	75.0	34.0	50.0	50.0
Molasses, cane	43.0	40.0	40.0	42.0
Straw	141.0	111.0	-	-
Fat	40.0	42.5	47.5	47.7
Limestone	4.7	-	10.0	7.9
Monocalcium phosphate	5.2	4.0	6.2	6.9
Salt	3.8	2.6	4.3	3.7
Phytase	0.2	0.5	0.5	0.4
Lysine-50%[a]	1.7	1.0	2.2	1.9
Threonine-10%[a]	0.4	0.4	0.3	0.5
Premix[b]	5.0	5.0	5.0	5.0
Analyzed content, g/kg				
Crude protein	132	136	161	164
Crude fat	54	54	59	60
Starch	274	86	293	189
Sugar	52	79	56	68
Non-starch polysaccharides[c]	314	472	250	340
Fermentable NSP[d]	123	300	113	216
Ash	73	77	75	75
NE (MJ/kg)[d]	8.52	8.59	9.42	9.42
Ileal digestible lysine[e]	4.4	4.4	7.1	7.1

[a] Lysine and threonine are mixed with maize as a carrier at a ratio of 1:1 and 1:9, respectively.

[b] Provided the following nutrients per kg of experimental diet: vitamin A, 7,000 IU; vitamin D3, 1,400 IU; vitamin E, 17 mg; riboflavin, 4 mg; niacinamide, 18 mg; d-panthothenic acid, 7 mg; choline chloride, 250 mg; vitamin B12, 15 ug; folic acid, 2.4 mg; biotin, 0.1 mg; cobalt, 0.25 mg (as $CoSO_4.7H_2O$); copper,10 mg (as $CuSO_4.5H_2O$); manganese, 24 mg (as MnO_2); iron, 80 mg (as $FeSO_4.7H_2O$); zinc, 54 mg (as $ZnSO_4$); iodine, 0.4 mg (as KI); selenium, 0.15 mg (as $Na_2SeO_3.5H_2O$) for the gestation diets.

[c] Non-starch polysaccharide (NSP) content was calculated as dry matter content minus ash, crude protein, crude fat, starch and sugar content.

[d] The level of fermentable NSP and NE in the gestation diets was calculated using the digestibility coefficients as measured in the trial of Van der Peet-Schwering et al. (2002). The level of fermentable NSP and NE in the lactation diets was calculated using digestibility coefficients as published in the Dutch feedstuff table (CVB, 2000).

[e] Calculated content.

Housing

From weaning until 105 d of gestation, sows were kept together in stable groups (no sows were added to the group) either in free access stalls in groups of 12 sows each or in the electronic feeding system in groups of 25 sows each. Non-experimental sows were used to maintain group size at either 12 or 25 sows. At mealtime in free access stalls, sows were confined in a feeding stall for 30 min so they could be fed individually. The feeding stalls were 2.30 x 0.63 m and had partly slatted floors that consisted of 2.00-m concrete solid floor and 0.30-m concrete slatted floor. The communal area per group of 12 sows was 3.25 x 3.78 m and was situated between two rows of six feeding stalls each. The communal area had a partly slatted floor. In the electronic feeding system, pens were 7.5 x 8.0 m (7.5 x 4.8-m concrete solid floor and 7.5 x 3.2-m concrete slatted floor). Sows were fed in a feeding station (Insentec B.V., Marknesse, The Netherlands). To identify the individual animals, each sow had an electronic ear transponder. Access to the feeding station was only possible if a sow had not consumed her daily ration.

Approximately 10 d before the expected time of parturition, irrespective of housing system during gestation, sows were moved to farrowing rooms each having six pens of 2.20 x 1.80 m. The concrete solid floor (1.00 x 1.80 m) was equipped with floor heating. Cross fostering of piglets took place within 3 days after parturition and occurred only among sows of the same experimental treatment. Piglets were weaned at an average age of 27.8 days (SD = 4.0). On the day of weaning, sows were moved to sow gestation rooms. All rooms were equipped with computer-controlled heating and mechanical ventilation systems.

Feeding

Gestating sows housed in free access stalls were fed the gestation diets twice a day (0800 and 1500). In the electronic feeding system, the feeding cycle started at 2300. Sows were free to consume their daily ration all at once or to divide it in more portions. Daily amount of both diets increased during gestation (d 0 to 60: 2.5 kg/d; d 60 to 85: 2.9 kg/d; d 85 to day of transfer to farrowing room: 3.4 kg/d). Gestating sows of parity 1, 2 and 3 were all fed the same daily amount of feed. Feeding levels were not adjusted for body condition of sows at weaning. In the farrowing room, sows were fed the lactation diets at 3.4 kg/d prior to parturition. During lactation, sows were fed on an ascending scale from parturition until d 6 after parturition and were given free access to the lactation diets from d 6 after parturition onwards. On the day of weaning, sows were fed 0.75 kg of the lactation diet in the farrowing room at 0800 and 1.25 kg of the gestation diet in the room for gestating sows at 1500. During the weaning-to-estrus interval (WEI) sows were fed the gestation diets at a level of 2.5 kg/d. All feeds were given as dry feed. All sows were given free access to drinking water. Piglets were given free access to a commercial creep feed from d 11 after birth until weaning.

Measurements

Feed. During the two-year experiment, experimental diets were sampled weekly. The weekly samples were pooled per 2 mo. Feed was analyzed every 2 mo for DM, ash, CP, crude fat, starch and sugars. All samples were analyzed in duplicate. DM, ash, CP and crude fat content were analyzed according to standard methods ISO 6496 (ISO, 1999b), ISO 5984 (ISO, 1978), ISO 5983 (ISO, 1979) and ISO 6492 procedure B (ISO, 1999a), respectively. The starch content was analyzed enzymatically as described by Brunt (2000). The sugar content was analyzed by the method of Luff Schoorl (EG, 1971). Dietary NSP was calculated as dietary DM minus dietary ash, CP, crude fat, starch and sugars.

Culling. During the experiment, culling of sows was recorded. Sows were culled for the following reasons: severe lameness, endometritis, illness and reproductive failure like return to estrus for the third time in one parity, not showing estrus after two treatments with PG600, and loosing piglets in the last month of gestation.

Body weight and backfat thickness. Individual BW and backfat thickness of the sows was measured at the start of the trial, at the day of transfer to the farrowing room, at d 112 of gestation and at weaning in all three parities. Backfat thickness was measured ultrasonically at three points 5 cm left of the median as described in Vesseur et al. (1997).

Reproductive performance. Number of total piglets born (= live born piglets + stillborn piglets + mummies) was recorded within 16 h after parturition. Number of weaned piglets was recorded at weaning. Individual weights of live piglets were obtained at parturition, after cross fostering and at weaning. Weaning-to-estrus interval, number of sows that returned to estrus after first insemination and farrowing rate after 1st and 2nd insemination were recorded for sows in all three parities.

Feed intake. Feed intake of the sows was recorded during the following periods: from weaning until mating, from mating until the day of transfer to the farrowing stall, the days before parturition in the farrowing stall, and during wk 1, 2, 3 and 4 of the lactation period, respectively.

Statistical analysis

All response variables were analyzed for the fixed effects of diet composition during gestation, diet composition during lactation, group-housing system during gestation, genotype and batch. Non-significant interactions were omitted from the model. Body weight and backfat thickness of the sows, changes in BW and backfat thickness, number of total piglets born, piglets birth weight, piglets weaning weight, piglets daily gain, WEI, feed intake during gestation and feed intake during lactation were analyzed by means of *F*-tests using generalized linear models. Weaning-to-estrus interval was log transformed prior to analysis to stabilize the variance. Live born piglets, stillborn piglets and weaned piglets were analyzed by means of *F*-tests using logistic regression (McCullagh and Nelder, 1989). Live born and stillborn piglets were expressed as a fraction of total piglets born. Weaned piglets were expressed as a fraction of live born piglets after fostering. The percentage of sows that returned to estrus after first insemination, and farrowing rate after first and second insemination were analyzed by means of chi-square tests using logistic regression for binomial distributed data. Response variables with repeated measurements, such as weekly feed intake during lactation, were analyzed by using a split-plot model. Sow was the main plot and sow within week was the residual error. The random effect of sow and the fixed effect of week were added to the model. The random sow effect was considered to be normally distributed with mean 0 and variance equal to σ^2_{sow}. Estimates of fixed effects in the model and components of variance were obtained using the Residual Maximum Likelihood (REML) procedure. Fixed effects were assessed using chi-squares for the Wald statistics. Pairwise differences between treatment means were tested using a *t*-test. All analyses were performed using the statistical program GenStat (2000). Some response variables were affected ($P < 0.05$) by batch and genotype. There was no interaction of batch and genotype with treatments therefore, the effects of batch and genotype are not presented.

Results

General

Out of the 444 postpuberal gilts assigned to the study, 29 gilts did not come into estrus and another 24 gilts were culled before first parturition (Table 2). Eleven parity 1 sows were culled at weaning, 16 sows did not come in estrus after weaning, and 17 sows were culled before second parturition. Eleven parity 2 sows were culled at weaning, eight sows did not become in estrus, and nine sows were culled before third parturition. Another 123 sows could not have a third litter for practical reasons and were therefore removed from the experiment. During gestation, sows were culled because of lameness or reproductive failure. At weaning, sows were culled because of lameness or endometritis. Dietary treatments during both gestation and lactation and housing system during gestation did not influence the number of culled sows at any moment.

Table 2. Main effects of dietary treatment during gestation and lactation and housing system during gestation on sows on trial

	Gestation diet		Lactation diet		Housing system during gestation	
	G-starch	G-NSP	L-starch	L-NSP	Free access stalls	Electronic feeding
No. of gilts assigned to exp.	223	221	220	224	230	214
Sows on trial, no.						
Parity 1						
At mating	208	207	202	213	209	206
At parturition	196	195	191	200	198	193
Parity 2						
At mating	181	183	180	184	183	181
At parturition	171	176	170	177	175	172
Parity 3						
At mating[a]	112	93	102	103	107	98
At parturition	106	90	97	99	98	98

[a] The first 65% of the sows that had a second litter were followed for their third parity. The other 35% of the parity 2 sows were removed from the experiment because the facilities could not be used anymore.

Performance during gestation

In parity 1, daily feed intake from onset until the day of transfer to the farrowing room was lower in sows fed the G-NSP diet than in those fed the G-starch diet (*P* < 0.05; Table 3). Besides, it was lower in sows housed in the electronic feeding system than in those housed in free access stalls (*P* < 0.001 and *P* < 0.01 in parities 1 and 2, respectively). Sows that were fed the G-starch diet and then the L-NSP diet ate less before parturition than sows that were fed the G-starch diet and then the L-starch diet (2.69 vs 2.90 kg and 3.08 vs 3.37 kg in parities 1 and 2, respectively). Daily feed intake before parturition was not affected by housing system during gestation. Due to feed refusals, especially in parity 1 sows, the actual feed intakes before parturition were lower than the planned feed intakes.

In all three parities, BW gain and backfat gain from weaning (or onset to the experiment for gilts) until d 112 of gestation was lower in sows that were fed the G-NSP diet than in those that were fed the G-starch diet (P < 0.001; Table 3). Body weight gain was not affected by housing system during gestation. In parity 1, sows that were housed in free access stalls gained more backfat than those housed in the electronic feeding system (*P* < 0.001) whereas in parity 2, sows that were housed in free access stalls gained less backfat (*P* < 0.05).

Litter performance at birth and reproductive performance

The number of total piglets born was higher in sows fed the G-NSP diet than in those fed the G-starch diet (*P* = 0.07 and *P* = 0.05 in parities 1 and 2, respectively; Table 4). Lactation diet and housing system during gestation did not affect the number of total piglets born. In sows that were fed the G-NSP diet and then the L-NSP diet, the number of total piglets born was lower than in sows that were fed the G-NSP diet and then the L-starch diet (12.5 vs 13.8 in parity 3). Live born piglets and stillborn piglets (expressed as % of total piglets born) were not affected by gestation diet (Table 4) but live born piglets were higher and stillborn piglets were lower in sows fed the L-starch diet (*P* = 0.09 and *P* < 0.05, respectively, in parity 1) and in sows housed in the electronic feeding system (*P* < 0.01 in parity 2). Piglet birth weight was lower in sows fed the G-NSP diet (*P* = 0.07 and *P* < 0.05 in parities 1 and 2, respectively; Table 4) and higher in sows housed in the electronic feeding system (*P* < 0.05). Lactation diet did not affect piglet birth weight. Gestation diet and lactation diet did not affect total litter weight at birth whereas in parity 1, it was higher in sows housed in the electronic feeding system during gestation.

The weaning-to-estrus interval, the percentage of sows that returned to estrus after first insemination and farrowing rate after first and second insemination were not affected by gestation diet or by lactation diet (Table 5). Housing system during gestation affected the percentages of sows that returned to estrus ($P < 0.001$ and $P < 0.05$ in parities 1 and 2, respectively) and farrowing rate ($P < 0.05$ in parity 3).

Performance during lactation

In all three parities, lactation feed intake was higher in sows fed the G-NSP diet ($P < 0.001$; Table 6) but lower in sows fed the L-NSP diet ($P < 0.001$). These effects were consistent during the whole lactation period. Body weight and backfat losses during lactation were less in sows that were fed the G-NSP diet than in those that were fed the G-starch diet (Table 6). Body weight loss during lactation was not affected by lactation diet or by housing system during gestation. In parities 1 and 2, sows fed the L-NSP diet lost more backfat than those fed the L-starch diet ($P < 0.01$ and $P < 0.05$, respectively). Backfat loss was not affected by housing system during gestation.

Weaning percentage (expressed as % after fostering) was lower in sows fed the G-NSP diet than in those fed the G-starch diet ($P = 0.054$ and $P < 0.05$ in parities 1 and 2, respectively; Table 6) and higher in sows housed in the electronic feeding system ($P < 0.05$ in parity 1). Lactation diet did not affect the % of weaned piglets. Gestation diet and housing system during gestation did not affect piglets weaning weight and daily gain (Table 6). In all three parities, piglets weaning weight and daily gain were higher in sows fed the L-starch diet than in those fed the L-NSP diet.

Interaction between gestation diet and housing system during gestation

In both housing systems, BW and backfat gains during gestation were lower in sows that were fed the G-NSP diet than in those that were fed the G-starch diet but the effects were more pronounced in the electronic feeding system (Table 7). In parity 1 sows housed in free access stalls during gestation, BW and backfat losses during lactation were not affected by gestation diet. In the electronic feeding system, BW loss and backfat loss were less in sows that were fed the G-NSP diet ($P < 0.001$ and $P < 0.001$ for BW loss and backfat loss, respectively). In the free access stalls, WEI and the percentage of sows that returned to estrus were higher in sows fed the G-NSP diet than in those fed the G-starch diet ($P < 0.05$ in parity 1 and $P < 0.05$ in parity 3, respectively; Table 7) whereas it was similar on both diets in sows housed in the electronic feeding system. In both housing systems, sows that were fed the G-NSP diet ate more during lactation than those that were fed the G-starch diet but the effects were more pronounced in the electronic feeding system (Table 7).

Table 3. Main effects of dietary treatment during gestation and lactation and housing system during gestation on performance during gestation[a]

	Gestation diet		Lactation diet		Housing system			
	G-starch	G-NSP	L-starch	L-NSP	Free access stalls	EF[b]	SEM[c]	Interaction[d]
Feed intake (as-fed basis), kg/d								
Parity 1								
From onset to FS[g]	2.61[e]	2.58[f]	2.58[e]	2.61[f]	2.68[e]	2.51[f]	0.01	-
From FS to parturition	2.75[e]	3.08[f]	3.00[e]	2.83[f]	2.87	2.97	0.04	G x L
Parity 2								
From weaning to FS	2.74	2.73	2.73[e]	2.75[f]	2.75[e]	2.72[f]	0.01	-
From FS to parturition	3.23[e]	3.38[f]	3.38[e]	3.22[f]	3.33	3.28	0.03	G x L
Parity 3								
From weaning to FS	2.77	2.76	2.76	2.77	2.77	2.76	0.01	-
From FS to parturition	3.42	3.43	3.45	3.40	3.41	3.43	0.02	-
Body weight, kg								
Parity 1								
Onset of experiment	123.9	124.0	124.0	123.9	124.0	123.9	0.5	-
Change from onset to d 112	78.0[e]	67.3[f]	72.8	72.5	73.8	71.5	0.9	G x H
Parity 2								
At weaning parity 1	158.2[e]	151.6[f]	156.5	153.4	156.1	153.8	1.1	G x L
Change from weaning to d 112	72.4[e]	64.8[f]	68.8	68.5	68.3	69.0	1.0	G x H
Parity 3								
At weaning parity 2	185.6[e]	176.6[f]	184.0[e]	178.2[f]	180.9	181.3	1.7	-
Change from weaning to d 112	65.0[e]	52.6[f]	57.9	59.7	59.3	58.3	1.4	G x H
Backfat thickness, mm								
Parity 1								
Onset of experiment	13.7	13.7	13.7	13.7	13.6	13.8	0.1	-
Change from onset to d 112	7.0[e]	4.4[f]	5.8	5.7	6.2[e]	5.2[f]	0.2	G x H
Parity 2								
At weaning parity 1	14.3[e]	12.7[f]	14.0[e]	13.0[f]	14.0[e]	13.0[f]	0.2	-
Change from weaning to d 112	5.2[e]	4.0[f]	4.5	4.7	4.3[e]	4.9[f]	0.2	G x H
Parity 3								

At weaning parity 2	14.4[e]	12.6[f]	14.2[e]	12.8[f]	13.8	13.1	0.3	-
Change from weaning to d 112	5.1[e]	3.1[f]	3.9	4.2	4.1	4.1	0.3	-

[a] Data are given as means and SEM.
[b] EF is electronic feeding.
[c] Within a row, SEM is the same for all main treatment comparisons.
[d] G x H: gestation diet x housing system interaction (see Table 7 for subclass means); G x L: gestation diet x lactation diet interaction; - : no interaction.
[e,f] Within a row and within a main treatment comparison, means without a common superscript letter differ ($P < 0.05$).
[g] FS is day of transfer to the farrowing room.

Table 4. Main effects of dietary treatment during gestation and lactation and housing system during gestation on litter performance at birth[a]

	Gestation diet		Lactation diet		Housing system			
	G-starch	G-NSP	L-starch	L-NSP	Free access stalls	EF[b]	SEM[c]	Interaction[d]
No. of total piglets born								
Parity 1	10.5[g]	11.0[h]	10.6	10.8	10.6	10.8	0.2	-
Parity 2	11.5[e]	12.2[f]	11.9	11.8	11.9	11.8	0.2	-
Parity 3	12.9	13.1	13.2	12.8	12.9	13.1	0.3	G x L
Live born piglets, % of total born								
Parity 1	95.9	95.1	96.1[g]	94.9[h]	95.2	95.8	0.5	-
Parity 2	95.6	95.5	95.5	95.5	94.4[e]	96.7[f]	0.5	-
Parity 3	95.6	95.9	95.6	95.9	95.6	95.8	0.7	-
Stillborn piglets, % of total born								
Parity 1	3.7	3.8	3.1[e]	4.4[f]	3.8	3.7	0.4	-
Parity 2	3.7	3.8	3.8	3.7	4.8[e]	2.7[f]	0.5	-
Parity 3	3.3	3.9	3.8	3.5	3.7	3.5	0.6	-
Piglet birth weight, kg								
Parity 1	1.41[g]	1.37[h]	1.39	1.38	1.36[e]	1.42[f]	0.02	-
Parity 2	1.50[e]	1.44[f]	1.46	1.48	1.44[e]	1.50[f]	0.02	-
Parity 3	1.45	1.40	1.41	1.43	1.41	1.43	0.02	-
Total litter weight at birth, kg								
Parity 1	14.30	14.51	14.38	14.43	13.93[e]	14.89[f]	0.25	-
Parity 2	16.68	16.84	16.82	16.70	16.44	17.01	0.32	-
Parity 3	18.10	17.96	18.13	17.93	17.81	18.24	0.39	-

[a] Data are given as means and SEM.
[b] EF is electronic feeding.
[c] Within a row, SEM is the same for all main treatment comparisons.
[d] G x L: gestation diet x lactation diet interaction; - : no interaction.
[e,f] Within a row and within a main treatment comparison, means without a common superscript letter differ ($P < 0.05$).
[g,h] Within a row and within a main treatment comparison, means without a common superscript letter differ ($P < 0.10$).

Table 5. Main effects of dietary treatment during gestation and lactation and housing system during gestation on reproductive performance[a]

	Gestation diet		Lactation diet		Housing system			
	G-starch	G-NSP	L-starch	L-NSP	Free access stalls	EF[b]	SEM[c]	Interaction[d]
WEI, d[e]								
Parity 1	11.1	11.9	11.2	11.8	12.5	10.5	1.0	G x H
Parity 2	9.8	9.7	9.9	9.7	9.9	9.7	1.0	-
Parity 3	6.4	6.8	6.2	7.0	7.4	5.8	1.0	-
Return to estrus after 1st insemination, %								
Parity 1	13.0	13.0	13.9	12.1	6.9[f]	19.1[g]	2.0	-
Parity 2	12.3	13.6	12.7	13.2	9.2[f]	16.7[g]	2.4	-
Parity 3	11.5	14.0	9.6	16.0	12.8	12.7	3.3	G x H
Farrowing rate after 1st and 2nd insemination, %								
Parity 1	93.6	94.2	94.0	93.8	94.4	93.5	1.8	-
Parity 2	95.7	97.2	95.6	97.4	96.0	97.0	1.5	-
Parity 3	95.3	95.8	95.7	95.3	92.4[f]	98.7[g]	2.1	-

[a] Data are given as means and SEM.
[b] EF is electronic feeding.
[c] Within a row, SEM is the same for all main treatment comparisons.
[d] G x H: gestation diet x housing system interaction (see Table 7 for subclass means); - : no interaction.
[e] WEI: onset treatment-to-estrus interval in parity 1 sows; weaning-to-estrus interval in parity 2 and parity 3 sows.
[f,g] Within a row and within a main treatment comparison, means without a common superscript letter differ ($P < 0.05$).

Table 6. Main effects of dietary treatment during gestation and lactation and housing system during gestation on performance of sows and piglets during lactation[a]

	Gestation diet		Lactation diet		Housing system			
	G-starch	G-NSP	L-starch	L-NSP	Free access stalls	EF[b]	SEM[c]	Interaction[d]
Feed intake during lactation (as-fed basis), kg/d								
Parity 1	4.42[f]	4.80[g]	4.79[f]	4.43[g]	4.43	4.67	0.05	G x H
Parity 2	5.15[f]	5.63[g]	5.59[f]	5.19[g]	5.36	5.42	0.05	G x H
Parity 3	5.36[f]	5.81[g]	5.78[f]	5.38[g]	5.49	5.68	0.08	-
BW loss from d 112 to weaning, kg								
Parity 1	43.1[f]	39.7[g]	40.3	42.4	41.7	41.0	1.0	G x H
Parity 2	46.8[f]	41.2[g]	43.3	44.7	43.7	44.3	1.2	G x H
Parity 3	48.2[f]	41.2[g]	45.6	43.8	45.8	43.6	1.7	L x H
BF loss from d 112 to weaning, mm[e]								
Parity 1	6.2[f]	5.4[g]	5.5[f]	6.2[g]	5.9	5.8	0.2	G x H
Parity 2	5.7[f]	4.6[g]	4.9[f]	5.4[g]	5.1	5.2	0.2	-
Parity 3	5.4[f]	4.1[g]	4.9	4.6	4.6	5.0	0.3	-
Weaned piglets, % after fostering								
Parity 1	94.8[h]	93.1[i]	94.0	93.8	93.0[f]	94.9[g]	0.6	-
Parity 2	93.2[f]	91.0[g]	91.6	92.6	91.9	92.2	0.8	-
Parity 3	91.7	91.8	92.4	91.0	91.7	91.7	1.0	-
Piglet weaning weight, kg								
Parity 1	7.5	7.6	7.8[f]	7.3[g]	7.6	7.5	0.1	L x H
Parity 2	7.6	7.7	7.9[f]	7.4[g]	7.6	7.7	0.1	-
Parity 3	7.5	7.6	7.7	7.5	7.6	7.5	0.1	-
Piglet daily gain, g								
Parity 1	213	215	222[f]	206[g]	215	212	2.6	L x H
Parity 2	229	230	236[f]	222[g]	230	229	2.5	-
Parity 3	223	222	229[f]	217[g]	226	220	4.0	-

[a] Data are given as means and SEM.
[b] EF is electronic feeding.
[c] Within a row, SEM was the same for all main treatment comparisons.
[d] G x H: gestation diet x housing system interaction (see Table 7 for subclass means); L x H: lactation diet x housing system interaction; - : no interaction.
[e] BF is backfat loss from d 112 of gestation to weaning.
[f,g] Within a row and within a main treatment comparison, means without a common superscript letter differ ($P < 0.05$).
[h,i] Within a row and within a main treatment comparison, means without a common superscript letter differ ($P < 0.10$).

Table 7. Gestation diet x housing system subclass means for performance characteristics

	Free access stalls		Electronic feeding		
	G[a]-starch	G-NSP	G-starch	G-NSP	SEM
Body weight, kg					
Parity 1					
Change from onset to d 112	76.7[b]	70.8[c]	79.3[b]	63.8[d]	1.3
Change from d 112 to weaning	-41.8[b]	-41.7[b]	-44.4[b]	-37.7[c]	1.4
Parity 2					
Change from weaning to d 112	70.4[b]	66.1[d]	74.4[c]	63.6[d]	1.4
Change from d 112 to weaning	-45.0[bc]	-42.5[cd]	-48.6[b]	-39.9[d]	1.7
Parity 3					
Change from weaning to d 112	62.9[b]	55.6[c]	67.1[b]	49.6[d]	1.9
Backfat thickness, mm					
Parity 1					
Change from onset to d 112	7.3[b]	5.2[c]	6.8[b]	3.7[d]	0.2
Change from d 112 to weaning	-6.0[bc]	-5.7[cd]	-6.4[b]	-5.1[d]	0.3
Parity 2					
Change from weaning to d 112	4.6[b]	4.0[b]	5.7[c]	4.0[b]	0.3
Weaning-to-estrus interval, d					
Parity 1	11.0[b]	14.0[c]	11.2[b]	9.9[b]	1.1
Return to estrus after 1st insemination, %					
Parity 3	6.8[b]	18.9[c]	16.3[c]	9.2[bc]	4.4
Feed intake during lactation (as-fed basis), kg/d					
Parity 1	4.43[b]	4.67[c]	4.40[b]	4.93[d]	0.07
Parity 2	5.20[b]	5.53[c]	5.10[b]	5.74[d]	0.07

[a] G is gestation; gestation diets were fed from onset/weaning until the day of transfer to the farrowing stall.
[b,c,d] Means within a row without a common superscript letter differ ($P < 0.05$).

Discussion

Effects of diet composition during gestation on body weight and backfat thickness

In spite of an increased gut fill when high fiber diets were fed (Bakker, 1996), in all three parities, BW gain from weaning until d 112 of gestation was lower in sows fed the G-NSP diet than in those fed the G-starch diet. Because sows were weighed on the day of transfer to the farrowing room and at d 112 of gestation, it could be calculated that the extra gut fill caused by the G-NSP diet compared with the G-starch diet was on average about 6 kg. Moreover, backfat gain from weaning until d 112 of gestation was lower in sows fed the G-NSP diet. Differences in BW and backfat gains during gestation were not expected because sows on both diets were fed iso-energetic and iso-nitrogenous (in terms of fecal digestible protein). The net energy value of the gestation diets was calculated using the apparent fecal digestibilities as measured previously (Van der Peet-Schwering et al., 2002) and using the net energy values of the digestible nutrients (CVB, 2000). The efficiency of utilization of energy from fermentable NSP is considered to be 30% lower than that from digestible starch (Noblet et al., 1994). Rijnen et al. (2001), however, showed that group-housed sows are capable of using energy from fermentable NSP (i.e., NSP from sugar beet pulp) as efficiently as energy form digested starch due to reduced physical activity. Therefore, we assumed the estimated net energy value of fermentable NSP to be similar to that of digested starch (13.5 MJ/kg). Considering the lower BW and backfat gains during gestation in sows fed the G-NSP diet, the energy value of fermentable NSP may have been overestimated. It might be that the results of Rijnen et al. (2001) are not applicable to all types of NSP or that the results depend on the level of fermentable NSP in the diet. It may also be that the activity of the sows in the present experiment is lower than in the sows used by Rijnen et al. (2001). In the study of Ramonet et al. (2000), the high fiber diet consisting of a mixture of fiber-rich feedstuffs of different origin (like sugar beet pulp, soybean hulls, sunflower meal and wheat bran) did not reduce heat production related to physical activity in gestating sows compared to the low fiber diet. Consequently, total heat production was higher and energy retention was lower compared to sows fed a low fiber diet. In our study sugar beet pulp and soybean hulls were used as major fibrous ingredients whereas in the study of Rijnen et al. (2001) only sugar beet pulp was used. The botanical origin of the dietary fiber seems an important factor influencing the effect of fiber on heat production related to physical activity. Besides the level of fermentable NSP in the G-NSP diet was higher than in the diets of Rijnen et al. (2001). It might be that sows have a minimum level of physical activity and that a further increase in dietary fermentable NSP only will reduce energy retention and not heat production related to physical activity. If we had used the net energy value of fermentable NSP according to Noblet et al. (1994), the net energy value of the G-NSP diet would have been 8% lower than that of the G-starch diet resulting in a 198 MJ lower NE intake from d 1 to d 112 of gestation. Over all parities, the differences in BW gain (including extra gut fill of 6 kg) and backfat gain between sows that were fed the G-starch diet or the G-NSP diet were about 16 kg and 2 mm, respectively. Energy costs for the deposition of 2 mm backfat (i.e. 3.8 kg of lipid) would be 128 MJ NE (Everts et al., 1994). A 70 MJ (198 MJ – 128 MJ) NE lower intake would result in a 2.5 kg lower protein deposition during gestation. Based on Everts et al. (1994), a 198 MJ lower NE intake during gestation would result in a 15 kg lower BW gain (3.8 kg lipid + 2.5 kg protein + 3.4 x 2.5 kg water). It seems that in our trial the net energy value of fermentable NSP according to Noblet et al. (1994) gives a better estimation of the NE of the diet than the net energy value according to Rijnen et al. (2001). This calls for further investigation of the energetic efficiency of fermentable NSP from various ingredients.

Body weight and backfat losses during lactation were less in sows fed the G-NSP diet than in those fed the G-starch diet. This can be explained by higher feed intake levels during lactation of the sows fed the G-NSP diet (+ 8.6, + 9.3 and + 8.4% in parities 1, 2 and 3, respectively). These results are in agreement with the results of Dourmad (1991), Revell et al. (1998) and Prunier et al. (2001). They demonstrated that backfat thickness at farrowing is negatively correlated with voluntary feed intake during lactation. Lean sows at parturition eat more, lose less BW and lose less backfat during lactation than fat sows. The higher feed intake during lactation, however, might also be due to an extended gastrointestinal tract and a longer colon in pigs fed high fiber diets (Jørgensen et al., 1996) which might stimulate feed intake. The higher feed intake during lactation did not compensate the lower energy intake during gestation because sows fed the G-NSP diet were about 4.5% lighter at weaning and had about 12.0% less backfat at weaning from parity 1 and 2 than sows that were fed the G-starch diet (Table 3).

Effects of diet composition during lactation on body weight and backfat thickness

Nutrient requirements of lactating sows are high and therefore they are fed highly digestible diets. The use of high fiber diets for lactating sows has hardly been studied. In our experiment, parity 1 and 2 sows fed the L-NSP diet lost more backfat during lactation than sows fed the L-starch diet. Lower feed intake levels during lactation explain this. These results are in contrast with the results of Zoiopoulos et al. (1982) who showed that the inclusion of either 400-g oat husks or 300-g straw in diets for lactating sows increased mean daily intakes of dry matter during lactation compared to a low fiber control diet. The inclusion of fibrous ingredients, however, reduced the daily energy intake. The origin of the dietary fiber probably explains these different results. Brouns et al. (1995) gave gestating sows free access to six diets each containing a high level of a fibrous ingredient. Voluntary feed intake of the sugar beet pulp diet was significantly lower than that of the other five high fiber diets (2.3 kg/d vs. 7.1 kg/d). Sugar beet pulp gives a higher degree of satiety in the gastrointestinal tract than other fibrous ingredients (Vestergaard, 1997) and therefore voluntary feed intake is reduced. It is not clear whether this is the result from physical or from metabolic effects during gestation. Sugar beet pulp has a high water-holding capacity (Bertin et al., 1988) which results in an increased gut fill and it changes the postprandial glucose response inducing long lasting effects on satiety (Vestergaard, 1997). The L-NSP diet contained 20% sugar beet pulp and this probably explains the reduction in feed intake and energy intake compared to the L-starch diet. As the NE of the L-NSP diet may have been overestimated, the reduction in energy intake even might be greater than the reduction in feed intake. The reduced feed intake might also be a way to reduce heat production of the sows fed the L-NSP diet as high fiber diets may increase heat production in adult sows (Ramonet et al., 2000) and most lactating sows are suffering from heat stress (Quiniou and Noblet, 1999).

Effects of group-housing system during gestation on body weight and backfat thickness

Body weight and backfat gain from onset until d 112 of gestation was lower in gilts housed in the electronic feeding system than in those housed in free access stalls, especially in gilts fed the G-NSP diet. This was due to a lower feed intake. In the free access stalls sows were fed twice a day. Feed refusals were hardly noticed. In the electronic feeding system sows were free to consume their daily ration all at once or to divide it in more portions. Especially in gilts fed the G-NSP diet, the daily amount of feed was too high to be consumed in one meal. However, gilts did not return to the feeding station for a second time to eat the rest of their daily ration. These results are in agreement with the results of Backus et al. (1997). A lower social rank of gilts compared to older sows might explain why gilts did not return to the feeding system for a second time. Another explanation might be that gilts that are fed once daily are less active and have a lower feeding motivation than gilts that are fed twice daily (Robert et al., 2002). This probably also applies to gilts that eat most of their diet in one large meal. A third explanation might be that in gilts fed the G-NSP diet the real feed intake is somewhat lower than the feed intake registered by the feeding computer. Video recordings showed that especially gilts that were fed the G-NSP diet did not always eat all the feed that was dispensed in the feeding trough probably because their feed intake rate was limiting. The feed in the feeding trough however is registered as eaten by the sow it was dispensed to. We used a feed intake rate of 90 g/min and this was probably too high for gilts fed a high NSP diet (Brouns et al., 1997).

In parity 2, backfat gain from onset till d 112 of gestation was higher in sows housed in the electronic feeding system than in those housed in free access stalls. This is in agreement with the results of Backus et al. (1997) and suggests that sows housed in an electronic feeding system use their feed more efficiently than sows housed in free access stalls. This can presumably be explained by a reduced physical activity. Sows housed in an electronic feeding system are less active and the level of stereotypic behavior is lower than in sows housed in free access stalls (Backus et al., 1997). Besides, sows that are fed once daily are less active (Robert et al., 2002).

Reproductive performance

The numbers of total piglets born and live born piglets were 0.5 piglet higher in sows fed the G-NSP diet. This is in agreement with a review of Reese (1997) who reported that the number of live born piglets is increased with 0.3 piglet when sows are fed high fiber diets. Vestergaard and Danielsen (1998) did not find an effect on the number of live born piglets in sows that were fed the high NSP diet. In their study, however, sows were fed a lactation diet from weaning until mating whereas in our study sows were fed the G-NSP diet already before mating. Ashworth and Antipatis (1999) concluded that the level of feed intake before mating had a greater influence on embryo survival than the level of feed intake after mating. Another explanation for the higher number of total piglets born might be the less negative energy balance during lactation of the sows fed the G-NSP diet. Sows fed the G-NSP diet during gestation ate 0.4 kg/d more during lactation and lost less weight (about 5.3 kg) and backfat (about 1.1 mm) than sows fed the G-starch diet. A less negative energy balance during lactation is associated with an increased subsequent embryo survival (Baidoo et al., 1992). However, this does not explain the higher number of total piglets born in parity 1 sows. The less negative energy balance in sows fed the G-NSP diet did not result in a shorter weaning-to-estrus interval, which is in contrast with results of Baidoo et al. (1992) and Zak et al. (1997). The treatment-induced difference in feed intake during lactation in our research was presumably too small to induce an effect on weaning-to-estrus interval.

Piglet birth weight was lower in sows that were fed the G-NSP diet than in those that were fed the G-starch diet. This is in agreement with the results of Reese (1997) and Vestergaard and Danielsen (1998). The higher number of live born piglets or the lower energy intake during gestation might explain the lower piglet birth weight. Total litter weight at birth was not affected by gestation diet. The percentage of weaned piglets after fostering was lower in sows that were fed the

G-NSP diet. In parity 1 sows, this was mainly caused by a higher number of piglets that died because of biting by the sow. We do not have an explanation for these findings. Presumably, it is not due to the composition of the gestation diet because behavioral measurements showed no differences in standing and lying activity and in aggressive behavior in lactation between sows that were fed a starch or a NSP diet during gestation (Van der Peet-Schwering et al., unpublished data). In parity 2 sows fed the G-NSP diet, the higher number of culled piglets can mainly be explained by a lower birth weight of the piglets. Lactation diet did not affect any of the reproductive traits. Only piglet daily gain was 14 g/d lower in sows that were fed the L-NSP diet. The lower piglet daily gain can possibly be explained by the 0.4 kg/d lower feed intake during lactation of the sows fed the L-NSP diet. The reduction in feed intake was apparently too small to negatively affect other reproductive traits, like weaning-to-estrus interval and live born piglets.

The number of sows that returned to estrus after first insemination was higher in sows housed in the electronic feeding system than in sows housed in the free access stalls. This might be explained by a higher level of aggression in sows housed in the electronic feeding system than in sows housed in free access stalls (Backus et al., 1997). In the electronic feeding system there are less possibilities for sows to avoid other sows. Especially sows with a lower social rank may have suffered from this.

Conclusion

In conclusion, the results of this study show that, although high NSP diets negatively influence BW and backfat thickness of the sows, reproductive performance is not negatively influenced. The number of live born piglets is 0.5 piglet higher when sows are fed a high NSP diet during gestation. Feeding a high NSP diet during both gestation and lactation does not further improve the number of live born piglets. Sows that are fed a high NSP diet during gestation and a high starch diet during lactation eat most during lactation. Overall, it is possible to feed sows a high NSP diet during gestation and lactation without negative effects on reproductive performance. However, the energetic efficiency of fermentable NSP from various ingredients in sows needs further investigation.

Implications

Feeding sows a diet with a high level of fermentable non-starch polysaccharides during gestation and a high level of starch during lactation is an appropriate feeding strategy. Feeding a diet with a high level of fermentable non-starch polysaccharides from weaning until mating and during gestation increased the number of live born piglets. Feeding a high starch diet during lactation increased feed intake and reduced backfat losses during lactation. The European obligation to feed sows without piglets some fiber every day can have beneficial effects on the number of live born piglets and on the feed intake of sows during lactation.

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Chapter 4

Development of stereotypic behavior in sows fed a starch diet or a non-starch polysaccharides diet during gestation and lactation over two parities

C. M. C. van der Peet-Schwering[a], H. A. M. Spoolder[a], B. Kemp[b], G. P. Binnendijk[a], L. A. den Hartog[c], M. W. A. Verstegen[b]

[a] Applied Research Division of Animal Sciences Group, Wageningen UR
P.O. Box 2176, 8203 AD Lelystad, The Netherlands

[b] Wageningen Institute of Animal Sciences, Wageningen UR
P.O. Box 338, 6700 AH Wageningen, The Netherlands

[c] Nutreco Agriculture Research and Development
P.O. Box 220, 5830 AE Boxmeer, The Netherlands

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Abstract

The effect of feeding sows a starch diet or a diet with a high level of fermentable non-starch polysaccharides (NSP) during gestation, lactation or both gestation and lactation over the first two parities on the development of stereotypic behavior was studied in sows housed in groups during gestation and individually during lactation. A total of 119 postpuberal gilts were allotted to a 2 x 2 factorial experiment. Treatments were diet composition during gestation (**G-Starch**: 274 g/kg starch and 123 g/kg fermentable NSP or **G-NSP**: 86 g/kg starch and 300 g/kg fermentable NSP) and diet composition during lactation (**L-Starch**: 293 g/kg starch and 113 g/kg fermentable NSP or **L-NSP**: 189 g/kg starch and 216 g/kg fermentable NSP). Sows on both gestation diets were fed iso-energetic. During lactation, sows were given free access to the lactation diets. Behavioral measurements were carried out in weeks 3, 12 and 15 after start of the experiment or after weaning in parity 1 and 2 sows, respectively, three days before the expected date of parturition and one week before weaning in the first three hours after the morning meal using a scan-sampling technique. Feeding group-housed sows a diet high in fermentable NSP during gestation reduced the frequency of total non-feeding oral activities (= sham chewing + other non-feeding oral activities) in gestation compared with a starch diet ($P < 0.001$ and $P < 0.05$, in parities 1 and 2, respectively). In both parity 1 and 2 sows, the greatest reduction was realized in week 15 and the smallest reduction in week 3. During lactation, the composition of the gestation diet did not affect the frequency of total non-feeding oral activities. Feeding sows a diet high in fermentable NSP during lactation reduced the frequency of total non-feeding oral activities in lactation in parity 2 sows ($P < 0.05$) but not in parity 1 sows compared with a starch diet. Moreover, it tended to reduce, although not statistically significant ($P = 0.15$), the frequency of total non-feeding oral activities during subsequent gestation. This study shows that diets high in fermentable NSP during gestation reduce the level of stereotypic behavior in gestation. It seems that diets high in fermentable NSP during lactation may have an additional reducing effect on the development of stereotypic behavior in subsequent gestation.

Introduction

In practice, gestating sows are fed at a restricted level to maintain optimal body condition and productivity. Food restriction, however, is identified as one of the major factors associated with the development of stereotypic behavior in sows (Terlouw et al., 1991; Spoolder et al., 1995). Stereotypic behavior becomes more fixed in form over time and is therefore most common in higher parity sows (Stolba et al., 1983). High fibre levels in diets for gestating sows may reduce stereotypic behavior during gestation due to reduced hunger (Robert et al., 1997; Vestergaard, 1997). The botanical origin of dietary fiber, however, can influence the effect on stereotypic behavior. In a study by Vestergaard (1997), the diet with a high level of fermentable non-starch polysaccharides (NSP) from sugar beet pulp reduced sham chewing and aggression compared to the low fiber control diet whereas the diet with a high level of non-fermentable NSP from grass meal, wheat bran and oat hulls had no clear effect on behavior compared with the control diet. In the studies of Robert et al. (1997) and Vestergaard (1997), all sows were fed the same standard lactation diet. The occurrence of stereotypic behavior during lactation was not measured and therefore it is not known whether the compositions of the gestation diet or the lactation diet influence the level of stereotypic behavior during lactation. Moreover, it is not known whether the composition of the lactation diet influences the development of stereotypic behavior in the subsequent gestation. It might be that a high fiber diet in lactation curbs the development of stereotypic behavior in the subsequent gestation because high fiber diets are more effective in reducing stereotypic behavior when they are fed for a long period (Robert et al., 1993) or because sows are more satiated during lactation, breaking the channeling process as proposed by Lawrence and Terlouw (1993). The channeling of complex behavior by the environment into a few and often performed sequences of behavior is a crucial factor in the development of stereotypic behavior. However, these effects may be counterbalanced by a reduction in energy intake as a result of feeding a high fiber diet in lactation. Consequently, sows may lose more weight and backfat during lactation and have a higher feeding motivation in gestation to restore the lost body reserves.

In most of the studies with high fiber diets, gestating sows were housed individually or in very small groups. However, stereotypic behavior occurs less in group-housed gestating sows than in individually housed gestating sows (Vieuille-Thomas et al., 1995; Backus et al., 1997). Recent European legislation has made group housing of gestating sows compulsory from 2013 onwards. In group housing, however, stereotypic behavior is still existing at levels that indicate that the environment and/or feeding levels do not meet the sow’s behavioral needs. Therefore, this experiment was conducted to determine whether feeding a diet high in fermentable NSP during gestation, lactation or both gestation and lactation over the first two parities affects the development of stereotypic behavior in sows housed in groups during gestation and individually during lactation.

Material and methods

Animals, experimental design and housing

Hundred and nine rotational-bred postpuberal gilts (involving the breeds: Dutch Landrace, Finnish Landrace and Dutch Large White) with an average age of 217 d (SD = 3.1) were allotted to a 2 x 2 factorial experiment. Treatments were diet composition during gestation (including weaning-to-estrus interval) (**G-Starch**: 274 g/kg starch and 123 g/kg fermentable NSP or **G-NSP**: 86 g/kg starch and 300 g/kg fermentable NSP) and diet composition during lactation (**L-Starch**: 293 g/kg starch and 113 g/kg fermentable NSP or **L-NSP**: 189 g/kg starch and 216 g/kg fermentable NSP). Gilts were blocked by body weight, backfat thickness and genotype in groups of 12 with each of the 10 blocks containing two or three gilts in each experimental treatment. At the first estrus after assignment to the experiment gilts were inseminated and kept on trial for two parities. Gilts and sows that returned to estrus after first insemination were introduced in the subsequent group at the day of weaning of that group and rebred. From weaning (or onset of the experiment for gilts) until day 105 of gestation, sows were kept in stable groups of about 12 sows each in free access stalls. During feeding sows were kept in a feeding stall for half an hour so they could be fed individually. All sows in a group were fed the same diet. The feeding stalls were 2.30 x 0.63 m and had partly slatted floors that consisted of 2.00-m concrete solid floor and 0.30-m concrete slatted floor. The communal area per group of 12 sows was 3.25 x 3.78 m and was situated between two rows of six feeding stalls each. The communal area had a partly slatted floor. Approximately 10 days before the expected time of parturition, sows were moved to farrowing rooms each having six pens of 1.80 x 2.20 m. The concrete solid floor (1.00 x 2.20 m) was equipped with floor heating. All rooms for gestating and lactating sows were equipped with computer-controlled heating and mechanical ventilation systems. Piglets were weaned at an average age of 27 days. The care and treatment of the animals was according to Dutch animal welfare legislation.

Feeding

The two diets for the gestating sows differed mainly in starch and fermentable NSP content (Table 1). Starch in the starch diet was primarily derived from wheat, peas and tapioca, whereas

NSP in the NSP diet was derived from sugar beet pulp and soybean hulls, which are both highly fermentable NSP sources. To feed the gestating sows iso-energetic, a digestibility trial was conducted with both gestation diets (Van der Peet-Schwering et al., 2002). The levels of net energy in the starch diet and NSP diet were 8.52 and 8.59 MJ/kg, respectively. To comply with the Dutch welfare laws requiring 14% crude fiber in gestating sow diets, some straw was added to both diets. Straw is a poorly fermentable NSP source. The two diets for the lactating sows also differed mainly in starch and fermentable NSP content (Table 1). Starch in the starch diet was primarily derived from tapioca, whereas NSP in the NSP diet was derived from sugar beet pulp. The levels of net energy were formulated to be the same in both lactation diets (9.42 MJ/kg).

Gestating sows were fed twice a day at 8.00 h and 15.00 h. Daily ration of both experimental diets increased during gestation (day 0 to 60: 2.5 kg/d; day 60 to 85: 2.9 kg/d; day 85 to day of transfer to farrowing room: 3.4 kg/d). Gestating sows of parity 1 and 2 were fed the same daily amount of feed. In the farrowing room, sows were fed the lactation diets twice a day (at 8.00 h and 15.00 h). Before parturition, sows were fed 3.4 kg/d of the lactation diets. During lactation, sows were fed on an ascending scale from parturition until day 6 after parturition. Sows were given free access to the lactation diets from day 6 after parturition onwards. All sows were given free access to drinking water.

Behavioral measurements

As stereotypic behaviors are most prevalent in the postprandial period (Robert et al. 1993; Meunier-Salaün et al., 2001), behavioral measurements were carried out between 8.30 and 11.30-h using a scan-sampling technique (Martin and Bateson, 1993). The behavior of each sow was recorded at 9-min intervals. Thus, 20 recordings per sow were collected at each observation day. Behavioral recordings were collected on Wednesday in weeks 3, 12 and 15 after start of the experiment for parity 1 sows and in weeks 3, 12 and 15 after weaning for parity 2 sows, respectively. On these observation days sows were about 2, 11 and 14 weeks pregnant. In addition, behavior was recorded three days before the expected date of parturition and one week before weaning in both parities. Thus, in total the behavior of each sow was observed at 10 different days during the two parities. In sows that returned to estrus, behavioral recordings were also collected in week 18 after the start of the experiment or after weaning (is week 14 of gestation). In weeks 2, 11 and 14 of gestation and three days before the expected date of parturition sows were fed 2.5, 2.9, 3.4 and 3.4 kg/d, respectively. The postures standing (body supported by all four legs), sitting (body supported by the two front legs and hindquarters) and lying were recorded for each sow.

Table 1. Composition of experimental diets (as-fed basis)

	Gestation diet		Lactation diet	
Item	G-Starch	G-NSP	L-Starch	L-NSP
Ingredient, g/kg				
Wheat	113.7	31.8	-	-
Peas	102.0	-	105.0	129.0
Tapioca	274.0	70.0	367.0	168.0
Soybeans, extracted	10.0	38.0	97.0	81.0
Soybean hulls	-	56.1	-	-
Sunflower seed, extracted	180.0	180.0	185.0	150.0
Wheat middlings	-	-	80.0	100.0
Sugar beet pulp	-	383.0	-	206.0
Lucerne	75.0	34.0	50.0	50.0
Molasses, cane	43.0	40.0	40.0	42.0
Straw	141.0	111.0	-	-
Fat	40.0	42.5	47.5	47.7
Limestone	4.8	-	10.0	7.9
Monocalcium phosphate	5.4	4.1	6.2	6.9
Salt	3.8	2.6	4.3	3.7
Phytase	0.2	0.5	0.5	0.4
Lysine-50%	1.7	1.0	2.2	1.9
Threonine-10%	0.4	0.4	0.3	0.5
Premix[a]	5.0	5.0	5.0	5.0
Analyzed content, g/kg				
Crude protein	132	136	161	164
Crude fat	54	54	59	60
Starch	274	86	293	189
Sugar	52	79	56	68
Non-starch polysaccharides[b]	314	472	250	340
Ash	73	77	75	75
Ileal digestible lysine[c]	4.4	4.4	7.1	7.1

[a] Provided the following nutrients per kg of experimental diet: vitamin A, 7,000 IU; vitamin D3, 1,400 IU; vitamin E, 17 mg; riboflavin, 4 mg; niacinamide, 18 mg; d-panthothenic acid, 7 mg; choline chloride, 250 mg; vitamin B12, 15 mcg; folic acid, 2.4 mg; biotin, 0.1 mg; cobalt, 0.25 mg (as $CoSO_4.7H_2O$); copper,10 mg (as $CuSO_4.5H_2O$); manganese, 24 mg (as MnO_2); iron, 80 mg (as $FeSO_4.7H_2O$); zinc, 54 mg (as $ZnSO_4$); iodine, 0.4 mg (as KI); selenium, 0.15 mg (as $Na_2SeO_3.5H_2O$) for the gestation diets.

[b] Non-starch polysaccharide content was calculated as dry matter content minus ash, crude protein, crude fat, starch and sugar content.

[c] Calculated content.

In addition, the following mutually exclusive activities were recorded for each sow: sham chewing (any chewing movement which involves no object in the mouth), other non-feeding oral activities (such as licking and biting of the floor, trough or bars in the pen), inactive (standing, sitting or lying without apparently performing any behavior), eating and drinking. Sham chewing and other non-feeding activities were classified as stereotypic behavior (Stolba et al., 1983; Lawrence and Terlouw, 1993).

Statistical analysis

The following behavioral recordings were statistically analyzed: total non-feeding oral activities (= sham chewing + other non-feeding oral activities), sham chewing, other non-feeding oral activities, drinking, standing and lying. The frequency of the different postures and activities performed by each sow was expressed as a percentage of the total number of recordings in a sow on each observation day. In sows that returned to estrus the behavioral recordings in weeks 3, 15 and 18 after weaning were analyzed. The recordings in weeks 15 and 18 in sows that returned to estrus were similar to the recordings in weeks 12 and 15 after weaning in sows that did not return to estrus with regard to week of gestation and feeding level of the sows. The timing of recordings in week 3 after weaning in sows that returned to estrus and in sows that did not return to estrus were comparable with regard to the feeding level of the sows but not with regard to the stage of gestation. However, the frequencies of behavioral recordings in week 3 after weaning were similar in sows that returned to estrus and in those that did not return to estrus. Therefore, behavioral recordings of sows that returned to estrus or that did not return to estrus were analyzed together (weeks 3, 12 and 15 for sows that did not return to estrus and weeks 3, 15 and 18 for sows that did return to estrus). The levels of behavioral recordings during gestation (recordings in week 2, 11 and 14 of gestation) and during lactation (recordings before parturition and before weaning) were analyzed for the fixed effects of block, diet composition during gestation and diet composition during lactation using a mixed logistic model. In the model the relationship between the probability P ($0 < P < 1$) of observing the specific behavior and the explanatory variables was described using the logit-link function. For the data in parity 1 sows in weeks 3, 12 and 15 after onset to the experiment the logit function was:

$$\text{Logit}(p_{ijkl}) = \ln(p_{ijkl} / (1 - p_{ijkl})) = c + \text{block}_i + \text{gestation diet}_j + \text{sow}_k + \text{observation day}_l + (\text{gestation diet x observation day})_{jl} \qquad \text{(model 1)}$$

where c represents the constant term; block_i = fixed effect of block (i = 10); gestation diet_j = fixed effect of gestation diet (j = 2); sow_k = random effect of sow k, considered to be normally distributed with mean 0 and variance equal to σ^2_{sow}; observation day_l = fixed effect of observation day (l = 3). The random sow effect was added to the model to describe the correlation between recordings in time on the same sow. Behavioral recordings in parity 1 sows in the farrowing room and behavioral recordings in parity 2 sows were analyzed by adding the main effect lactation diet and the interactions gestation diet x observation day and lactation diet x observation diet to model 1.

Gestation diet by lactation diet by observation day interactions and gestation diet by lactation diet interactions were not observed for any of the response variables and were therefore omitted from the model.

Estimates of model parameters and components of variance were obtained using the Iterative Reweighted Residual Maximum Likelihood (IRREML) procedure of Engel and Keen (1994). Fixed effects were assessed using chi-squares for the Wald statistics. Pairwise differences between treatment means were tested using a t-test. All analyses were performed using the statistical program GenStat (2000).

Results

Behavior in parity 1 sows during gestation

The frequency of total non-feeding oral activities was lower in sows fed the G-NSP diet than in sows fed the G-starch diet (Table 2). Both sham chewing and other non-feeding oral activities were lower in sows fed the G-NSP diet. The frequencies of drinking and lying were not affected by gestation diet. The frequency of standing was lower in sows fed the G-NSP diet than in those fed the G-starch diet.

There was an interaction between gestation diet and observation day with regard to total non-feeding oral activities ($P < 0.05$; Figure 1). In sows that were fed the G-starch diet, the frequency of total non-feeding oral activities was similar in weeks 3, 12 and 15 ($P > 0.10$). However, in sows that were fed the G-NSP diet, the frequency of total non-feeding oral activities was lower in week 15 compared to week 3 ($P < 0.001$) and week12 ($P < 0.01$). There was also an interaction between gestation diet and observation day with regard to sham chewing ($P < 0.01$; Figure 2). In sows that were fed the G-starch diet, the frequency of sham chewing was higher in week 12 compared to week 3 ($P < 0.05$) and higher in week 15 compared to week 12 ($P < 0.05$). In sows that were fed the G-NSP diet, the frequency of sham chewing was higher in week 12 compared to week 3 ($P < 0.01$) and week 15 ($P < 0.01$) whereas it was similar in week 3 and 15. The frequency of other non-feeding oral activities decreased during gestation regardless of treatment. It was lower in week 12 compared to week 3 ($P < 0.05$) and lower in week 15 compared to week 12 ($P < 0.05$) (12.8, 7.8 and 5.0% in weeks 3, 12 and 15, respectively). The frequency of standing also decreased during gestation regardless of treatment. It was lower in week 12 compared to week 3 ($P < 0.001$; Figure 3) and lower in week 15 compared to week 12 ($P < 0.05$). The frequency of lying was higher in weeks 12 and 15 compared to week 3 ($P < 0.001$ and $P < 0.001$, respectively) whereas it was similar in weeks 12 and 15 (80.9, 87.7 and 87.9% in weeks 3, 12 and 15, respectively). The frequency of drinking was not affected by observation day.

Table 2. Percentage of observations spent on specific behavior[a] in parity 1 sows during gestation as affected by gestation diet

	Gestation diet		
	G-Starch	G-NSP	*P* - value
Total non-feeding oral activities	23.8	13.7	**< 0.001**
Sham chewing	14.4	5.6	**< 0.001**
Other non-feeding oral activities	9.4	8.1	**0.08**
Drinking	1.4	1.1	0.25
Standing	10.9	8.8	**0.02**
Lying	84.5	86.2	0.12

[a] Data are presented as untransformed means. Therefore, SEM is not presented.

Behavior in parity 1 sows during lactation

The frequencies of total non-feeding oral activities, drinking and lying in the farrowing room were not affected by gestation diet or by lactation diet (Table 3). The frequency of sham chewing was higher in sows fed the G-starch diet than in those fed the G-NSP diet whereas the frequency of other non-feeding oral activities was lower in sows fed the G-starch diet. Lactation diet did not affect the frequencies of sham chewing and other non-feeding oral activities. The frequency of standing was higher in sows fed the L-starch diet than in those fed the L-NSP diet whereas it was not affected by gestation diet.

The frequencies of total non-feeding oral activities (Figure 1), sham chewing (Figure 2) and other non-feeding oral activities were not affected by observation day in the farrowing room. The frequency of standing was higher in the week before weaning than in the week before parturition ($P < 0.001$; Figure 3) whereas the frequency of lying was lower in the week before weaning than in the week before parturition (76.9 versus 85.7%; $P < 0.001$). The frequency of drinking was higher in the week before weaning than in the week before parturition (3.1 versus 1.4%; $P < 0.01$).

Behavior in parity 2 sows during gestation

The frequencies of total non-feeding oral activities and of sham chewing were lower in sows fed the G-NSP diet than in those fed the G-starch diet (Table 4). The frequencies of other non-feeding oral activities, drinking and standing were not affected by gestation diet. The frequency of lying was higher in sows fed the G-NSP diet than in those fed the G-starch diet. In sows that were fed the L-NSP during lactation, the frequencies of both total non-feeding oral activities and of sham chewing tended to be lower, although not statistically significant ($P = 0.15$ and $P = 0.12$, respectively), in subsequent gestation than in sows that were fed the L-starch diet. The preceding lactation diet did not affect the frequencies of other behavior during gestation.

There was an interaction between gestation diet and observation day with regard to total non-feeding oral activities ($P < 0.01$; Figure 1). In sows that were fed the G-starch diet, the frequency of total non-feeding oral activities was higher in week 12 compared to week 3 ($P < 0.05$; Figure 1) whereas the frequency in week 15 did not differ from that in week 3 and week 12. In sows that were fed the G-NSP diet, the frequency of total non-feeding oral activities decreased during gestation. It was lower in week 15 compared to week 3 ($P < 0.01$) whereas the frequency in week 12 was intermediate. There also was an interaction between gestation diet and observation day with regard to sham chewing ($P < 0.01$; Figure 2). In sows that were fed the G-starch diet, the frequency of sham chewing was higher in week 12 compared to week 3 ($P < 0.01$) whereas the frequency in week 15 did not differ from that in week 3 and week 12. In sows that were fed the G-NSP diet, the frequency of sham chewing was lower in week 15 compared to week 3 ($P < 0.10$) and week 12 ($P < 0.10$). The frequency of other non-feeding oral activities decreased during gestation regardless of treatment. It was lower in week 15 compared to week 3 ($P < 0.01$) whereas the frequency in week 12 was intermediate (7.2, 5.1 and 4.0% in weeks 3, 12 and 15, respectively). The frequency of standing decreased during gestation regardless of treatment. It was lower in week 12 compared to week 3 ($P < 0.001$; Figure 3) and lower in week 15 compared to week 12 ($P < 0.01$). The frequency of lying was higher in week 12 compared to week 3 ($P < 0.001$) and higher in week 15 compared to week 12 ($P < 0.10$) (77.3, 85.8 and 89.2% in weeks 3, 12 and 15, respectively). The frequency of drinking was higher in week 3 compared to weeks 12 and 15 (2.2, 1.2 and 0.9%, in week 3, 12 and 15, respectively; $P < 0.05$).

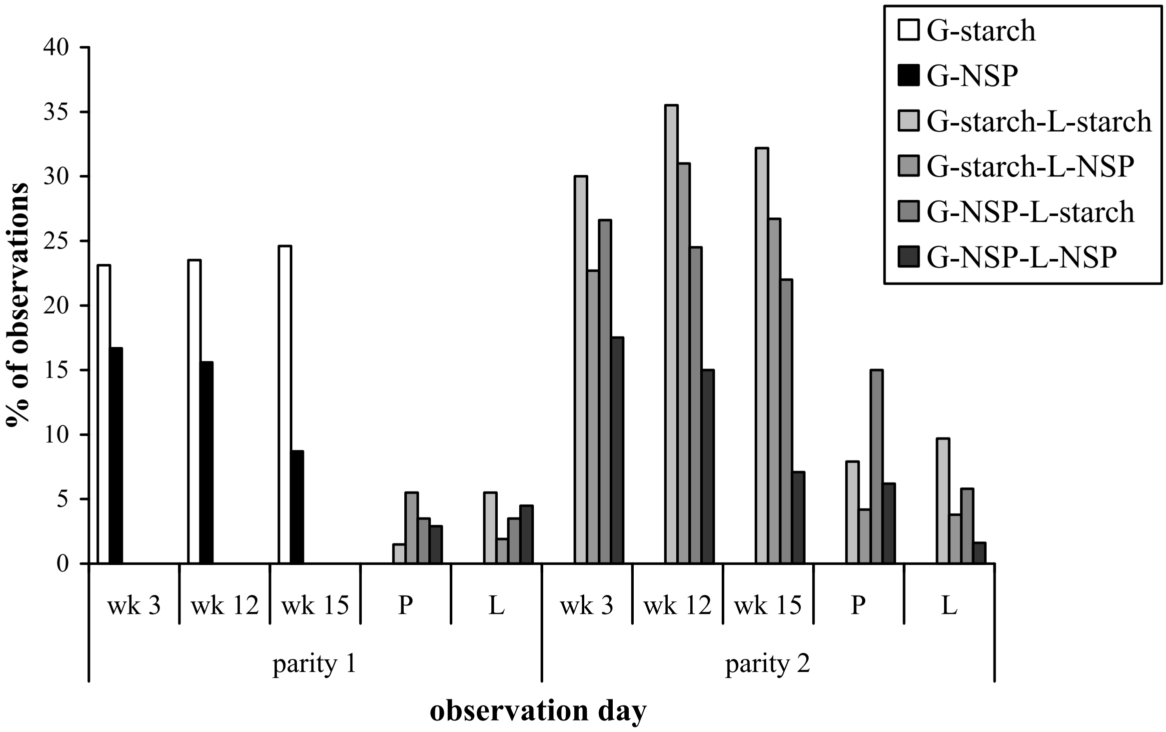

Figure 1. Percentage of observations spent on total non-feeding oral activities during gestation (wk 3, wk 12 and wk 15), three days before parturition (P) and during lactation (L) as affected by gestation diet and lactation diet

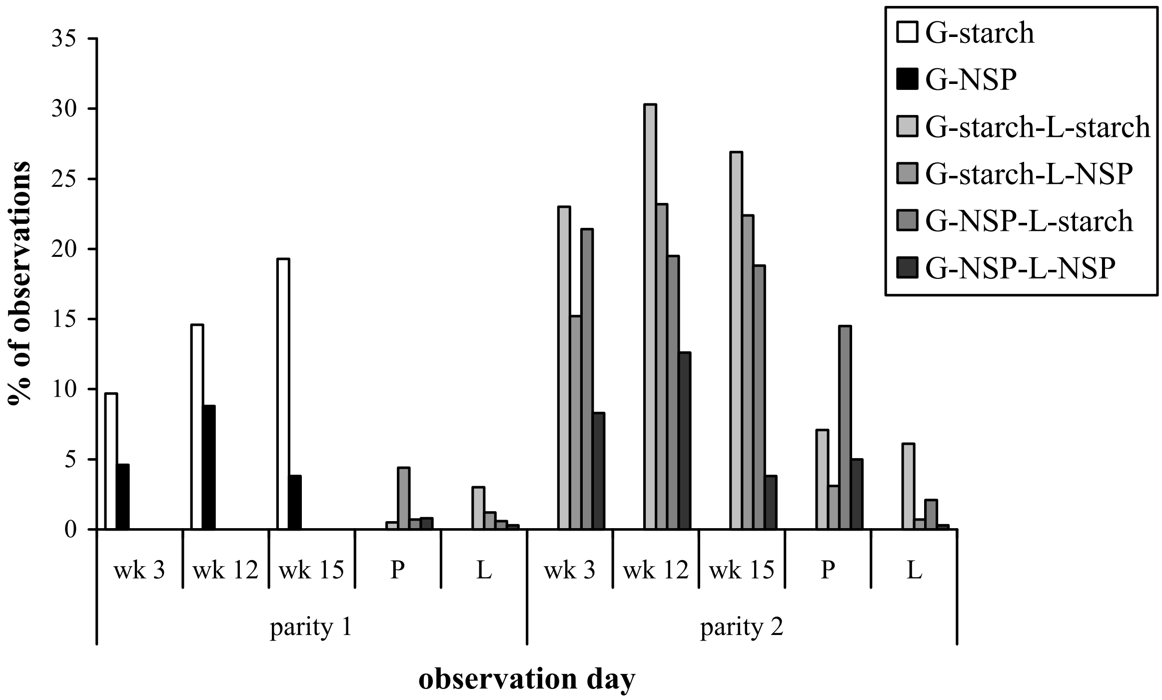

Figure 2. Percentage of observations spent on sham chewing during gestation (wk 3, wk 12 and wk 15), three days before parturition (P) and during lactation (L) as affected by gestation diet and lactation diet

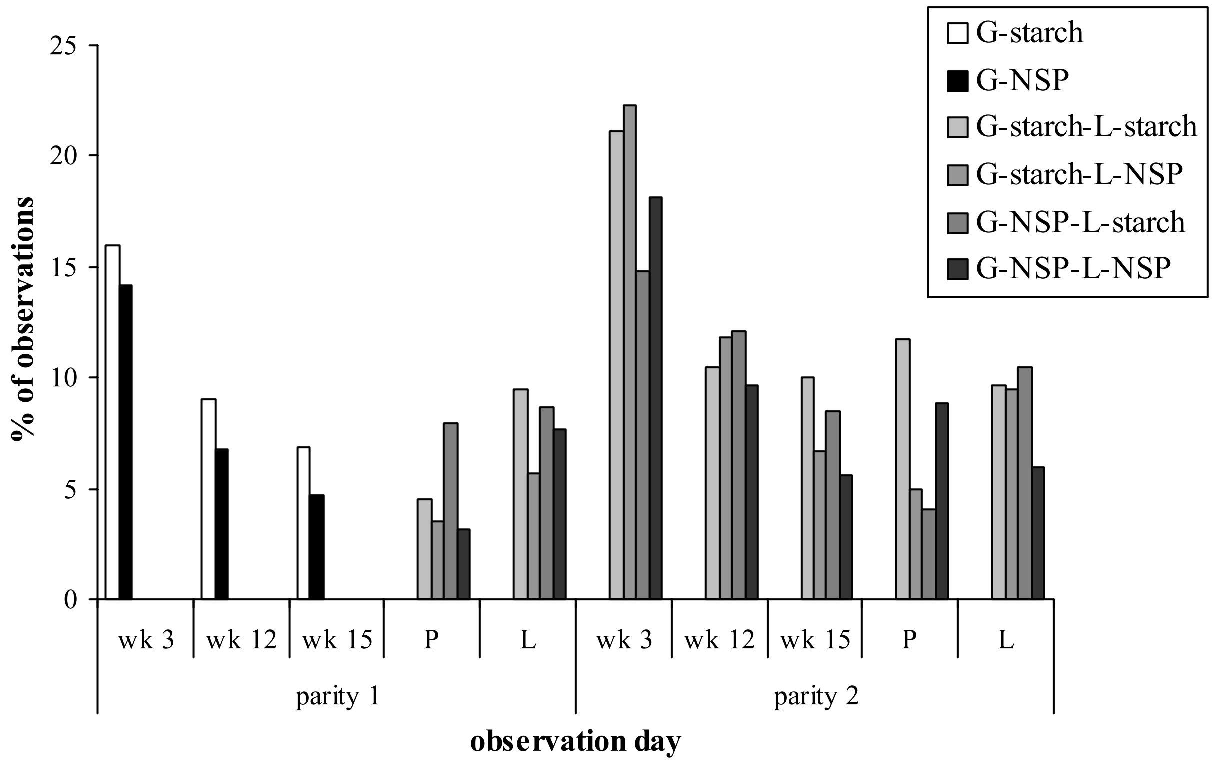

Figure 3. Percentage of observations that sows are standing during gestation (wk 3, wk 12 and wk 15), three days before parturition (P) and during lactation (L) as affected by gestation diet and lactation diet

Behavior in parity 2 sows during lactation

The frequencies of total non-feeding oral activities and of sham chewing in the farrowing room were not affected by gestation diet but they were lower in sows fed the L-NSP diet than in those that were fed the L-starch diet (Table 5). The frequencies of other non-feeding oral activities, drinking, standing and lying were not affected by gestation diet or by lactation diet.

In sows that were fed the G-NSP diet and then the L-starch diet, the frequencies of total non-feeding oral activities (Figure 1) and of sham chewing (Figure 2) were higher in the week before parturition than in the week before weaning ($P < 0.05$ and $P < 0.001$, respectively). In the other experimental treatments, these frequencies were similar in the weeks before parturition and before weaning. The frequency of other non-feeding oral activities was higher in the week before weaning than in the week before parturition regardless of treatment (3.0 versus 0.9%; $P < 0.05$). The frequencies of standing and lying were not affected by observation day in the farrowing room. The frequency of drinking was higher in the week before weaning than in the week before parturition (4.2 versus 2.6%; $P < 0.05$).

Table 3. Percentage of observations spent on specific behavior[a] in parity 1 sows during lactation as affected by gestation diet and by lactation diet

	Gestation diet		Lactation diet		*P*-value[b]	
	G-starch	G-NSP	L-starch	L-NSP	G	L
Total non-feeding oral activities	3.7	3.6	3.5	3.7	0.84	0.66
Sham chewing	2.4	0.6	1.2	1.7	**0.002**	0.24
Other non-feeding oral activities	1.4	3.0	2.3	2.1	**0.01**	0.72
Drinking	2.0	2.6	2.2	2.4	0.41	0.94
Standing	5.9	6.9	7.8	5.0	0.32	**0.04**
Lying	81.9	80.5	80.0	82.4	0.62	0.39

[a] Data are presented as untransformed means. Therefore, SEM is not presented.
[b] G: gestation diet; L: lactation diet; gestation diet x lactation diet interactions were not significant.

Table 4. Percentage of observations spent on specific behavior[a] in parity 2 sows during gestation as affected by gestation diet and by lactation diet

	Gestation diet		Lactation diet		*P*-value[b]	
	G-starch	G-NSP	L-starch	L-NSP	G	L
Total non-feeding oral activities	29.7	18.9	28.5	20.1	**0.03**	0.15
Sham chewing	23.4	14.1	23.3	14.3	**0.07**	0.12
Other non-feeding oral activities	6.2	4.8	5.2	5.8	0.11	0.69
Drinking	1.4	1.6	1.6	1.4	0.60	0.80
Standing	14.0	11.6	13.1	12.5	0.14	0.70
Lying	82.4	85.4	83.7	84.1	**0.06**	0.86

[a] Data are presented as untransformed means. Therefore, SEM is not presented.

[b] G: gestation diet; L: lactation diet; gestation diet x lactation diet interactions were not significant.

Table 5. Percentage of observations spent on specific behavior[a] in parity 2 sows during lactation as affected by gestation diet and by lactation diet

	Gestation diet		Lactation diet		*P*-value[b]	
	G-starch	G-NSP	L-starch	L-NSP	G	L
Total non-feeding oral activities	6.5	6.4	9.1	3.8	0.66	**0.03**
Sham chewing	4.1	4.6	6.6	2.0	0.26	**0.02**
Other non-feeding oral activities	2.5	1.9	2.6	1.8	0.19	0.51
Drinking	4.0	3.2	3.7	3.5	0.55	0.86
Standing	9.2	7.8	9.4	7.6	0.36	0.24
Lying	79.7	80.4	81.6	78.5	0.61	0.22

[a] Data are presented as untransformed means. Therefore, SEM is not presented.

[b] G: gestation diet; L: lactation diet; gestation diet x lactation diet interactions were not significant.

Discussion

Feeding group-housed gilts and sows a diet high in fermentable NSP during gestation reduces the frequency of total non-feeding oral activities and of sham chewing in gestation compared with a starch diet. Previous research with high fiber diets reported similar results (Robert et al., 1993, 1997, 2002; Vestergaard, 1997; Ramonet et al., 1999). In both parity 1 and 2 sows, the greatest reduction was realized in week 15 and the smallest reduction in week 3. This can possibly be explained by the higher feeding level in week 15. The voluntary feed intake of a diet with a high level of fermentable NSP (e.g. sugar beet pulp) is much lower than that of a starch diet (Brouns et al., 1995) because sugar beet pulp gives a higher degree of satiety in the gastrointestinal tract (Vestergaard, 1997). Thus, sows that were fed the G-NSP diet (containing 40% sugar beet pulp) at a level of 3.4 kg were fed more closely to their voluntary feed intake and are therefore more satiated than sows that were fed the G-starch diet at a level of 3.4 kg. This probably also explains the reduction in stereotypic behavior as gestation progressed in sows fed the G-NSP diet. In sows fed the G-starch diet, stereotypic behavior did not decrease with progress of gestation. It seems, therefore, that progress of gestation or an increase in feeding level during gestation as such will not reduce stereotypic behavior. It is probably the combination of a diet with a high level of fermentable NSP and an increasing feeding level that reduces stereotypic behavior as gestation progresses.

The frequency of lying in gestation was slightly higher in sows fed the G-NSP diet than in those fed the G-starch diet whereas the frequency of standing was slightly lower in sows fed the G-NSP diet. These results are confirmed by other authors (Bergeron et al., 2000; Robert et al., 2002) who reported that individually housed sows lie more and stand less when they are fed a high fiber diet. However, the effects of a high fiber diet on the time spent lying and standing were more pronounced in their research. Feeding a high fiber diet increased the percentage of time that sows were lying from 52.4 to 74.6% compared to a low fiber diet (Robert et al., 2002), whereas in our research the frequency of lying was increased from 83.5 to 85.8%. Similar differences were observed in the time spent standing. Feeding a high fiber diet reduced the percentage of time that sows were standing from 45 to 35% (Bergeron et al., 2000) compared with a low fiber diet whereas in our research the frequency of standing was reduced from 12.5 to 10.2%. An interaction between housing system and feeding level seems to explain these differences in results. Individually housed sows stand more and lie less than group housed sows partly due to lack of comfort and because of difficulties when lying down (Terlouw et al., 1991). The proportion of standing in the individually housed sows was reduced by a high feeding level compared to a low feeding level. In group housed sows the proportion of standing was not affected by feeding level (Terlouw et al., 1991). Thus, probably in a housing system with a high frequency of lying behavior, a high fiber diet is less likely to influence the lying and standing behavior. However, the frequency of lying increased and the frequency of standing decreased with progress of gestation. This is probably caused by an increased weight of the fetuses and weight of the sow, making the sow less active (Vestergaard, 1997).

The frequencies of total non-feeding oral activities and of sham chewing during gestation were affected, although not statistically significant, by the composition of the preceding lactation diet (P = 0.15 and P = 0.12, respectively; Table 4). In sows that were fed the L-starch diet, the frequencies of total non-feeding oral activities and of sham-chewing during the subsequent gestation were 28.5 and 23.3%, respectively, whereas in sows that were fed the L-NSP diet these frequencies were 20.1 and 14.3%, respectively. Feeding a diet with a high level of NSP during lactation might exert two opposing effects on oral behaviors during subsequent gestation. On the one hand, lactating sows that are fed a diet with 20% sugar beet pulp are expected to be more satiated. This may reduce the frequency of stereotypic behavior during lactation and the subsequent gestation. On the other hand, daily feed intake during lactation in sows fed the L-NSP diet was about 0.4 kg lower than in those fed the L-starch diet (Van der Peet-Schwering et al., 2003). Consequently, sows fed the L-NSP diet lost more body weight and backfat during lactation. Probably, these sows have an increased feed motivation during subsequent gestation to restore the lost body reserves. A higher feed motivation is thought to cause the development of stereotypic behavior (Lawrence and Terlouw, 1993). These two opposing effects might partly neutralize each other resulting in a smaller effect of diet composition during lactation on the development of stereotypic behavior during subsequent gestation. It is not clear whether the lower feed intake and energy intake in sows fed the L-NSP diet is the result from physical or from metabolic effects during digestion. On the one hand, sugar beet pulp has a high water-holding capacity (Bertin et al., 1988) and this will result in an increase in gastric distension and gut fill. On the other hand, sugar beet pulp changes the postprandial glucose response inducing long lasting effects on satiety (Vestergaard, 1997). Moreover, sows fed a diet with a high level of sugar beet pulp showed higher plasma levels of acetic acid (Brouns et al., 1994). These depress voluntary feed intake in ruminants (Farningham and Whyte, 1993) and maybe also in sows. Presumably, a lower level of sugar beet pulp in the lactation diet (less than 20%) will decrease feed and energy intake in lactation to a lesser degree and therefore may significantly reduce stereotypic behavior in subsequent gestation.

The levels of total non-feeding oral behavior and of sham chewing during lactation were much lower than during gestation and they were not affected by gestation diet. These lower levels during lactation might be explained by interactions with the piglets (Stolba et al., 1983). Stereotypic behavior is performed to cope with an inadequate environment (Dantzer, 1986) and is associated with a release of endorphins (Cronin, 1985). Endorphins play a role in the adaptation to stress (Cronin, 1985). Suckling also seems to stimulate the release of endorphins (Armstrong et al., 1988). It might be that during lactation stereotypic behavior is inhibited because suckling stimulates the release of endorphins. Thus, suckling may suppress stereotypic behavior during lactation. Another explanation for the lower level of stereotypic behavior during lactation might be the high feeding level during lactation. During lactation sows had free access to their diets. Ad libitum feeding in gestating sows is very effective in reducing stereotypic behavior (Bergeron et al., 2000). Maybe, this also applies to lactating sows. Ad libitum feeding of a diet with a high level of fermentable NSP may further reduce stereotypic behavior. In our study, feeding the L-NSP diet did not reduce the frequencies of total non-feeding oral activities and of sham chewing in parity 1 sows during lactation. In parity 2 sows, however, feeding the L-NSP diet reduced the frequencies of total non-feeding oral activities and of sham chewing during lactation from 9.1 to 3.8% ($P < 0.05$) and from 6.6 to 2.0% ($P < 0.05$), respectively, compared with the L-starch diet. The effect of feeding the L-NSP diet during lactation on stereotypic behavior might even have been greater if energy intake in lactation would not have been decreased in sows fed the L-NSP diet. Robert et al. (1997) concluded that high fiber diets are more effective in reducing stereotypic behavior if the nutrient requirements of the animals are met.

The frequency of total non-feeding oral activities and of sham chewing in gestation increased from parity 1 to parity 2. This is in agreement with results of Stolba et al. (1983) and Robert et al. (1993). However, the increases differed among the experimental treatments. In sows that were fed the starch diet during both gestation and lactation, the frequencies of total non-feeding oral activities and of sham chewing in gestation increased from 23.8 to 32.5% and from 14.4 to 26.6%, respectively, from parity 1 to parity 2. The frequencies of total non-feeding oral activities and of sham chewing in lactation increased from 3.6 to 9.0% and from 1.8 to 6.5%, respectively, from parity 1 to parity 2. In sows that were fed the NSP diet during both gestation and lactation, the frequencies of total non-feeding oral activities in gestation and lactation did not increase from parity 1 to parity 2 (13.7 and 13.3% in gestation in parities 1 and 2, respectively; 3.7 and 3.6% in lactation in parities 1 and 2, respectively). The frequencies of sham chewing in gestation and in lactation increased from 5.6 to 8.3% and from 0.5 to 2.4%, respectively, from parity 1 to parity 2. Robert et al. (1993) suggested that high fiber diets are most effective in reducing stereotypic behavior in young sows that receive these diets for a long period. This is confirmed in our research. The ratio between sham chewing and total non-feeding oral activities also increased from parity 1 to parity 2. The increase differed among the experimental treatments. In sows that were fed the starch diet during both gestation and lactation, the ratios in gestation and lactation increased from 60.5% to 81.8% and from 50.0 tot 72.2%, respectively, from parity 1 to parity 2. In sows that were fed the NSP diet during both gestation and lactation, the ratios in gestation and lactation increased from 40.9 to 62.4% and from 13.5 to 66.7%, respectively, from parity 1 to parity 2. It seems that oral activities are becoming more fixed in form over time, resulting in one type of behavior –sham chewing- increasingly dominating the behavioral repertoire. The data suggest that high fiber diets could not reduce the speed of this 'channeling' process compared to starch diets. However, the relative frequency of sham chewing in relation to total non-feeding oral activities remained lower in the NSP groups. In sows that were fed the NSP diet during gestation and the starch diet during lactation, a similar development in stereotypic behavior in gestation was seen as in the sows fed the NSP diet during both gestation and lactation but the level of stereotypic behavior was higher. In sows that were fed the starch diet during gestation and the NSP diet during lactation, a similar development in stereotypic behavior in gestation was seen as in the sows fed the starch diet during both gestation and lactation but the level of stereotypic behavior was lower.

In conclusion, feeding group-housed sows a diet with a high level of fermentable NSP during gestation reduces the level of stereotypic behavior in gestation compared with a starch diet. It seems that feeding sows a diet with a high level of fermentable NSP during lactation has an additional reducing effect on the development of stereotypic behavior in subsequent gestation.

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Chapter 5

Effects of additional starch or fat in late-gestating high non-starch polysaccharides diets on litter performance and glucose tolerance in sows

C. M. C. van der Peet-Schwering[§], B. Kemp[†], G. P. Binnendijk[§], L. A. den Hartog[‡], P. F. G. Vereijken[*], and M. W. A. Verstegen[†]

[§] Applied Research Division of Animal Sciences Group, Wageningen UR
P.O. Box 2176, 8203 AD Lelystad, The Netherlands

[†] Wageningen Institute of Animal Sciences, Wageningen UR
P.O. Box 338, 6700 AH Wageningen, The Netherlands

[‡] Nutreco Agriculture Research and Development
P.O. Box 220, 5830 AE Boxmeer, The Netherlands

[*] Biometris, Wageningen UR
P.O. Box 100, 6700 AC Wageningen, The Netherlands

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Abstract

The effects of feeding additional starch or fat from d 85 of gestation until parturition on litter performance and on glucose tolerance in sows that were fed a diet with a high level of fermentable non-starch polysaccharides (NSP) were studied. The day after breeding, a total of 141 multiparous sows were assigned to the experiment. At d 85 of gestation, sows were assigned to the treatments. Three treatments were applied. Sows were fed 3.4 kg/d of a high NSP diet or the same quantity of the high NSP diet and an additional daily amount of 360 g starch (from wheat starch), or the same quantity of the high NSP diet and an additional daily amount of 164 g fat (from soybean oil). During lactation, all sows were given free access to the same lactation diet. About 1 week before the expected time of parturition, an oral glucose tolerance test was performed in 38 randomly chosen sows by feeding sows pelleted glucose (3 g/kg $BW^{0.75}$). Blood samples for analyses of glucose were taken at –10, 10, 20, 30, 40, 50, 60, 70, 80, 90, 105, and 120 min after glucose was fed. The supply of additional dietary starch or fat did not increase piglets birth weight and total litter weight at birth. Live-born piglets (expressed as % of total born piglets) tended to be higher and stillborn piglets tended to be lower in sows that were fed the high NSP diet than in sows that were fed additional fat whereas it was intermediate in sows that were fed additional starch ($P < 0.10$). Piglet mortality after birth was not affected by dietary treatment. Body weight and backfat gains in the last month of gestation were higher in sows fed additional starch or fat than in sows fed the high NSP diet ($P < 0.05$). Feed intake in lactation was highest in sows fed the high NSP diet, lowest in sows fed additional starch at the end of gestation and intermediate in sows fed additional fat ($P < 0.05$). The differences in lactation feed intake did not result in differences in BW and backfat losses during lactation. Sows that were fed additional fat had the greatest glucose area under the curve ($P < 0.05$) indicating that these sows were less tolerant for glucose. In conclusion, feeding additional energy (starch or fat) in late-gestating sows that are fed a high NSP diet does not increase litter weight at birth or piglet survival but it does increase maternal gain. Feeding sows additional energy from fat may induce glucose intolerance. Feeding sows additional energy from starch does not induce glucose intolerance.

Introduction

High levels of fermentable non-starch polysaccharides (NSP) in diets for gestating sows reduce stereotypic behavior probably due to reduced hunger (Vestergaard, 1997; Van der Peet-Schwering et al., 2003b). Piglet birth weight, however, is lower in sows fed a high NSP diet during gestation than in sows fed a starch diet (Van der Peet-Schwering et al., 2003a). A deficiency in glucogenic energy, especially at the end of gestation, in sows fed a high NSP diet might explain the lower birth weight of the piglets. For fetal development glucose is required (Père et al., 2000). In high NSP diets, the starch content is generally low and therefore these diets may provide insufficient glucogenic energy to sustain optimal fetal growth at the end of gestation. It can be hypothesized that in case of a shortage of glucogenic energy, feeding sows additional starch (glucogenic energy) at the end of gestation will increase the birth weight of the piglets while feeding sows additional fat (lipogenic energy) does not affect birth weight. To meet the increasing demand for glucose by the fetuses, insulin sensitivity and glucose tolerance in sows decrease after 85 d of gestation (Schaefer et al., 1991; Père et al., 2000). The rate of glucose utilization by maternal tissues decreases, which allows for improved placental transfer of glucose. This improved placental transfer may result in hyperinsulinism and hyperglycemia in the fetuses. Hyperinsulinism can cause extreme hypoglycemia 1 to 1.5 h after birth resulting in postnatal death (Sepe et al., 1985). Kemp et al. (1996) indeed reported greater piglet mortality in sows that were less glucose tolerant. Feeding sows additional energy at the end of gestation may induce glucose intolerance in sows (Kemp et al., 1996). Therefore, this experiment was conducted to determine the effects of feeding additional starch or fat from d 85 of gestation to parturition on litter performance and on glucose tolerance in sows that are fed a high NSP diet.

Material and methods

Animals, Experimental Design and Housing

The day after breeding, a total of 141 rotational-bred (involving the breeds: Dutch Landrace, Finnish Landrace and Dutch Large White) multiparous sows were allotted to the experiment. At d 85 of gestation, sows were assigned to the treatments based on parity number and BW. Mean parity number of the sows was 4.8 (SD = 0.4). Three treatments were applied from d 85 of gestation until parturition. Sows in the control group were fed a high NSP diet. Sows in the extra starch group received an additional daily amount of 580 g wheat starch (equivalent to 500 g starch containing 6.7

MJ glucogenic NE; glucogenic energy mainly comes from glucose) compared to the control group. Sows in the extra fat group received an additional daily amount of 200 g soybean oil (equivalent to 198 g fat containing 6.7 MJ lipogenic NE; lipogenic energy mainly comes from lipids) compared to the control group. The wheat starch and soybean oil, respectively, were not top-dressed but incorporated in the total diet. Due to differences in the calculated and analyzed contents of starch and fat in the diets and due to feed refusals, the contrasts between treatments were somewhat smaller than intended. Daily starch and fat intakes were 270 and 176 g, 630 and 171 g, and 282 and 340g, respectively, in sows that were fed the high NSP diet, the extra starch diet or the extra fat diet. Thus, sows in the extra starch and in the extra fat group received additional daily amounts of starch and fat of 360 g and 164 g, respectively, instead of 500 g and 198 g, respectively. During gestation, sows were housed individually in stalls of 2.00 x 0.64 m. The stalls had partly slatted floors that consisted of 0.90-m concrete solid floor and 1.10-m concrete slatted floor. Approximately 10 d before the expected time of parturition, sows were moved to farrowing rooms each having six pens of 2.20 x 1.80 m. The concrete solid floor (1.00 x 1.80 m) was equipped with floor heating. Cross fostering of piglets took place within 3 days after parturition and occurred only among sows of the same experimental treatment. Cross fostering was used in cases where large or small litter sizes occurred. Piglets were weaned at an average age of 27.5 days (SD = 2.3). All rooms were equipped with computer-controlled heating and mechanical ventilation systems. The care and treatment of the sows were according to Dutch animal welfare legislation. The institutional Animal Care and Use Committee of the Wageningen University approved all experimental protocols.

Diets and Feeding

Until d 85 of gestation, all sows were fed the high NSP diet. From d 85 of gestation until parturition, sows were fed the high NSP diet, the extra starch diet or the extra fat diet (Table 1). The extra starch diet contained 85.4% of the high NSP diet and 14.6% of wheat starch. The extra fat diet contained 94.5% of the high NSP diet and 5.5% of soybean oil. Gestating sows were fed twice per day (0800 and 1500). The daily amount of feed increased during gestation (d 0 to 60: 2.5 kg/d; d 60 to 85: 2.9 kg/d). From d 85 to parturition, sows were fed 3.40 kg/d of the high NSP diet (according to Van der Peet-Schwering et al., 2003a), 3.98 kg/d of the extra starch diet (equivalent to 3.40 kg of the high NSP diet and 0.58 kg of wheat starch), or 3.60 kg/d of the extra fat diet (equivalent to 3.4 kg of the high NSP diet and 0.20 kg of soybean oil), respectively. Due to feed refusals, the actual daily feed and energy intakes from d 85 of gestation until parturition were 3.38 kg and 28.5 MJ NE, 3.89 kg and 34.6 MJ NE, and 3.54 kg and 34.8 MJ NE, respectively, in sows that were fed the high

NSP diet, the extra starch diet, or the extra fat diet. From parturition until weaning all sows were fed the same lactation diet (Table 1). Sows were fed on an ascending scale from parturition until d 6 after parturition and were given free access to the lactation diet from d 6 after parturition until weaning. All feeds were given as pelleted dry feed. During gestation, drinking water was supplied twice per day during 1 hour (0800 to 0900 and 1500 to 1600). In the farrowing room, sows were given free access to drinking water. Piglets were given free access to a commercial creep feed (CHV-Landbouwbelang, Veghel, The Netherlands; 9.82 MJ/kg NE; 177 g/kg CP; 10.5 g/kg ileal digestible lysine; 3.5 g/kg digestible phosphorus) from d 11 after birth until weaning.

Measurements

Feed and feed intake. Experimental diets were sampled weekly. The weekly samples were pooled per 3 mo. Feed was analyzed every 3 mo for DM, ash, CP, crude fat, starch and sugars. All samples were analyzed in duplicate. The contents of DM, ash, CP and crude fat were analyzed according to standard methods ISO 6496 (ISO, 1999b), ISO 5984 (ISO, 1978), ISO 5983 (ISO, 1979) and ISO 6492 procedure B (ISO, 1999a), respectively. The starch content was analyzed enzymatically by the method of Brunt (2000). The sugar content was analyzed by the method of Luff Schoorl (EG, 1971). Dietary NSP was calculated as dietary DM minus dietary ash, CP, crude fat, starch and sugars. Feed intake of the sows was recorded from d 85 of gestation until parturition and during wk 1, 2, 3 and 4 of the lactation period, respectively. In addition, creep feed intake of the piglets was recorded.

Sow and piglet performance. Individual BW and backfat thickness of the sows were measured at d 84 of gestation, at the day of transfer to the farrowing room and at weaning. Backfat thickness was measured ultrasonically at 3 points 5 cm left of the median as described by Vesseur et al. (1997). Number of total piglets born (is live-born piglets plus stillborn piglets plus mummies) and individual weights of the live-born piglets and stillborn piglets were recorded within 16 hours after parturition. Time and cause of piglet mortality during the suckling period were recorded. At weaning, number of weaned piglets and individual weights of the weaned piglets were recorded.

Oral glucose tolerance test. Approximately 1 week before the expected time of parturition, an oral glucose tolerance test was performed in 65 randomly chosen sows. Twenty-seven of the 65 sows did not eat the total amount of glucose administered within 10 min after feeding and were therefore omitted from the statistical analysis. After an overnight feed withdrawal, at 0800, sows were fed pelleted glucose (3 g/kg $BW^{0.75}$). Blood samples were taken from the sows after making a small incision in the tail at –10, 10, 20, 30, 40, 50, 60, 70, 80, 90, 105 and 120 minutes after glucose

Table 1. Composition of experimental diets (as-fed basis)

Item	Gestation diet			Lactation diet
	High NSP[a]	Extra starch[b]	Extra fat[c]	
Ingredient, g/kg				
Wheat	45.0	38.0	43.0	-
Tapioca	50.0	42.0	48.0	367.0
Soybean meal (49 % CP)	37.0	32.0	35.0	97.0
Soybean hulls (12 % CP)	48.0	41.0	45.0	-
Sunflower meal (31 % CP)	180.0	154.0	170.0	185.0
Sugar beet pulp	401.3	342.3	378.6	-
Alfalfa meal	21.0	18.0	20.0	50.0
Wheat starch	-	146.0	-	-
Peas	-	-	-	105.0
Wheat middlings	-	-	-	80.0
Molasses, cane	51.0	44.0	48.0	40.0
Straw	110.0	94.0	104.0	-
Mixed animal fat	42.6	36.5	40.0	37.5
Soybean oil	-	-	55.0	10.0
Limestone	-	-	-	10.0
Monocalcium phosphate	4.8	4.1	4.5	6.2
Salt	2.5	2.1	2.4	4.3
Phytase (960 phytase units/kg)	0.4	0.3	0.4	0.5
Lysine-50%[d]	1.0	1.0	1.0	2.2
Threonine-10%[d]	0.4	0.4	0.4	0.3
Premix[e]	5.0	4.3	4.7	5.0
Calculated composition, g/kg				
Crude protein	129	111	122	156
Crude fat	52	45	104	60
Starch	72	187	69	325
Sugar	78	67	73	34
Ash	72	62	68	77
Non-starch polysaccharides[f]	491	420	464	219
NE (MJ/kg)[g]	8.44	8.90	9.84	9.41
Ileal digestible lysine	4.3	3.8	4.1	7.1
Calcium	6.6	5.6	6.2	9.1
Phosphorus	4.0	3.5	3.8	5.7
Analyzed composition, g/kg				
Crude protein	128	113	123	-
Crude fat	52	44	96	-
Starch	80	162	80	-
Sugar	78	68	73	-
Ash	86	79	87	
Non-starch polysaccharides	466	427	444	-

[a] NSP is non-starch polysaccharides.
[b] The extra starch diet is a dilution of the high NSP diet based on inclusion of 14.6% wheat starch.
[c] The extra fat diet is a dilution of the high NSP diet based on inclusion of 5.5% soybean oil.
[d] Lysine and threonine were mixed with maize as a carrier at a ratio of 1:1 and 1:9, respectively.
[e] Provided the following nutrients per kg of premix: vitamin A, 1,400,000 IU; vitamin D3, 280,000 IU; vitamin E, 3,400 mg; riboflavin, 800 mg; niacinamide, 3,600 mg; d-panthothenic acid, 1,400 mg; choline chloride, 50,000 mg; vitamin B12, 3,000 ug; folic acid, 480 mg; biotin, 20 mg; cobalt, 50 mg (as $CoSO_4.7H_2O$); copper,2,000 mg (as $CuSO_4.5H_2O$); manganese, 4,800 mg (as MnO_2); iron, 16,000 mg (as $FeSO_4.7H_2O$); zinc, 10,800 mg (as $ZnSO_4$); iodine, 80 mg (as KI); selenium, 30 mg (as $Na_2SeO_3.5H_2O$).
[f] Non-starch polysaccharide content was calculated as dry matter content minus ash, crude protein, crude fat, starch and sugar content.
[g] Net energy was calculated using digestibility coefficients as published in the Dutch feed tables (CVB, 2000). However, based on the results of Rijnen et al. (2001), the estimated energy value of fermentable NSP was assumed to be similar to that of digested starch (13.5 MJ/kg).

was fed (Kemp et al., 1996). Glucose concentration in each blood sample was measured immediately using the Glucosemeter Elite™ (Bayer Diagnostics, Mijdrecht, The Netherlands; accuracy = 7.5%). For each sow, the following characteristics were calculated: basal (-10 min sample) glucose concentration, maximum increase in glucose concentration, time of the maximum concentration, area under the entire 120-min curve, and area under the curve for the first 70 min (Kemp et al., 1996). The glucose peak ended at about 70 min after glucose was fed and therefore, area under the curve for the first 70 min was calculated. The maximum increase in glucose concentration was calculated by subtracting the basal glucose concentration from the maximum glucose concentration achieved. The areas under the curves (**AUC**) from 0 to 120 min and from 0 to 70 min were calculated as the area above basal glucose concentrations by integrating the observed glucose concentrations (minus the basal glucose concentration) using the extended trapezoidal rule formula (Abramowitz and Stegun, 1965).

Statistical analysis

Bodyweight and backfat thickness of the sows, changes in BW and backfat thickness, number of total born piglets, piglets birth weight, total litter weight at birth (is birth weight of live-born piglets plus birth weight of stillborn piglets), piglets weaning weight, and feed intake of sows and piglets during lactation were analyzed by means of F-tests using generalized linear models for the fixed effects of dietary treatment during the last month of gestation, genotype and parity of the sow (parity 3, 4, 5 or ≥ 6). Number of total piglets born was used as a covariate in the analysis of piglets birth weight and total litter weight at birth. BW at d 84 and backfat thickness at d 84 were used as covariates in the analysis of BW gain and BW loss, and backfat gain and backfat loss, respectively. Live-born piglets, stillborn piglets, postnatal deaths from birth to d 3 and from birth to d 7, and weaned piglets were analyzed by means of F-tests using logistic regression (McCullagh and Nelder, 1989) for the fixed effects of dietary treatment during the last month of gestation, genotype and parity of the sow. Live-born piglets and stillborn piglets were expressed as a fraction of total piglets born. Piglet mortality from birth to d 3 was expressed as a fraction of live-born piglets. Piglet mortality from birth to d 7 and weaned piglets were expressed as a fraction of live-born piglets after fostering. Response variables with repeated measurements, such as weekly feed intake during lactation, were analyzed by using a split-plot model. The fixed effect of week and the random effect of sow were added to the model. The random sow effect was considered to be normally distributed with mean 0 and variance equal to σ^2_{sow}. Glucose characteristics were analyzed by means of F-tests using generalized linear models for the fixed effects of dietary treatment during the last month of gestation and genotype. Estimates of fixed effects in the model and components of variance were obtained using the Residual Maximum Likelihood (REML) procedure. Fixed effects were assessed using chi-squares for the Wald statistics. After a significant overall test, pairwise differences between treatment means were tested using a t-test. All analyses were performed using the statistical program GenStat (2000).

Results

Litter performance

The number of total piglets born, birth weigh of live-born piglets, birth weight of stillborn piglets, total litter weight at birth, no. of piglets after fostering, piglet mortality from birth to d 3 or d 7 after birth, weaned piglets (expressed as % after fostering), and piglet weaning weight did not differ among sows that were fed a high NSP diet and sows that were fed additional starch or fat at the end of gestation (Table 2). Live-born piglets (expressed as % of total born piglets) was higher in sows that were fed the high NSP diet than in sows that were fed additional fat at the end of gestation whereas it was intermediate in sows that were fed additional starch ($P < 0.10$; Table 2). Stillborn piglets (expressed as % of total born piglets) was lower in sows that were fed the high NSP diet than in sows that were fed additional fat whereas it was intermediate in sows that were fed additional starch ($P < 0.10$; Table 2).

Table 2. Litter performance of sows as affected by dietary treatment from d 85 of gestation until parturition

	Gestation diet			
Item	High NSP[a]	Extra starch[b]	Extra fat[c]	SEM
No. of litters	48	51	42	
Total piglets born/litter[d]	12.6	13.2	13.0	0.4
Live-born piglets, % of total born	95.0^{x}	92.9^{xy}	91.0^{y}	1.3
Stillborn piglets, % of total born	4.3^{x}	5.1^{xy}	7.7^{y}	1.1
Birth weight of live-born piglets, kg	1.40	1.44	1.39	0.03
Birth weight of stillborn piglets, kg	1.09	1.07	1.05	0.10
Total litter weight at birth, kg	17.58	17.92	17.15	0.34
No. of piglets after fostering	11.6	12.0	11.6	0.3
Mortality from birth to d 3, % of live-born	7.6	8.0	7.8	1.3
Mortality from birth to d 7, % after fostering	10.0	9.2	9.7	1.6
Weaned piglets, % after fostering	89.1	88.7	88.0	1.3
Piglet weaning weight, kg	7.8	7.9	7.9	0.1

[a] NSP is non-starch polysaccharides.
[b] The extra starch diet is a dilution of the high NSP diet based on inclusion of 14.6% wheat starch.
[c] The extra fat diet is a dilution of the high NSP diet based on inclusion of 5.5% soybean oil.
[d] No. of total born piglets is live-born piglets plus stillborn piglets plus mummies.
[x,y] Within a row, LSmeans without a common superscript differ ($P < 0.10$).

Body weight and backfat thickness

Bodyweight gain from d 84 of gestation until the day of transfer to the farrowing room was higher in sows fed additional starch or fat at the end of gestation than in sows fed the high NSP diet ($P < 0.05$; Table 3). Backfat gain from d 84 gestation until the day of transfer to the farrowing room was higher in sows fed additional fat at the end of gestation than in sows fed the high NSP diet whereas it was intermediate in sows fed additional starch ($P < 0.05$; Table 3). Bodyweight and backfat losses in the farrowing room were not affected by dietary treatment in the last month of gestation (Table 3).

Table 3. Body weight and backfat thickness of sows as affected by dietary treatment from d 85 of gestation until parturition

	Gestation diet			
Item	High NSP[a]	Extra starch[b]	Extra fat[c]	SEM
Number of sows	48	51	42	
Body weight, kg				
At d 84 of gestation	226.0	225.2	228.7	5.3
Gain from d 84 to FR[d]	17.5[x]	22.0[y]	23.0[y]	0.8
Loss from FR to weaning	33.3	37.1	34.4	1.9
Backfat thickness, mm				
At d 84 of gestation	14.2	14.5	14.8	0.9
Gain from d 84 to FR	1.1[x]	1.8[xy]	2.3[y]	0.3
Loss from FR to weaning	2.8	3.3	3.4	0.3

[a] NSP is non-starch polysaccharides.
[b] The extra starch diet is a dilution of the high NSP diet based on inclusion of 14.6% wheat starch.
[c] The extra fat diet is a dilution of the high NSP diet based on inclusion of 5.5% soybean oil.
[d] FR is day of transfer to the farrowing room.
[x,y] Within a row, LSmeans without a common superscript differ ($P < 0.05$).

Feed intake

In weeks 1 and 2 of lactation, feed intake of the sows was not affected by dietary treatment during the last month of gestation. In week 3 of lactation, however, sows fed the high NSP diet ate more than sows fed additional starch or fat in the last month of gestation ($P < 0.05$; Table 4). In week 4 of lactation, sows fed additional starch at the end of gestation ate less than sows in the other two experimental treatments ($P < 0.10$). Overall feed intake during 4 weeks of lactation was highest in sows fed the high NSP diet, lowest in sows fed additional starch at the end of gestation and intermediate in sows fed additional fat ($P < 0.10$).

Table 4. Feed intake of sows and piglets as affected by dietary treatment from d 85 of gestation until parturition

Item	Gestation diet			SEM
	High NSP[a]	Extra starch[b]	Extra fat[c]	
Number of sows	48	51	42	
Feed intake sows, kg/d				
Week 1 of lactation[d]	4.02	4.00	3.96	0.13
Week 2 of lactation	6.70	6.60	6.48	0.13
Week 3 of lactation	7.65[x]	7.08[y]	7.14[y]	0.13
Week 4 of lactation	7.65[w]	7.27[z]	7.73[w]	0.13
Mean of weeks 1 to 4	6.45[w]	6.14[z]	6.24[wz]	0.11
Total creep feed intake per piglet, kg	0.28	0.29	0.29	0.02

[a] NSP is non-starch polysaccharides.
[b] The extra starch diet is a dilution of the high NSP diet based on inclusion of 14.6% wheat starch.
[c] The extra fat diet is a dilution of the high NSP diet based on inclusion of 5.5% soybean oil.
[d] In week 1 of lactation, sows were fed a common amount of feed.
[x,y] LSmeans within a row without a common superscript letter differ ($P < 0.05$).
[w,z] LSmeans within a row without a common superscript letter differ ($P < 0.10$).

Glucose tolerance

Basal glucose concentration, maximum increase in glucose concentration, and time of the maximum concentration were not affected by dietary treatment in the last month of gestation (Table 5). Areas under the entire 120 min curve and under the curve for the first 70 min were higher in sows fed additional fat in the last month of gestation than in sows fed the high NSP diet or in sows fed additional starch ($P < 0.05$ and $P < 0.01$, respectively). The highest glucose concentrations were measured at 40 min after glucose was fed (Figure 1).

Table 5. Glucose characteristics in sows at d 108 of gestation as affected by dietary treatment from d 85 of gestation until parturition

Item	Gestation diet			SEM
	High NSP[a]	Extra starch[b]	Extra fat[c]	
No. of sows	11	14	13	
Basal glucose, mmol/L[d]	2.72	2.68	2.53	0.09
Maximum increase, mmol/L[e]	1.47	1.41	1.54	0.19
Time of maximum glucose, min[f]	40.3	39.6	37.4	4.4
Area under the 120 min curve, (mmol/L).min[g]	60.9[x]	56.9[x]	97.3[y]	12.4
Area under the 70 min curve, (mmol/L).min[g]	41.1[w]	42.5[w]	65.9[z]	9.5

[a] NSP is non-starch polysaccharides.
[b] The extra starch diet is a dilution of the high NSP diet based on inclusion of 14.6% wheat starch.
[c] The extra fat diet is a dilution of the high NSP diet based on inclusion of 5.5% soybean oil.
[d] Glucose concentration in the sample taken 10 min before glucose feeding.
[e] Maximum glucose concentration minus basal glucose concentration.
[f] Time at which maximum glucose concentrations was measured.
[g] Areas under the curve are calculated as the areas above basal glucose concentrations.
[x,y] LSmeans within a row without a common superscript letter differ ($P < 0.05$).
[w,z] LSmeans within a row without a common superscript letter differ ($P < 0.10$).

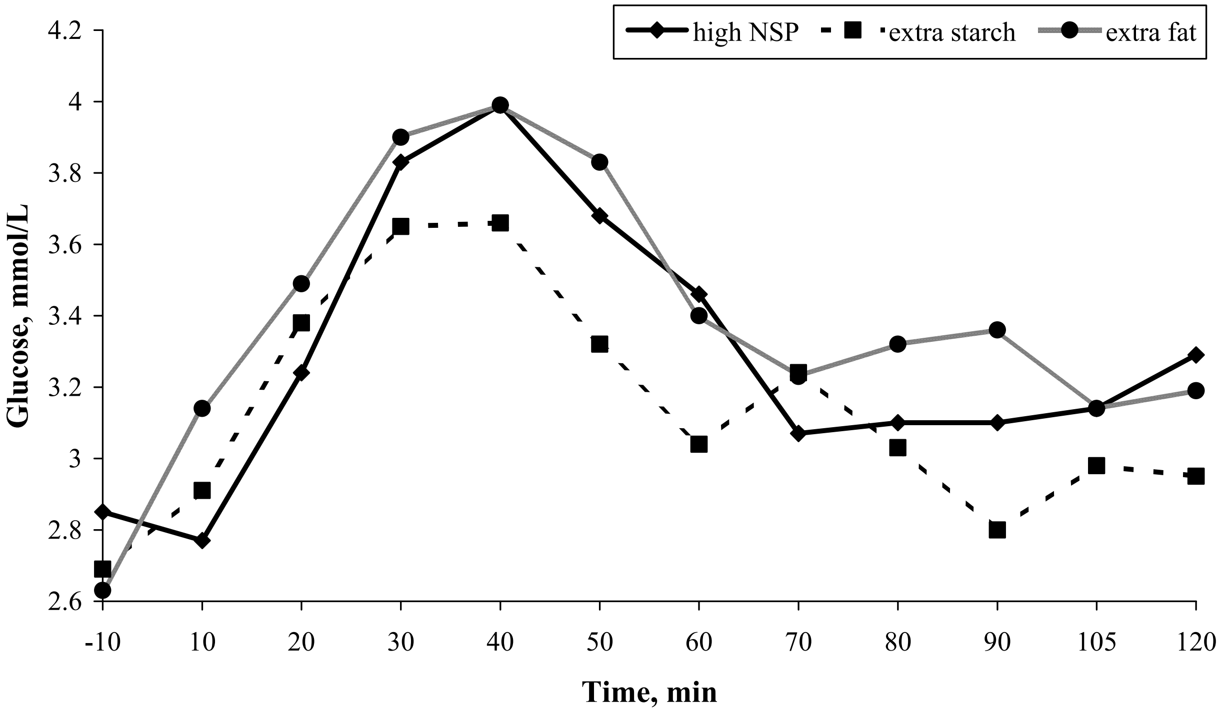

Figure 1. Mean glucose concentrations (mmol/L) before and after glucose was fed to sows (from –10 to 120 minutes) at d 108 of gestation as affected by dietary treatment from d 85 of gestation until parturition (high NSP diet (-◆-), extra starch diet (**- ■ -),** extra fat diet (- ●-)).

Discussion

The supply of additional dietary fat in late-gestating sows fed a high NSP diet did not increase piglets birth weight and total litter weight at birth. These results are in agreement with studies of Sinclair et al. (2001) and Averette Gatlin et al. (2002). In a review, Pettigrew and Moser (1991) also reported that fat supplementation during late pregnancy had no effect on piglets birth weight. Moreover, the supply of additional dietary starch in late-gestating sows fed a high NSP diet did not increase piglets birth weight and total litter weight at birth. This suggests that the supply of glucogenic energy in late-gestating sows that are fed a high NSP diet is sufficient for fetal growth. Daily starch plus sugar intake in the last month of gestation in sows that were fed the high NSP diet, the additional starch diet or the additional fat diet were 534, 895 and 542 g/d, respectively. Thus, a daily intake of about 550 g starch plus sugar in late-gestating sows seems sufficient for fetal growth. Van der Peet-Schwering et al. (2003a) reported a lower birth weight of the piglets in sows that were fed a high NSP diet during gestation compared to those that were fed a starch diet. In that study, the higher number of live-born piglets in sows that were fed the high NSP probably explains the lower piglet birth weight.

Stillborn piglets were highest in sows that were fed additional fat. These results are in contrast with results of Shurson et al. (1986) and Stahly et al. (1986). In their studies, the number of stillborn piglets was not affected by supplemental dietary fat at the end of gestation. Averette Gatlin et al. (2002), however, reported an increase in the number of stillborn piglets when late-gestating sows were fed a diet with 10% supplemental fat. They did not have an explanation for this increase in stillborn piglets. It might be that sows that are fed additional fat in late gestation are less glucose tolerant and that therefore stillborn piglets are increased. Sows that were fed additional fat at the end of gestation had the greatest glucose AUC (Table 5) and this indicates that these sows were less tolerant for glucose. Studies in rodents have also shown that high-fat feeding results in an increase in insulin resistance and consequently in an increase in glucose intolerance (Kraegen et al, 1991). Schaefer et al. (1991) reported that the number of stillborn piglets tended to be higher in sows that were less glucose tolerant.

Weldon et al. (1994) indicated that feeding gestating sows extra energy may cause glucose intolerance. In our study, however, feeding additional starch at the end of gestation did not increase glucose intolerance in sows. The glucose AUC in sows that were fed additional starch was not increased compared to sows that were fed the high NSP-diet. In a study with grazing mares that were fed supplemental dietary energy (starch and sugar or fat and fiber) similar results were found (Hoffman et al., 2003). Mares that were fed supplemental starch and sugar had higher basal glucose concentrations, lower glucose AUC, and a more rapid glucose clearance rate than mares that were fed additional fat and fiber. These results indicate that mares that were fed supplemental starch and sugar have a better glucose tolerance. An adaptation to high starch levels in mares and sows that were fed additional starch and sugar (mares and sows were adapted to the diets for 4 mo and 3 weeks, respectively) probably explains the better glucose tolerance. Thus, it seems that feeding late-gestating sows extra energy from fat may induce glucose intolerance but that feeding sows extra energy from starch does not induce glucose intolerance.

Kemp et al. (1996) reported an increased piglet mortality in the first 7 d after birth in sows that were less glucose tolerant at d 104 of gestation. In our study, sows that were fed additional fat were less glucose tolerant and therefore a higher piglet mortality could be expected. Piglet mortality, however, was not affected by gestation feeding regime (Table 2). Moreover, reason of mortality was not affected by gestation feeding regime. In fact, in most studies there was no effect of feeding supplemental dietary fat in late gestation on piglet mortality after birth (Pettigrew, 1981; Azain, 1993). Moreover, in some studies, survival rate among piglets was increased, especially when late-gestating sows were fed medium-chain tryglycerides (Azain, 1993; Jean and Chiang, 1999).

Medium-chain triglycerides are rapidly metabolized to ketone bodies that can readily cross the placenta and probably spare glucose for glycogen synthesis and, hence, increase the glycogen stores (Jean and Chiang, 1999).

Body weight and backfat gains in the last month of gestation were higher in sows that were fed additional starch or additional fat than in sows that were fed the high NSP diet. The higher BW and backfat gains can be explained by higher daily energy intakes. It has frequently been demonstrated that a higher energy intake during gestation increases backfat thickness at farrowing and decreases voluntary feed intake of the sows during lactation (Dourmad, 1991; Revell et al., 1998). Our results are in agreement with these results although voluntary feed intake during lactation was only slightly decreased in sows that were fed additional starch or additional fat in late gestation. Revell et al. (1998) found that an increase in backfat thickness at parturition from 17.9 to 24.3 mm resulted in a decrease in lactation feed intake of 1.6 kg/d. In our study, the differences in backfat gain were 0.7 and 1.2 mm for sows that were fed additional starch or additional fat, respectively, compared to the high NSP diet. Therefore, only small differences in lactation feed intake could be expected. Probably as a result of the only small differences in feed intake during lactation, BW and backfat losses during lactation were similar in sows that were fed the high NSP diet and in sows that were fed additional starch or additional fat.

Implications

The supply of additional energy (starch or fat) in late-gestating sows that are fed a diet with a high level of non-starch polysaccharides does not increase litter weight at birth but it does increase maternal gain. This suggests that a daily intake of about 550 g starch and sugar in late gestation is sufficient for fetal growth and that it is not necessary to supply additional energy to late-gestating sows that are fed a diet with a high level of non-starch polysaccharides. Feeding late-gestating sows additional energy from fat tended to increase stillborn piglets (expressed as % of total born piglets) and increased the area under the curve for glucose indicating that feeding additional fat may result in less glucose tolerant sows. Feeding late-gestating sows additional energy from starch does not affect glucose tolerance.

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Chapter 6

Performance and individual feed intake characteristics of group-housed sows fed a non-starch polysaccharides diet ad libitum during gestation over three parities

C. M. C. van der Peet-Schwering[§], B. Kemp[†], J. G. Plagge[§], P. F. G. Vereijken[*], L. A. den Hartog[‡], H. A. M. Spoolder[§], and M. W. A. Verstegen[†]

[§] Applied Research Division of Animal Sciences Group, Wageningen UR
P.O. Box 2176, 8203 AD Lelystad, The Netherlands

[†] Wageningen Institute of Animal Sciences, Wageningen UR
P.O. Box 338, 6700 AH Wageningen, The Netherlands

[*] Biometris, Wageningen UR
P.O. Box 100, 6700 AC Wageningen, The Netherlands

[‡] Nutreco Agriculture Research and Development
P.O. Box 220, 5830 AE Boxmeer, The Netherlands

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Abstract

The objective of this experiment was to study the effects of feeding group-housed gestating sows a diet with a high level of fermentable non-starch polysaccharides (NSP) ad libitum on the development in individual feed intake characteristics and reproductive performance during three successive reproduction cycles. Performance of the ad libitum fed sows was compared to the performance of sows that were fed a conventional diet restrictedly. Feed intake characteristics during gestation were only measured in the ad libitum fed sows. One hundred and nineteen sows were assigned to one of two gestation feeding regimes. Gestating sows were fed a conventional Dutch diet restrictedly or a diet with a high level of fermentable NSP ad libitum. During lactation, sows were given free access to a commercial lactation diet from d 6 after parturition onwards. The ad libitum fed sows ate 1.3 kg/d more during gestation than the restrictedly fed sows ($P < 0.001$) resulting in higher body weight and backfat gains during gestation ($P < 0.05$). Sows that were fed ad libitum during gestation lost more body weight and backfat during lactation ($P < 0.001$) than sows that were fed restrictedly during gestation. Feed intake during lactation, however, was similar in sows that were fed restrictedly or ad libitum during gestation. The numbers of total piglets born, live-born piglets and stillborn piglets, piglets birth weight, weaning-to-estrus interval and percentage of sows that returned to estrus after first insemination were not affected by gestation feeding regime. Mean daily voluntary feed intake over the three reproduction cycles in the ad libitum fed gestating sows was 4.2 kg/d. Depending on the number of preceding reproduction cycles that a sow was fed ad libitum, the maximum voluntary feed intake was reached in parity 3, 4 or 5 and then remained stable in subsequent parities. Mean daily feed intake of the ad libitum fed sows increased from weeks 2 to 6 of gestation and then decreased to week 15 of gestation. The mean number of daily visits with feed intake over the three reproduction cycles was 13.8. On average, ad libitum fed sows spent 90 min/d on eating. This study shows that it is possible to feed gestating sows a diet with a high level of fermentable NSP ad libitum during three successive reproduction cycles without negative effects on reproductive performance.

Introduction

Feed restriction is identified as one of the major factors associated with the development of stereotypic behavior in gestating sows (Terlouw et al., 1991). Ad libitum feeding of gestating sows is very effective in reducing stereotypic behavior (Bergeron et al., 2000). However, ad libitum feeding with the conventional low fiber diets is not a viable option because of the high feed intake capacity of sows and its concomitant obesity (Petherick and Blackshaw, 1989). Diets with a high level of fermentable non-starch polysaccharides (NSP) can limit ad libitum feed intake to acceptable levels (Brouns et al., 1995). However, data on the development in individual feed intake characteristics during gestation and in successive parities of group-housed ad libitum fed gestating sows are lacking. Reproductive performance of sows of parities 1 and 2 does not appear to be influenced by providing diets containing a high level of fermentable NSP ad libitum from d 28 of gestation (Whittaker et al., 2000). From a Danish field study, there are some indications that ad libitum feeding of a diet with a high level of fermentable NSP during gestation may reduce piglet birth weight compared to restricted feeding of a low fiber diet (Fisker and Sørensen, 1999). This may be explained by a decreasing feed intake in the last month of gestation in ad libitum fed sows. Long term consequences of feeding gestating sows ad libitum from d 1 of gestation are not known.

Therefore, the first objective of this experiment was to study the development in individual feed intake characteristics of group-housed gestating sows that are fed a high NSP diet ad libitum over three successive reproduction cycles. The second objective was to determine the effects of feeding a high NSP diet ad libitum compared to feeding a conventional diet restrictedly on reproductive performance and development in body weight and backfat thickness during three successive reproduction cycles.

Material and Methods

Animals, Experimental Design and Diets

A total of 119 crossbred (Dutch Large White x Dutch Landrace) nulliparous, primiparous and multiparous sows were allotted to the experiment during three successive trials. In each trial, on the day of weaning 40 sows were blocked by parity number and body weight and assigned to one of two gestation feeding regimes. The same treatment was applied over three successive reproduction cycles. Sows were fed a conventional diet typical for the Netherlands restrictedly or a diet with a high level of fermentable NSP ad libitum (Table 1). To comply with the Dutch law (National

Reference Center, 1998), the conventional diet contained 34% NSP. The high NSP diet contained 50% NSP. Estrus was checked twice a day in the presence of a mature boar, using the back pressure test. Sows that showed estrus were inseminated each day of standing estrus with a commercial dose of semen (3×10^9 sperm cells) of a Dutch Large White boar. Sows that returned to estrus after first insemination were rebred. Rebred sows were moved to the farrowing room and weaned three weeks later than the other sows in the group (sows that did not return to estrus) and therefore replaced by another sow at the day of weaning of the group. If a sow was culled during the experiment, another sow replaced her and was added to the group at the day of weaning. Thus, part of the sows that were initially allotted to the experiment were followed for only one or two reproduction cycles. Moreover, replacement sows were followed for only one or two reproduction cycles. The number of sows on trial in reproduction cycles 1, 2 and 3 is presented in table 2. The care and treatment of the sows were according to Dutch animal welfare legislation. The Institutional Animal Care and Use Committee of the Wageningen University approved all experimental protocols.

Housing

From weaning until seven days after insemination, sows were housed individually in stalls of 2.00 x 0.64 m. Seven days after insemination, sows were moved to one of two gestation rooms and were kept in stable groups (no sows were added to the group). Both gestation rooms contained two pens for 10 sows each. Pens were 4.6 x 4.9 m (2.6 x 4.9-m concrete solid floor and 2.0 x 4.9-m metal slats). In one gestation room, sows were fed restrictedly in an electronic sow feeding station (Insentec B.V., Marknesse, The Netherlands). To identify the individual animals, each sow had an electronic ear transponder. Access to the feeding station was only possible if a sow had not consumed her daily ration. The feeding station was located between the two pens. Therefore, sows from both pens could use the same feeding station. In the morning, sows in pen 1 were given access to the feeding station, whereas in the afternoon, sows in pen 2 were given access to the feeding station. In the other gestation room, in both pens sows were fed ad libitum using IVOG-feeding stations (Insentec B.V., Marknesse, The Netherlands) for gestating sows. These feeding stations were adapted from feeding stations used for growing-finishing pigs (De Haer, 1992). The IVOG-feeding stations consist of a single space feeder placed on load cells that weighed within a range of 0 to 50 kg. Each weighing was rounded in steps of 10 g. To identify individual animals, each sow had an electronic ear transponder that was read by two antennas in the IVOG-feeding station. The IVOG-feeding station recorded feeder weight and time at the beginning and end of each visit to the

Table 1. Composition of the experimental diets (as-fed basis)

Item	Conventional diet[a], Restrictedly fed	High NSP[b] diet, Ad libitum fed	Lactation diet
Ingredient, %			
Wheat	5.00	-	25.00
Barley	-	4.90	15.00
Corn	-	-	10.00
Bakery by-product	5.00	-	-
Tapioca	22.00	8.10	7.50
Palm kernel (extracted)	10.00	-	-
Linseed expeller	2.50	-	2.50
Rapeseed meal (extracted)	5.00	-	2.00
Soybean hulls	10.00	8.40	-
De-hulled soybean meal (extracted)	3.00	-	8.00
Sunflower meal (extracted)	1.00	13.90	6.50
Sugar beet pulp	10.00	45.39	-
Lucerne	6.50	5.40	-
Wheat middlings	10.00	7.30	12.50
Molasses, cane	5.00	2.50	4.00
Fish meal	-	-	3.00
Animal fat	3.50	1.17	1.60
Soybean oil	-	0.22	-
Monocalcium phosphate	0.39	0.28	0.61
Salt	0.23	-	0.40
Phytase (960 phytase units/kg)	0.06	0.05	0.05
Lysine-50%[c]	0.20	-	0.20
Threonine-10%[c]	0.01	-	0.04
DL-Methionine	0.01	-	-
Vitamin-mineral premix[d]	0.60	0.39	1.10
Clinoptilolite[e]	-	2.00	-
Analyzed content, %			
Crude protein	12.6	12.8	-
Crude fat	6.3	2.9	-
Ash	6.5	8.4	-
Crude fiber	12.6	15.9	-
Calculated content, %			
Crude protein	12.3	12.2	16.2
Crude fat	5.7	2.7	4.5
Starch	24.0	10.8	38.0
Sugar	5.6	4.7	5.5
NSP[f]	34.0	50.0	22.0
Fermentable NSP	21.0	34.3	10.2
NE (MJ/kg)[g]	8.53	7.03	9.23
Ileal digestible lysine	0.41	0.33	7.4

[a] A conventional gestation diet typical for the Netherlands.
[b] NSP is non-starch polysaccharide.
[c] Lysine and threonine are mixed with maize as a carrier at a ratio of 1:1 and 1:9, respectively.
[d] Provided the following nutrients per 5 g of premix: vitamin A, 7,000 IU; vitamin D3, 1,400 IU; vitamin E, 17 mg; riboflavin, 4 mg; niacinamide, 18 mg; d-panthothenic acid, 7 mg; choline chloride, 250 mg; vitamin B12, 15 ug; folic acid, 2.4 mg; biotin, 0.1 mg; cobalt, 0.25 mg (as $CoSO_4.7H_2O$); copper,10 mg (as $CuSO_4.5H_2O$); manganese, 24 mg (as MnO_2); iron, 80 mg (as $FeSO_4.7H_2O$); zinc, 54 mg (as $ZnSO_4$); iodine, 0.4 mg (as KI); selenium, 0.15 mg (as $Na_2SeO_3.5H_2O$).
[e] Clinoptilolite was added to the high NSP diet to make the feces of the sows less sticky.
[f] NSP content was calculated as dry matter content minus ash, crude protein, crude fat, starch and sugar content.
[g] NE was calculated according to the Dutch feedstuff table (CVB, 2000).

feeder. In reproduction cycle 3 in trials1 and 2, sows were fed ad libitum with a dry feeder because, for practical reasons, the facility could not be scheduled. Therefore, it was not possible to feed sows with the IVOG-feeding station and, consequently, individual feed intake characteristics could not be measured. This means that individual feed intake characteristics during gestation were measured in 74, 53 and 13 sows in reproduction cycle 1, 2 and 3, respectively.

Approximately 10 d before the expected time of parturition, irrespective of feeding regime during gestation, sows were moved to farrowing rooms each having ten pens of 2.20 x 1.80 m. The concrete solid floor (1.20 x 1.80 m) was equipped with floor heating. Cross fostering of piglets took place within 3 days after parturition and occurred only among sows of the same experimental treatment. Cross fostering was used in cases where large or small litter sizes occurred. Piglets were weaned at an average age of 28.3 d (SD = 3.6). All rooms were equipped with computer-controlled heating and mechanical ventilation systems.

Feeding

In the electronic sow feeding system, the feeding cycle started at 0730 in pen 1 and at 1400 in pen 2. Sows were free to consume their daily ration all at once or to divide it in more portions. Daily amount of the conventional diet increased during gestation (nulliparous and primiparous sows: d 0 to 35: 2.3 kg/d; d 36 to 85: 2.6 kg/d; d 86 to day of transfer to farrowing room: 3.0 kg/d; multiparous sows: d 0 to 35: 2.6 kg/d; d 36 to 85: 2.8 kg/d; d 86 to day of transfer to the farrowing room: 3.4 kg/d). The ad libitum fed sows had free access to the high NSP diet until the day of transfer to the farrowing room. In the farrowing room, all sows were fed the same commercial lactation diet (Table 1) twice a day (0800 and 1500). In the farrowing room, sows were fed the lactation diet at 3.0 kg/d (nulliparous and primiparous sows) or 3.4 kg/d (multiparous sows) prior to parturition. During lactation, sows were fed on an ascending scale from parturition until d 6 after parturition and were given free access to the lactation diet from d 6 after parturition onwards. On the day of weaning, sows were fed 0.5 kg of the lactation diet in the farrowing room at 0800. The day after weaning, sows were returned to their gestation diets. During the weaning-to-estrus interval (WEI) sows were fed the gestation diets at a level of 3.0 kg/d. All feeds were given as dry pelleted feeds. All sows were given free access to drinking water. Piglets were given free access to a commercial creep feed from d 11 after birth until weaning.

Measurements

Feed and feed intake. Experimental diets were sampled weekly. The weekly samples were pooled within 2-mo periods. Feed was analyzed every 2 mo for DM, ash, CP, crude fat and crude fiber. All samples were analyzed in duplicate. The contents of DM, ash, CP, crude fat and crude fiber were analyzed according to standard methods ISO 6496 (ISO, 1999b), ISO 5984 (ISO, 1978), ISO 5983 (ISO, 1979), ISO 6492 procedure B (ISO, 1999a) and NEN 5417 (NEN, 1988), respectively. Feed intake of the sows was recorded in the gestation room and during lactation.

Feed intake characteristics. The IVOG-feeding station recorded feeder weight and time at the beginning and end of each visit to the feeder. The total number of visits per day and the number of visits in which feed was consumed were calculated together with the feed intake (g), time (s) and feeding rate (g/min) per visit in which feed was consumed. Before feed intake characteristics were calculated, the IVOG data were screened. There were two exclusion criteria for possible erroneous data. Firstly, a negligible decrease in feeder weight may cause the recording of a decrease of 10 g due to rounding (Eissen et al., 1998). Therefore, feed intake values of –10 g were tolerated, whereas greater negative values were excluded. The second exclusion criterion was based on the calculated feeding rate per visit (g/min). Visits with a feeding rate of ≥ 400 g/min were excluded, as they were considered unrealistic. This feeding rate was arbitrarily chosen.

Culling rate. During the experiment, culling of sows was recorded. Sows were culled for the following reasons: severe lameness, aggressive behavior, endometritis and reproductive failure including return to estrus for the second time in one parity and abortions in the last month of gestation.

Body weight and backfat thickness. Individual BW and backfat thickness of the sows was measured at the day of transfer to the gestation room, in wk 8 after insemination, at the day of transfer to the farrowing room and at weaning. Backfat thickness was measured ultrasonically at 3 points 5 cm left of the median as described in Vesseur et al. (1997). The distance between the shoulder and last rib was divided in three equal parts to create four points. At the last three points backfat thickness was measured.

Reproductive performance. Number of total piglets born (= live-born piglets + stillborn piglets + mummies) and individual weights of live-born piglets were recorded within 24 h after parturition. At weaning, number of weaned piglets and individual weights of the weaned piglets was recorded. Weaning-to-estrus interval, number of sows that returned to estrus after first insemination and farrowing rate after 1st insemination were recorded for sows in all three reproduction cycles.

Statistical analysis

Total number of visits per day at the IVOG-station, number of visits in which feed was consumed, duration of a visit with feed intake, feed intake per visit, feeding rate and feed intake per day were analyzed using mixed models for the fixed effects of trial, initial parity number (parity number at the start of the trial), reproduction cycle and the interaction between initial parity number and reproduction cycle and the random effect of sow. To study the development of daily feed intake per week of gestation, the model was extended with the fixed effect of week of gestation and an additional random error term for sow differences within a reproduction cycle to describe dependencies between weekly measurements on the same sow. Body weight and backfat thickness of the sows, changes in BW and backfat thickness, number of total piglets born, piglets birth weight, live piglet litter weight at birth, piglets weaning weight, WEI and feed intake during lactation were analyzed using mixed models for the fixed effects of trial, initial parity number, reproduction cycle, gestation feeding regime and the interaction between reproduction cycle and gestation feeding regime and the random effects of sow and pen. Non-significant interactions (except for the interaction between reproduction cycle and feeding regime) were omitted from the model. The random effects of sow, sow within reproduction cycle and pen were considered to be normally distributed with mean 0 and variance equal to σ^2_{sow}, $\sigma^2_{sow.reproduction\ cycle}$ and σ^2_{pen}, respectively. Weaning-to-estrus interval was log transformed prior to analysis to stabilize the variance. Live-born piglets and stillborn piglets were analyzed as a fraction of total piglets born. Weaned piglets were expressed as a fraction of live-born piglets after fostering. Live-born piglets, stillborn piglets and weaned piglets were analyzed using logistic regression (McCullagh and Nelder, 1989). The percentage of sows that returned to estrus after first insemination, and farrowing rate after first insemination were analyzed using logistic regression for binomial distributed data. Initially, response variables were only analyzed in sows that were followed for three reproduction cycles. Additionally, response variables were analyzed in sows that were followed for two or three reproduction cycles and in sows that were followed for one, two or three reproduction cycles. Because the results of these three analyses were very similar, the results of the analysis in sows that were followed for one, two or three reproduction cycles are presented. Estimates of fixed effects and components of variance in the mixed models were obtained using the Residual Maximum Likelihood (REML) procedure. Fixed effects were assessed using chi-squares for the Wald statistics. Pairwise differences between treatment means were tested using a *t*-test. All analyses were performed using the statistical program GenStat (2000).

Results

General

Initially, a total of 119 gilts and sows were assigned to the experiment. Additionally, another 36 sows (16 in the restrictedly fed group and 20 in the ad libitum fed group) (Table 2) were assigned to the experiment to replace culled sows and sows that returned to estrus. During the experiment 12 restrictedly fed sows and 16 ad libitum fed sows were culled. Main reasons for culling were lameness and reproductive failure.

Feed intake characteristics of ad libitum fed sows

Feed intake during gestation of the ad libitum fed sows increased with increasing reproduction cycle (Table 3). However, there was an interaction with initial parity number (Table 4; $P < 0.05$). In sows with initial parity number 1, 2, 3 or 4, feed intake during gestation increased with increasing reproduction cycle whereas in sows with initial parity number ≥ 5, feed intake was similar in reproduction cycles 1, 2 and 3. The total number of visits to the IVOG-feeding station and visits with feed intake were higher in reproduction cycles 2 and 3 than in reproduction cycle 1 (Table 3). Time per visit was lowest and feeding rate was highest in reproduction cycle 2. Feed intake per visit did not increase with increasing reproduction cycle. Mean daily feed intake over the three reproduction cycles in the ad libitum fed sows was dependent on the week of gestation (Figure 1; $P < 0.001$). Mean daily feed intake increased from 3.49 kg/d in week 2 of gestation to 4.76 kg/d in week 6 of gestation. Then it decreased to 3.75 kg/d in week 15 of gestation.

Table 2. Sows and number of litters per gestation feeding regime

	Restricted	Ad libitum
Sows[a], no.		
Reproduction cycle 1	16	20
Reproduction cycle 2	13	16
Reproduction cycle 3	40	38
Litters[b], no.		
Reproduction cycle 1	69	74
Reproduction cycle 2	53	54
Reproduction cycle 3	40	38

[a] The number of sows in reproduction cycles 1, 2 and 3 represent the number of sows that were followed for 1, 2 or 3 reproduction cycles, respectively.
[b] The number of litters in reproduction cycles 1, 2 and 3 represent the number of litters that is studied per reproduction cycle.

Table 3. Feed intake characteristics of ad libitum fed gestating sows[a]

	Reproduction cycle				
	1	2	3	SEM	P-value
No. of observations	74	53	13		
Feed intake during gestation, kg/d	3.79[c]	4.24[d]	4.57[e]	0.08	< 0.001
Daily visits					
Total number	14.3[c]	16.3[d]	16.5[d]	0.8	0.002
Visits with feed intake	12.3[c]	14.3[d]	14.7[d]	0.7	< 0.001
Visits with feed intake					
Time per visit, min	6.9[c]	6.0[d]	6.7[cd]	0.4	0.013
Feed intake per visit, g	349	347	344	18.3	0.960
Feeding rate, g/min	50.5[c]	59.3[d]	52.8[c]	1.3	< 0.001

[a] Data are given as means and SEM.
[c,d,e] Means without a common superscript differ.

Table 4. Effect of interaction between initial parity number and reproduction cycle on feed intake (kg/d) of ad libitum fed gestating sows[a]

	Reproduction cycle			
Initial parity number	1	2	3	SEM
1	2.88[b]	3.90[c]	4.70[d]	0.28
2	3.55[b]	4.25[c]	4.86[d]	0.21
3	4.08[b]	4.27[bc]	4.78[c]	0.24
4	3.88[b]	4.28[c]	4.26[bc]	0.24
≥ 5	4.56	`4.52	4.55	0.17

[a] Data are given as means and SEM.
[b,c,d] Within a row, means without a common superscript differ (*P* < 0.05).

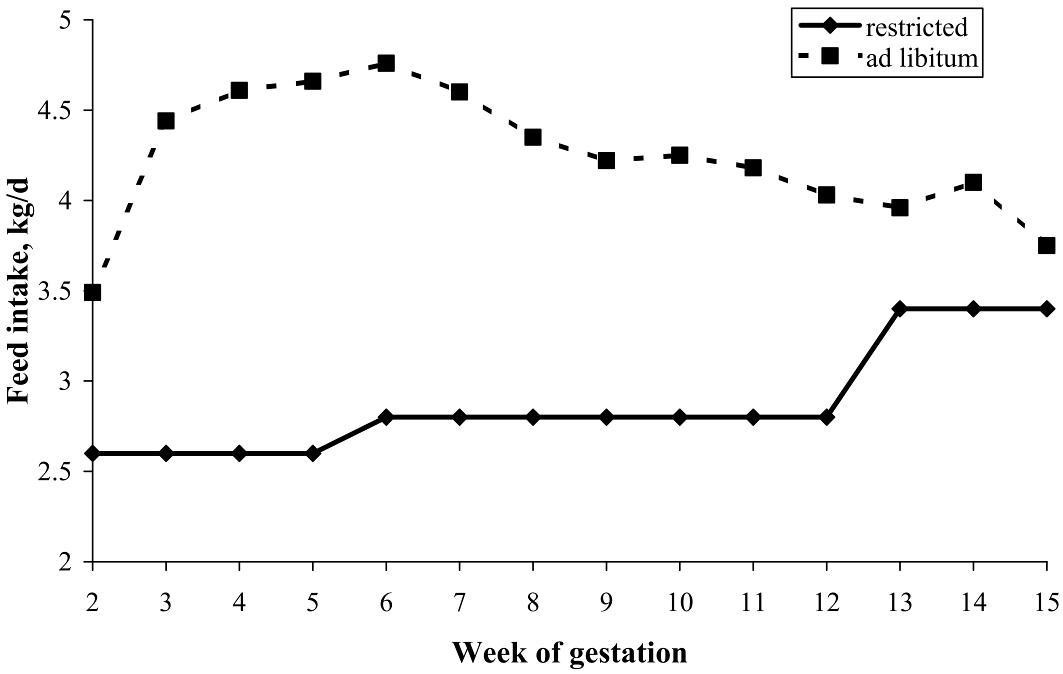

Figure 1. Mean daily feed intake during gestation over three reproduction cycles in restrictedly fed (-◆-) and ad libitum fed (- ■ -) gestating sows

Performance during gestation

In all three reproduction cycles, the ad libitum fed sows ate more during gestation and gained more BW and backfat during gestation than the restrictedly fed sows (Table 5). In reproduction cycle 1, BW at d 7 of gestation was similar in the ad libitum fed and restrictedly fed sows whereas in reproduction cycles 2 and 3, the ad libitum fed sows were heavier at d 7 of gestation (10.9 and 19.6 kg, respectively) (Table 5). The same tendency was seen for backfat. In reproduction cycle 1, the ad libitum fed sows had 1.0 mm less backfat than the restrictedly fed sows whereas in reproduction cycles 2 and 3, they had 1.1 and 2.4 mm, respectively, thicker backfat at d 7 of gestation (Table 5). On average over all three reproduction cycles, BW gains in the first 8 weeks of gestation were 25.3 and 44.0 kg ($P < 0.001$; Figure 2), respectively, in the restrictedly and ad libitum fed sows whereas in the latter half of gestation, BW gains were 32.8 and 31.3 kg ($P = 0.65$), respectively. Backfat gains in the first 8 weeks of gestation and in the latter half of gestation were 3.4 and 5.1 mm ($P < 0.05$) and 2.7 and 2.7 mm ($P = 0.90$), respectively, in the restrictedly and ad libitum fed sows (Figure 3).

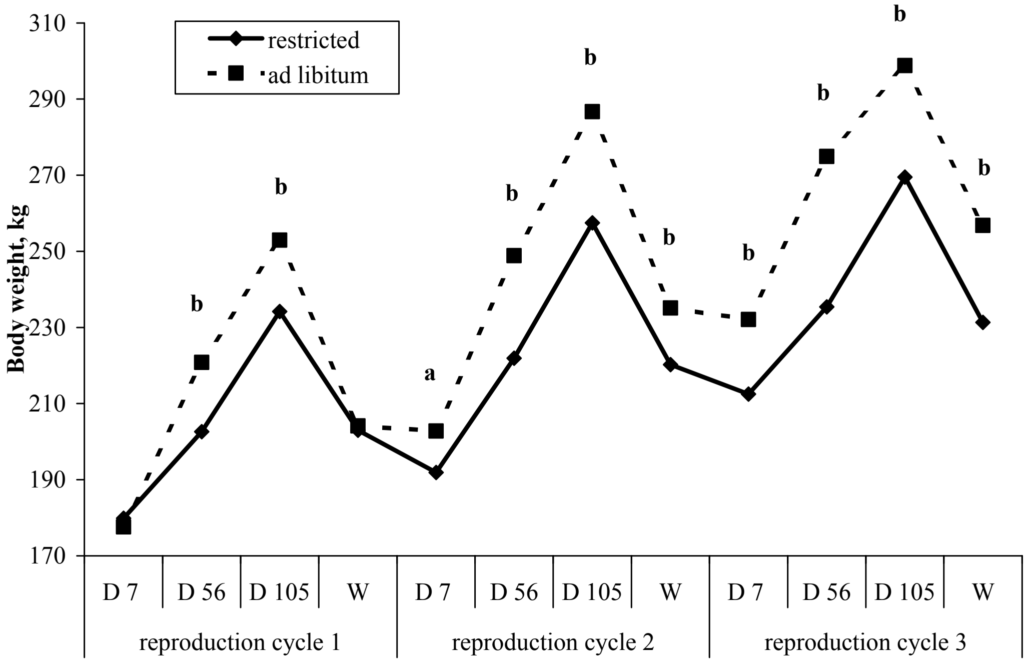

Figure 2. Body weight at days 7, 56 and 105 of gestation and at weaning (W) during three reproduction cycles in restrictedly fed (-◆-) and ad libitum fed (- ■ -) gestating sows. The letters "a" and "b" indicate that BW differs between restrictedly and ad libitum fed sows at $P < 0.01$ and $P < 0.001$, respectively.

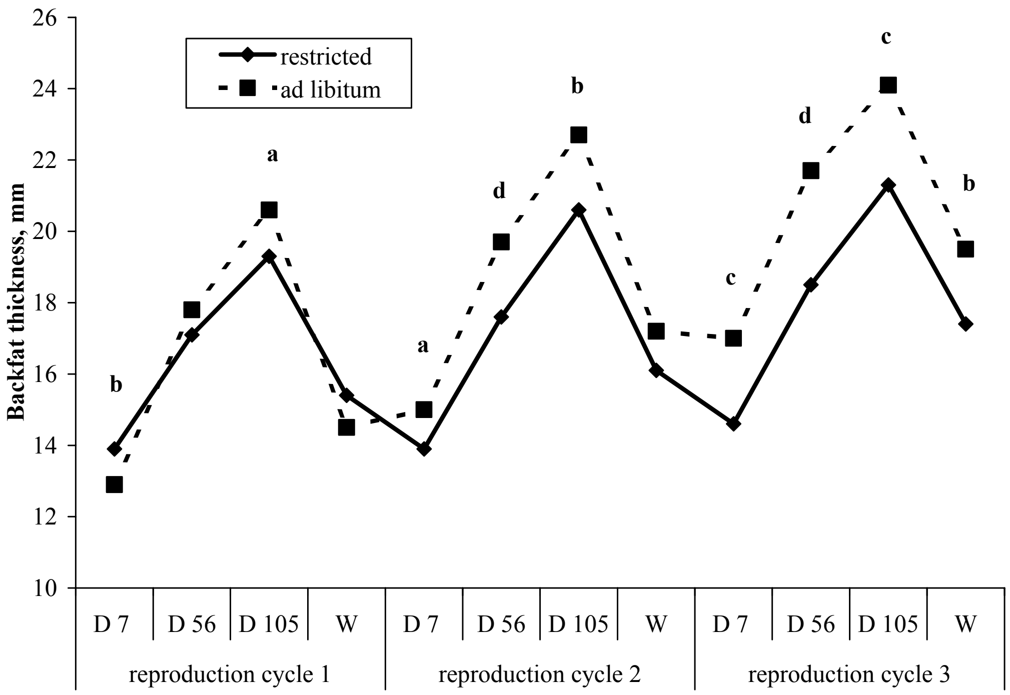

Figure 3. Backfat thickness at days 7, 56 and 105 of gestation and at weaning (W) during three reproduction cycles in restrictedly fed (-◆-) and ad libitum fed (- ■ -) gestating sows. The letters "a", "b", "c" and "d" indicate that backfat thickness differs between restrictedly and ad libitum fed sows at $P < 0.10$, $P < 0.05$, $P < 0.01$ and $P < 0.001$, respectively.

Table 5. Performance during gestation as affected by gestation feeding regime[a]

	Restricted	Ad libitum	SEM	P-value
Initial parity number	3.4	3.8		
Feed intake in gestation room, kg/d				
Reproduction cycle 1	2.88	3.79	[b]	< 0.001
Reproduction cycle 2	2.86	4.24	[b]	< 0.001
Reproduction cycle 3	2.91	4.57	[b]	< 0.001
BW at d 7 of gestation, kg				
Reproduction cycle 1	179.7	177.6	2.7	0.55
Reproduction cycle 2	191.9	202.8	3.1	0.01
Reproduction cycle 3	212.5	232.1	3.8	< 0.001
BW gain from d 7 to FS[c], kg				
Reproduction cycle 1	55.1	75.2	2.8	< 0.001
Reproduction cycle 2	63.7	83.9	3.2	< 0.001
Reproduction cycle 3	53.8	68.5	4.0	0.01
Backfat at d 7 of gestation, mm				
Reproduction cycle 1	13.9	12.9	0.4	0.04
Reproduction cycle 2	13.9	15.0	0.5	0.07
Reproduction cycle 3	14.6	17.0	0.6	0.01
Backfat gain from d 7 to FS, mm				
Reproduction cycle 1	5.3	7.7	0.5	< 0.001
Reproduction cycle 2	6.4	8.0	0.6	0.03
Reproduction cycle 3	6.4	7.9	0.7	0.12

[a] Data are given as means and SEM.
[b] In the restrictedly fed sows, SEM is 0.01, 0.02 and 0.03 in reproduction cycle 1, 2 and 3, respectively; in the ad libitum fed sows, SEM is 0.07, 0,08 and 0.15 in reproduction cycle 1, 2 and 3, respectively.
[c] FS is day of transfer to the farrowing room.

Litter performance at birth and reproductive performance

The numbers of total piglets born, stillborn and live-born piglets and total litter and piglets birth weights were not affected by gestation feeding regime (Table 6). Moreover, weaning-to-estrus interval, the percentage of sows that returned to estrus after first insemination and farrowing rate were not affected by gestation feeding regime (Table 7).

Performance during lactation

In all three reproduction cycles, lactation feed intake was similar on both treatments (Table 8). These effects were consistent during the whole lactation period. However, the ad libitum fed sows lost more BW and backfat in the farrowing room than the restrictedly fed sows (Table 8). In reproduction cycle 1, BW and backfat thickness at weaning were similar in the ad libitum fed and restrictedly fed sows. In reproduction cycles 2 and 3, the ad libitum fed sows were 14.9 and 25.5 kg heavier at weaning, respectively, and had 0.9 and 2.1 mm thicker backfat.

Table 6. Litter performance at birth as affected by gestation feeding regime[a]

	Restricted	Ad libitum	SEM	P-value
No. of total born piglets				
Reproduction cycle 1	13.2	13.5	0.4	0.59
Reproduction cycle 2	14.4	13.5	0.5	0.17
Reproduction cycle 3	13.1	13.5	0.6	0.65
Live-born piglets, % of total born				
Reproduction cycle 1	92.8	93.4	1.0	0.65
Reproduction cycle 2	92.9	94.7	1.1	0.26
Reproduction cycle 3	94.4	94.0	1.4	0.83
Stillborn piglets, % of total born				
Reproduction cycle 1	4.9	4.3	0.8	0.59
Reproduction cycle 2	6.0	4.1	1.0	0.15
Reproduction cycle 3	3.3	4.9	1.1	0.33
Piglet birth weight, kg				
Reproduction cycle 1	1.53	1.56	0.04	0.50
Reproduction cycle 2	1.55	1.55	0.05	0.93
Reproduction cycle 3	1.51	1.50	0.06	0.88
Total litter weight at birth, kg				
Reproduction cycle 1	18.4	19.4	0.54	0.15
Reproduction cycle 2	20.5	19.5	0.66	0.23
Reproduction cycle 3	18.6	18.6	0.82	0.96

[a] Data are given as means and SEM.

Table 7. Sow reproductive performance as affected by gestation feeding regime[a]

	Restricted	Ad libitum	SEM	P-value
Weaning-to-estrus interval, d				
Reproduction cycle 1	5.9	5.2	0.5	0.37
Reproduction cycle 2	3.9	4.5	0.6	0.47
Reproduction cycle 3	5.5	4.5	0.7	0.30
Return to estrus after 1st insemination, %				
Reproduction cycle 1	5.4	11.8	3.2	0.17
Reproduction cycle 2	8.4	9.4	4.1	0.85
Reproduction cycle 3	7.8	5.6	4.5	0.73
Farrowing rate after 1st insemination, %				
Reproduction cycle 1	91.6	87.3	3.8	0.43
Reproduction cycle 2	91.2	89.1	3.3	0.64
Reproduction cycle 3	90.2	92.6	4.9	0.71

[a] Data are given as means and SEM.

Table 8. Performance of sows and piglets during lactation as affected by gestation feeding regime[a]

	Restricted	Ad libitum	SEM	P-value
Feed intake during lactation, kg/d				
Reproduction cycle 1	5.90	5.99	0.10	0.50
Reproduction cycle 2	5.94	6.03	0.12	0.60
Reproduction cycle 3	5.93	5.64	0.16	0.17
BW loss from FS[b] to weaning, kg				
Reproduction cycle 1	31.8	49.4	2.6	< 0.001
Reproduction cycle 2	34.8	51.3	3.0	< 0.001
Reproduction cycle 3	34.6	44.9	3.8	0.05
BW at weaning, kg				
Reproduction cycle 1	203.0	204.1	2.7	0.80
Reproduction cycle 2	220.2	235.1	3.1	0.01
Reproduction cycle 3	231.3	256.8	3.8	< 0.001
Backfat loss from FS to weaning, mm				
Reproduction cycle 1	4.0	6.1	0.4	< 0.001
Reproduction cycle 2	4.1	5.8	0.5	0.01
Reproduction cycle 3	3.5	5.1	0.6	0.06
Backfat at weaning, mm				
Reproduction cycle 1	15.4	14.5	0.5	0.19
Reproduction cycle 2	16.1	17.2	0.6	0.15
Reproduction cycle 3	17.4	19.5	0.7	0.04
Weaned piglets, % after fostering				
Reproduction cycle 1	85.0	90.2	1.5	0.02
Reproduction cycle 2	85.1	85.6	2.0	0.87
Reproduction cycle 3	88.4	85.6	2.4	0.42
Piglet weaning weight, kg				
Reproduction cycle 1	8.2	8.4	0.2	0.46
Reproduction cycle 2	8.5	8.5	0.3	0.93
Reproduction cycle 3	8.4	8.9	0.3	0.22

[a] Data are given as means and SEM.
[b] FS is day of transfer to the farrowing room.

Discussion

Feed intake characteristics of ad libitum fed sows

Mean daily feed intake during gestation over the three reproduction cycles was 4.2 kg, which is in agreement with the voluntary feed intake levels as published by Whittaker et al. (2000) (4.1 kg/d of a diet containing 60% sugar beet pulp) and Brouns et al. (1995) (4.1 kg/d of a diet containing 50% sugar beet pulp). Higher voluntary feed intakes were reported in gestating sows that were fed a conventional diet (7.2 kg/d; Bergeron et al., 2000) or diets containing fiber sources other than sugar beet pulp (7.1 kg/d; Brouns et al., 1995). Thus, diets containing at least 45% sugar beet pulp can reduce voluntary feed intake during gestation. It is not clear whether this reduction is the result from physical properties of the feed or from effects on metabolism during gestation. Sugar beet pulp has a high water holding capacity (Bertin et al., 1988), it delays gastric emptying (Guérin et al., 2001) and it results in higher postprandial glucose levels inducing long lasting effects on satiety (Vestergaard, 1997) compared to a conventional diet.

In sows with initial parity number 1, 2, 3 or 4, voluntary feed intake during gestation increased with increasing reproduction cycle (Table 4). In sows with initial parity number ≥ 5, feed intakes were similar in reproduction cycles 1, 2 and 3. It seems that voluntary feed intake in gestating sows is increasing from parity 1 to 5 and then remains stable in subsequent parities. Moreover, it seems that the voluntary feed intake level depends on the number of preceding reproduction cycles that the sow is fed ad libitum. The voluntary feed intake of a third parity sow that is fed ad libitum during all preceding reproduction cycles equals that of a fifth parity sow suggesting that this third parity sow already reached the maximum feed intake. A third parity sow that is fed ad libitum for the first time has not reached her maximum feed intake yet because her voluntary feed intake is increasing in the next reproduction cycles. Thus, it seems that the parity in which sows reach the maximum feed intake depends on parity number and on the number of preceding reproduction cycles that the sow is fed ad libitum.

Mean daily feed intake of the ad libitum fed sows increased from weeks 2 to 6 of gestation and then decreased to week 15 of gestation. Bergeron et al. (2000) also reported a decreasing feed intake during gestation in sows that were fed ad libitum with a conventional diet. In general, restrictedly fed sows are fed a constant or an increasing amount of feed during gestation. Thus, it seems that the development in feed intake during gestation in ad libitum fed sows differs from that in restrictedly fed sows.

The mean number of daily visits with feed intake in the ad libitum fed sows was 13.8. To our knowledge, individual feed intake characteristics in ad libitum fed group-housed gestating sows are not measured in other studies. However, in trials with ad libitum fed weanling pigs (Bruininx et al., 2001) and growing and finishing pigs (Ramaekers, 1996), the mean number of daily visits with feed intake was 12.5 and 11.6, respectively. It seems that the eating frequency in ad libitum fed weanling pigs, growing and finishing pigs and gestating sows is very similar. On average, the ad libitum fed gestating sows spent 90 min/d eating. Brouns and Edwards (1994) reported similar results. In gestating sows that are fed a conventional diet or a high fiber diet restrictedly, mean eating times were 16 and 51 min/d, respectively (Ramonet et al., 1999). Thus, eating time increases two to fivefold by feeding gestating sows a high NSP diet ad libitum. Mean feeding rate of the ad libitum fed sows was 54 g/min, which is much lower than reported in other studies with restrictedly fed sows (95 g/min to 152 g/min) as summarized by Rijnen et al. (2003). Ad libitum feeding of a high NSP diet affected development in feed intake during gestation, eating frequency, time spent on eating and feeding rate in gestating sows. Therefore, not only feed intake but also feed intake pattern in ad libitum fed sows (sows are free to choose at what time they eat and how often and how much they eat) differs from that in restrictedly fed sows where sows are forced to eat their daily ration in one or two meals a day.

Effects of gestation feeding regime on body weight and backfat thickness

The ad libitum fed sows ate 1.3 kg/d, that is 4.79 MJ NE/d (4.2 kg/d x 7.03 MJ NE – 2.9 kg/d x 8.53 MJ NE), more during gestation than the restrictedly fed sows. Therefore, the ad libitum fed sows gained more BW (+ 20.1, + 20.2 and + 14.7 kg in reproduction cycles 1, 2 and 3, respectively) and more backfat (+ 2.2, + 1.6 and + 1.5 mm in reproduction cycles 1, 2 and 3, respectively) in the gestation rooms than the restrictedly fed sows. These results are in agreement with the results of Whittaker et al. (2000). The differences in BW gain and backfat gain already occurred in the first 8 weeks of gestation. In the first half of gestation, the differences in daily energy intake between the restrictedly and ad libitum fed sows were higher than in the latter half of gestation (Figure 1) and this probably explains the greater differences in BW gain and backfat gain in the first 8 weeks of gestation.

Sows that were fed ad libitum during gestation lost more BW (48.5 versus 33.7 kg; $P < 0.001$) and backfat (5.6 versus 3.9 mm; $P < 0.001$) in the farrowing room than those that were fed restrictedly during gestation. However, feed intake during lactation was similar in sows that were fed restrictedly or ad libitum during gestation. The higher BW loss in the farrowing room in ad libitum fed sows can partly be explained by the loss of gut fill when sows are switched from a high NSP gestation diet to a commercial lactation diet. Van der Peet-Schwering et al. (2003) calculated that the extra gut fill caused by a high NSP compared to a starch diet during gestation is about 6 kg. The higher BW and backfat losses might also be explained by a higher BW and backfat of the ad libitum fed sows at the day of transfer to the farrowing room (279.5 and 253.7 kg and 22.5 and 20.4 mm, respectively, in the ad libitum and restrictedly fed sows; $P < 0.001$). Yang et al. (1989) reported that fatter and heavier sows at parturition lose more BW and backfat during lactation than leaner sows. A third explanation might be the higher total litter gain during lactation in the ad libitum fed sows. Mean total litter gain during lactation was 74.6 and 78.1 kg in the restrictedly and ad libitum fed sows, respectively. For 1 kg litter gain 4.2 kg milk is needed (Everts et al., 1995). Thus, a 3.5 kg higher litter gain means a 14.7 kg higher milk production of the ad libitum fed sows resulting in higher BW and backfat losses. To produce 14.7 kg milk containing 73.5 MJ NE (Everts et al., 1995) 1.1 mm backfat (i.e. 2.1 kg of lipid; Everts et al., 1994) will be mobilized (efficiency of utilization of energy from body reserves for milk production is 0.88; Noblet et al., 1990).

Similar levels of feed intake during lactation in sows that were fed restrictedly or ad libitum during gestation were not expected because the ad libitum sows were fatter at the day of transfer to the farrowing room (22.5 versus 20.4 mm; $P < 0.01$). It is often demonstrated that fatter sows at parturition eat less during lactation (Dourmad, 1991; Revell et al.,1998; Prunier et al., 2001) than lean sows. On the other hand, Jørgensen et al. (1996) showed that pigs that were fed high fiber diets had an extended gastrointestinal tract and a longer colon, which might stimulate feed intake during lactation. Matte et al. (1994) and Van der Peet-Schwering et al. (2003) indeed reported higher feed intakes during lactation in sows that were fed high fiber diets during gestation. It might be that these two opposite effects on feed intake counterbalance each other resulting in no effect on feed intake. Whittaker et al. (2000), however, found lower feed intakes during lactation in second parity sows but not in first parity sows that were fed a high fiber ad libitum during gestation. In their trial, mean daily NE intake during gestation in the restrictedly and ad libitum fed second parity sows was 23 and 34 MJ, respectively. In our research, the difference in daily NE intake during gestation between the restrictedly and ad libitum fed sows was 4.8 MJ. It might be that this difference in NE intake was too small to negatively affect feed intake during lactation. After three reproduction cycles, the ad libitum fed sows were 25 kg heavier and had deposited 3 mm more backfat than the restrictedly fed sows. This was due to an on average 19.3 % higher NE intake during gestation.

Reproductive performance

In spite of higher feed intakes during gestation, resulting in heavier and fatter sows at parturition and greater losses in BW and backfat during lactation, ad libitum feeding of gestating sows during three successive reproduction cycles did not affect reproductive performance. In all three reproduction cycles, the numbers of total piglets born, live-born piglets and stillborn piglets were similar in sows that were fed a conventional diet restrictedly or a high NSP diet ad libitum. This is in agreement with the results of Whittaker et al. (2000) who did not find effects on litter performance in parity 1 and 2 sows that were fed ad libitum from d 28 of gestation. Moreover, the greater losses in BW and backfat during lactation in the sows fed ad libitum during gestation did not result in a prolonged weaning-to-estrus interval, which is in contrast with results of Baidoo et al. (1992) and Zak et al. (1997). Aherne et al. (1990) and Whittemore (1996) suggested that, besides the amount of tissue mobilized during lactation, the amount of body reserves at farrowing and at weaning are critical factors affecting the weaning-to-estrus interval. The ad libitum fed sows were heavier at farrowing and weaning than the restrictedly fed sows and this might explain why no effect on the weaning-to-estrus interval was found. Another explanation might be that their was no difference in feed intake during lactation between the restrictedly and ad libitum fed gestating sows.

Piglets birth weight and total litter weights at birth were not affected by gestation feeding regime. This is in agreement with the results of Whittaker et al. (2000) but in contrast with the results of Fisker and Sørensen (1999). They found lower birth weights of piglets in sows that were fed a high NSP diet ad libitum compared to sows that were fed a conventional diet restrictedly and suggested that this might be explained by a deficiency in glucogenic energy at the end of gestation. As in both their and our research, ad libitum fed gestating sows received the same daily amount of starch and sugar (about 650 g/d), it seems not likely that a deficiency in glucogenic energy explains the lower birth weights. However, a decreasing feed intake in the last month of gestation in ad libitum fed sows might be an explanation. The higher energy intake in the ad libitum fed sows also did not result in heavier birth weights of the piglets. The energy intake of the restrictedly fed sows is presumably high enough to maximize piglets birth weight.

Implications

In this study, gestating sows that were fed ad libitum with a diet containing a high level of fermentable non-starch polysaccharides (45% sugar beet pulp) during three successive reproduction cycles ate 1.3 kg/d more during gestation than sows that were fed a conventional diet restrictedly. Although the higher feed intake during gestation resulted in heavier and fatter sows at parturition and greater losses in BW and backfat during lactation, ad libitum feeding of gestating sows during three successive reproduction cycles did not negatively affect reproductive performance. Moreover, lactation feed intake was similar in sows that were fed a diet with a high level of fermentable non-starch polysaccharides ad libitum or a conventional diet restrictedly during gestation. Therefore, ad libitum feeding of gestating sows with a diet containing a high level of non-starch polysaccharides during three successive reproduction cycles is possible without negative effects on reproductive performance.

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Chapter 7

General discussion

Introduction

Gestating sows are restricted in feed intake to maintain optimal body composition and productivity. Mean daily feed intake in gestating sows that are fed a low fiber diet restrictedly is about 2.8 kg/d whereas mean voluntary feed intake of a low fiber gestation diet is about 6.0 kg/d (unpublished data). Feed restriction is identified as one of the major factors associated with the development of stereotypic behavior in sows (Terlouw et al., 1991) and therefore, there is a growing interest in feeding high fiber diets to sows. Stereotypies are behaviors that are fixed in form, repetitive and apparently without purpose (Ödberg, 1978), and they are generally recognized as determinants for reduced well being in animals. Fiber is known to reduce feeding motivation in restrictedly fed gestating sows by increasing satiation (Brouns et al., 1994), which in return reduces the development of oral stereotypies (Lawrence and Terlouw, 1993). Dietary fiber is the sum of all non-starch polysaccharides (NSP) and lignin and is not hydrolyzed by enzymes but fermented by the gastrointestinal microflora. The botanical origin of dietary fiber can influence the effect on stereotypic behavior. There are indications that fermentable NSP (i.e., fermentable NSP from sugar beet pulp) in the diet is more involved in the feeling of satiety and in reducing stereotypic behavior than crude fiber or non-fermentable NSP (Brouns et al., 1995; Vestergaard, 1997). Sugar beet pulp has a high water holding capacity (Bertin et al., 1988) resulting in an increase in gastric distension and gut fill, it delays gastric emptying (Guerin et al., 2001) and it changes the postprandial glucose response inducing long lasting effects on satiety (Vestergaard, 1997). Feeding a diet with a high level of fermentable NSP during gestation reduces stereotypic behavior but it is still existing. Possibly, stereotypic behavior can be further reduced and animal welfare be further improved by feeding sows ad libitum during gestation (Bergeron et al., 2000) or by feeding them a high NSP diet during both gestation and lactation. Ad libitum feeding with a conventional low fiber diet is not an option because of the high feed intake capacity of the sows, resulting in fat sows and possibly in reproductive problems. Diets with a high level of sugar beet pulp, however, can limit feed intake to an acceptable level (Brouns et al., 1995) and are an option to be offered ad libitum to gestating sows.

Improved welfare may also improve reproductive performance of sows (Cronin, 1985). There are some indications from two Danish field studies (Sørensen, 1992, 1994) that litter size may be improved when sows are fed diets with a high level of fermentable NSP during both gestation and lactation. Moreover, Ferguson et al. (2003b) concluded that litter size may be increased by feeding sows a high level of dietary fermentable NSP during lactation and prior to insemination.

In the experiments described in this thesis the long-term effects of feeding sows high levels of dietary fermentable NSP (i.e., NSP from sugar beet pulp) restrictedly or ad libitum during gestation or ad libitum during lactation on behavior, feed intake, development in body weight and backfat thickness, and reproduction have been studied. In this discussion, the effects of feeding sows high levels of dietary fermentable NSP on the different aspects will be discussed based on the results in the different experiments described in Chapters 2 to 6. Moreover, in an integrated approach practical implications of feeding sows high levels of dietary fermentable NSP will be given.

Behavior

Feeding group-housed gestating gilts and sows a high level of dietary fermentable NSP reduced the frequency of total non-feeding oral activities and of sham chewing in gestation compared with a starch diet (chapter 4). This is in agreement with results of other studies (Robert et al., 1993, 1997, 2002; Vestergaard, 1997). In parity 1, total non-feeding oral activities and sham chewing during gestation were reduced from 23.8 to 13.7% and from 14.4 to 5.6%, respectively, by feeding a diet with a high level of fermentable NSP during gestation. In parity 2, total non-feeding oral activities and sham chewing were reduced from 29.7 to 18.9% and from 23.4 to 14.1%, respectively. High NSP diets are more effective in reducing stereotypic behavior when they are fed for a long period (Robert et al., 1993). Therefore, it was hypothesized that the frequency of stereotypic behavior during gestation might be further reduced by feeding sows a high NSP diet during both gestation and lactation. Feeding a high NSP diet during both gestation and lactation might increase the feeling of satiety and reduce feeding motivation (Lawrence and Terlouw, 1993). It appeared that feeding sows a high level of dietary fermentable NSP during lactation indeed had an additional reducing effect on the development of stereotypic behavior in subsequent gestation. Moreover, it appeared that in sows that were fed the high NSP diet during both gestation and lactation, the frequencies of total non-feeding oral activities (Table 1) in gestation and lactation did not increase from parity 1 to 2, whereas it is generally accepted that stereotypic behavior increases with parity number (Stolba et al., 1983). Also, in sows that were fed the starch diet during gestation and the NSP diet during lactation, the frequencies of total non-feeding oral activities during gestation and lactation did hardly increase from parity 1 to 2. However, in sows that were fed the starch diet during both gestation and lactation and in sows that were fed the NSP diet during gestation and the starch diet during lactation, the frequencies of total non-feeding oral activities in gestation and lactation increased from parity 1 to 2. Thus, it seems that the increase in the frequencies of total non-feeding oral activities in gestation and lactation from parity 1 to 2 depends on the composition of the lactation diet and not on the composition of the gestation diet. The frequencies of total non-feeding oral activities during gestation and lactation hardly increase from parity 1 to 2 in sows that are fed a lactation diet with a high level of fermentable NSP. Presumably, ad libitum fed lactating sows are more satiated during lactation when they are fed a diet with a high level of fermentable NSP than when they are fed a starch diet. It can be concluded that feeding sows a diet with a high level of fermentable NSP during both gestation and lactation is a favorable feeding strategy from a viewpoint of animal welfare.

Table 1. Percentage of observations spent on total non-feeding oral activities during gestation and lactation in parities 1 and 2 as affected by gestation diet and lactation diet

Gestation diet: Lactation diet:	Starch Starch	Starch NSP	NSP Starch	NSP NSP
Gestation parity 1	23.8	23.8	13.7	13.7
Lactation parity 1	3.6	3.7	3.5	3.7
Gestation parity 2	32.5	26.8	24.4	13.3
Lactation parity 2	9.0	4.0	10.4	3.6

In addition to feeding a high NSP diet during both gestation and lactation, ad libitum feeding of gestating sows might be a possibility to reduce stereotypic behavior further during gestation. Bergeron et al. (2000) concluded that ad libitum feeding with a conventional gestation diet is very effective in reducing stereotypic behavior. However, in their study mean daily feed intake of the sows during gestation was 7.2 kg. In our experiment gestating sows were fed ad libitum with a diet containing a high level of fermentable NSP. Mean daily feed intake during gestation was 4.2 kg (chapter 6). As stereotypic behaviors are most prevalent in the postprandial period (Robert et al., 1993) and the ad libitum fed sows in our experiment were eating about 14 times a day, it was not possible to compare adequately stereotypic behaviors in ad libitum fed and restrictedly fed sows. However, parameters related to general activity like the time spent standing and eating and skin lesions were measured. The time spent standing and eating was video-recorded over 72 h periods. Gestating sows that were fed the high NSP diet ad libitum spent less time standing (4.0 versus 7.9% of the day) than sows that were fed the conventional diet restrictedly. These results are in agreement with the results of Brouns et al. (1994) and Bergeron et al. (2000) and can be interpreted as a sign of enhanced satiety (Robert et al., 1993) in the ad libitum fed sows. Moreover, Ramonet et al. (1999) reported a positive correlation between standing and non-feeding oral activities. The ad libitum fed gestating sows spent 90 min/d eating whereas the restrictedly fed sows spent 24 min/d eating. An increase in time spent eating is associated with a reduction in feeding motivation and in stereotypic behaviors (Brouns et al., 1994). Skin lesions were recorded in weeks 6 and 12 of gestation. They were observed less frequently in the ad libitum fed sows. In weeks 6 and 12 of gestation, the percentage of sows with skin lesions were 46.2 and 28.2%, and 22.7% and 11.2%, respectively, in the restrictedly and ad libitum fed sows. Skin lesions in the first month after introduction of sows in the group are mainly caused by fights to establish the social hierarchy in the group. Skin lesions in the second and third month of gestation are mainly caused by competition for other resources such as feed (Backus et al., 1997). Thus, it seems that in ad libitum fed sows feeding motivation is more satisfied than in restrictedly fed sows. It can be concluded that ad libitum feeding of gestating sows with a diet containing a high level of fermentable NSP is an interesting feeding strategy from a viewpoint of animal welfare because it reduces feeding motivation and results in less skin lesions. Ad libitum feeding with a high NSP diet during both gestation and lactation might even be more interesting from a viewpoint of animal welfare but this feeding strategy was not investigated.

Development in body weight and backfat thickness

This section focuses on the effect of the different feeding strategies on the development in BW and backfat thickness of the sows and its relation with feed intake during lactation. It is often demonstrated that there is a relation between backfat thickness at parturition and feed intake during lactation: fatter sows at parturition eat less during lactation (Dourmad et al., 1991; Revell et al., 1998; Prunier et al., 2001). Revell et al. (1998) found that an increase in backfat thickness at parturition from 17.9 to 24.3 mm resulted in a decrease in lactation feed intake of 1.6 kg/d. Thus, 1 mm thicker backfat at parturition results in a 0.25 kg/d lower feed intake during lactation. In table 2, backfat at parturition and feed intake during lactation in the experiments described in this thesis are presented.

Table 2. Effect of gestation diet on backfat thickness at parturition (mm) and on feed intake during lactation (kg/d) in the different experiments described in this thesis

	Backfat thickness			Feed intake during lactation		
	High NSP[1]	Starch[2]	Fat	High NSP	Starch	Fat
Chapter 3						
Parity 1	18.1	20.7	-	4.80	4.42	-
Parity 2	16.7	19.5	-	5.63	5.15	-
Parity 3	15.7	19.5	-	5.81	5.36	-
Chapter 5	15.3	16.3	17.1	6.45	6.14	6.24
Chapter 6						
Parity 1	20.6	19.2	-	5.99	5.90	-
Parity 2	23.0	20.3	-	6.03	5.94	-
Parity 3	24.9	21.0	-	5.64	5.93	-

[1] In chapters 3 and 5, the high NSP gestation diet was fed restrictedly. In chapter 6, the high NSP diet was fed ad libitum.
[2] In chapters 3 and 6, gestating sows were fed about 3.4 kg/d of the starch diet in the last month of gestation. In chapter 5, sows were fed 3.89 kg/d of the starch diet in the last month of gestation.

Gestating sows that were fed a high level of dietary fermentable NSP restrictedly gained less backfat during gestation than sows that were fed a starch diet restrictedly (chapter 3). This resulted in 3.0 mm less backfat at parturition. Apparently, the energy value of fermentable NSP was overestimated. Feed intake during lactation was 0.44 kg/d higher in sows fed a high NSP restrictedly during gestation than in sows fed a starch diet restrictedly during gestation (chapter 3) resulting in less BW and backfat losses during lactation. Thus, in the trial in chapter 3, 1 mm thicker backfat resulted in a 0.15 kg/d lower feed intake during lactation. Gestating sows that were fed extra starch in the last month of gestation had 1 mm thicker backfat at parturition and ate 0.3 kg/d less during lactation than sows that were fed the high NSP diet (chapter 5). Gestating sows that were fed extra fat in the last month of gestation had 1.8 mm thicker backfat at parturition and ate 0.2 kg/d less during lactation than sows that were fed the high NSP diet. Thus, 1 mm thicker backfat resulted in a 0.11 k/d lower feed intake during lactation.

Gestating sows that were fed a high NSP diet ad libitum gained more backfat during gestation resulting in 2.7 mm thicker fat at parturition than sows that were fed a conventional diet restrictedly (chapter 6). Feed intake during lactation, however, was similar in the ad libitum and restrictedly fed sows. Thus, in this trial there seems no relationship between backfat at parturition and feed intake during lactation. Analysis of the data within treatments, however, showed that in both the ad libitum and the restrictedly fed sow there was a negative relation between backfat at parturition and feed intake during lactation. The mean feed intake level during lactation, however, was higher in sows that were fed ad libitum during gestation than in sows that were fed restrictedly during gestation probably because of an extended gastrointestinal tract (Jørgensen et al., 1996). In conclusion, in all trials described in this thesis, there is a negative relation between backfat thickness at parturition and feed intake during lactation. The relation, however, seems dependent on the feed composition and on the feeding strategy during gestation.

After three parities, sows that were fed a high NSP diet restrictedly during gestation were 15 kg lighter and had 2.5 mm less backfat at weaning than sows that were fed a starch diet during gestation (chapter 3). Lactation diet did not affect BW loss during lactation but sows that were fed the high NSP diet during lactation lost more backfat during lactation than sows that were fed a starch diet. After three parities, sows that were fed a high NSP diet during both gestation and lactation were 16 kg lighter and had 3.8 mm less backfat at weaning than sows that were fed a starch diet during both gestation and lactation (chapter 3). In the trial with ad libitum feeding of a high NSP diet (chapter 6), after three reproduction cycles the ad libitum fed sows were 25 kg heavier and had deposited 3 mm more backfat than the restrictedly fed sows. In both experiments, however, reproductive performance was not negatively influenced by feeding a high NSP diet during three successive reproduction cycles. These results are in agreement with results of Vesseur et al. (1994), who demonstrated that in sows with parity ≥ 2 BW loss during lactation did not affect weaning-to-estrus interval. Thus, although high NSP diets may affect BW and backfat thickness of the sows, it is possible to feed sows diets with a high level of fermentable NSP restrictedly or ad libitum during gestation or ad libitum during lactation without negative effects on reproductive performance.

The variation in BW and backfat thickness among sows at d 105 of gestation was greater in the ad libitum fed than in the restrictedly fed sows. In the restrictedly fed sows, BW at d 105 of gestation ranged from 152 to 317 kg whereas in the ad libitum fed sows, it ranged from 174 to 342 kg. Backfat thickness at d 105 of gestation ranged from 11 to 33 mm and from 10 to 43 mm in the restrictedly and ad libitum fed sows, respectively. In ad libitum fed sows that gained more than 90 kg BW or more than 12 mm backfat during gestation, number of live-born piglets, birth weight of live-born piglets, and feed intake of the sows during lactation were 12.9, 1.55 kg, and 6.05 kg/d, respectively, whereas the average over all sows was 12.7, 1.54 kg, and 5.89 kg/d, respectively. In ad libitum fed sows that gained less than 40 kg BW or less than 4 mm backfat during gestation, number of live-born piglets, birth weight of live-born piglets, and feed intake of the sow during lactation were 13.6, 1.45 kg, and 5.96 kg/d. Thus, reproductive performance of ad libitum fed sows with high or low BW gains or high or low backfat gains is comparable with reproductive performance of all ad libitum fed sows.

Reproductive performance

Total piglets born and live-born piglets

The numbers of total piglets born and live-born piglets were 0.5 piglet higher in sows that were fed the high NSP diet during gestation over three parities than in sows that were fed the starch diet (chapter 3). This is in agreement with the conclusions of a review by Reese (1997). He reported that the number of live born piglets is increased with 0.3 piglets when sows are fed high fiber diets. In several studies it was demonstrated that insulin is positively related with reproductive processes, like ovulation rate, follicle development, and weaning-to-estrus interval (Cox et al., 1987; Tokach et al., 1992). Van den Brand (2000) and Van den Brand et al. (2000), however, did not find significant relationships between plasma insulin concentrations and reproductive traits. They suggested that dietary manipulated plasma insulin concentration might only affect reproductive performance when a sustained high level is present. It might be that not the postprandial insulin peak level is important for reproduction, but that a long term increased insulin concentration is needed to affect reproductive traits. In his study, plasma insulin concentration was increased two times per day for about 4.5 h after feeding. In our study we did not measure plasma insulin levels but Vestergaard (1997) reported that diets with a high level of fermentable NSP changes the postprandial insulin profile in gestating sows compared with a starch diet. In sows that were fed the NSP diet, the postprandial insulin peak was delayed for one hour, the rise was less marked but persisted for almost 12 hours after feeding. Therefore, it might be that in our study a sustained high level of insulin is responsible for the higher number of total born piglets. Vestergaard et al. (1998) did not find a positive effect on the number of total born piglets and live born piglets in sows that were fed the high NSP diet. In their study, however, sows were fed a standard lactation diet from weaning until mating whereas in our study sows were fed the gestation diet with a high level of fermentable NSP from weaning until mating. Ashworth and Antipatis (1999) concluded that the level of feed intake before mating had a greater influence on embryo survival than the level of feed intake after mating. It might be that this is also true for diet composition. In an experiment of Ferguson et al. (2003a) gilts were fed a control diet or a diet containing 50% sugar beet pulp prior to mating. Embryo survival on d 30 of gestation was higher in gilts fed the sugar beet pulp diet than in those fed the control diet (85.2 and 76.7%, respectively). The authors suggested that the improved embryo survival is via an improved oocyte quality because more oocytes from gilts fed the sugar pulp diet matured in vitro compared to oocytes from gilts fed the control diet (77.3 and 68.4%, respectively). In a second experiment, sows were fed a cereal-based control diet from d 11 of lactation until insemination or a diet containing 20% sugar beet pulp during lactation and 40% prior to mating (Ferguson et al., 2003b). Numbers of total piglets born and live-born piglets were higher in sows that were fed the sugar beet pulp diet than in sows that were fed the control diet. In our trial, feeding lactating sows a diet with 20% sugar beet pulp did not affect the numbers of total piglets-born and live-born piglets (chapter 3). Thus, it seems that feeding sows a diet with a high level of sugar beet pulp from weaning until mating can increase the numbers of total and live-born piglets. In the experiment with ad libitum fed gestating sows we did not find an effect on numbers of total piglets born and live-born piglets in sows that were fed a diet with 45% sugar beet pulp from weaning until mating (chapter 6). Possibly, these results can be explained by the high feed intake after mating in the ad libitum fed sows. Daily feed intake in the first days after mating was not registered but daily feed intake in the second week after mating was 3.5 kg. Although Ashworth and Antipatis (1999) concluded that the level of feed intake before mating had a greater influence on embryo survival than the level of feed intake after mating, embryo survival was higher in gilts that were fed 3.5 kg/d prior to mating and 1.15 kg/d after mating than in gilts that were fed 3.5 kg/d prior to mating and 3.5 kg/d after mating (99% and 89.5% embryo survival, respectively). Moreover, Jindal et al. (1996) reported lower plasma progesterone concentrations and higher embryo mortality in gilts with a high feed intake after mating than in gilts with a low feed intake after mating. It might be that in the ad libitum fed sows the increased embryo survival by feeding a high NSP diet prior to mating is counteracted by the high feeding level after mating. As a result there is no effect on numbers of total piglets born and live-born piglets. In conclusion, feeding gestating sows a diet with a high level of fermentable NSP (i.e. NSP from sugar beet pulp) restrictedly or ad libitum during three successive parities does not negatively affect reproductive performance compared to feeding gestating sows a conventional diet restrictedly. Feeding a diet with a high level of fermentable NSP from weaning until mating may increase the numbers of total and live-born piglets.

Piglets birth weight

Piglets birth weight was lower in sows that were fed the high NSP diet during gestation than in sows that were fed the starch diet (chapter 3). This is in agreement with the results of Reese (1997) and Vestergaard and Danielsen (1998). The lower piglet birth weight might be explained by the higher number of live-born piglets or by a lower energy intake in the gestating sows fed the high NSP diet due to an overestimation of the energy value of fermentable NSP. Based on the results of Rijnen et al. (2001) the estimated net energy value of fermentable NSP was assumed to be similar to that of digested starch (13.5 MJ/kg). Body weight and backfat gains during gestation, however, were lower in sows fed the high NSP diet (chapter 3) which indicates an overestimation of the energy value of fermentable NSP. This means that the actual NE intake during gestation was lower in sows fed the high NSP diet than in those fed the starch diet. A third explanation for the lower piglet birth weight might be a deficiency in glucogenic energy in the last month of gestation as in high NSP diets the starch content is generally low. Daily starch plus sugar intake in the last month of gestation in sows that were fed the starch diet and the high NSP was 1080 and 550 g, respectively. It was hypothesized that in case of a shortage of glucogenic energy, feeding sows additional starch at the end of gestation may increase birth weight of the piglets while feeding sows additional fat will not affect birth weight. It appeared that both the supply of additional dietary starch and the supply of additional dietary fat in late-gestating sows fed a high NSP diet did not increase piglets birth weight and total litter weight at birth (chapter 5). This suggest that the lower birth weight of the piglets in sows fed a high NSP diet (chapter 3) cannot be explained by a lower energy intake compared to sows fed a starch diet nor by a deficiency in glucogenic energy. Daily starch plus sugar intake in the last month of gestation in sows that were fed the high NSP diet, additional starch or additional fat was 534, 895 and 542 g/d, respectively (chapter 5). Thus, a daily intake of about 550 g starch plus sugar in late-gestating sows seems sufficient for fetal growth. This is confirmed in the trial with the ad libitum fed sows (chapter 6). Piglets birth weights were similar in the ad libitum and restrictedly fed sows whereas daily starch plus sugar intakes in the last month of gestation in the ad libitum and restrictedly sows were 615 and 960 g, respectively. Fisker and Sørensen (1999) found lower piglets birth weights in sows that were fed a high NSP diet ad libitum compared to sows that were fed a conventional diet restrictedly. In our trial mean daily feed intake during gestation of the ad libitum and restrictedly fed sows was 4.2 and 2.9 kg, respectively. Daily feed intake in the ad libitum fed sows decreased from 4.76 kg in week 6 of gestation to 3.75 kg in week 15 of gestation (chapter 6). In the trial of Fisker and Sørensen (1999) daily feed intake during gestation of the ad libitum fed and restrictedly fed sows was 2.3 kg. Feed intake per week of gestation was not recorded in their trial but it is possible that feed intake in the last month of gestation was less than 2 kg/d in the ad libitum fed sows which explains the lower birth weight of the piglets.

Feed intake

The inclusion of fibrous ingredients in the diet can reduce daily feed intake. In the ad libitum fed sows (diet contained about 45% sugar beet pulp), mean daily feed intake during gestation over three reproduction cycles was 4.2 kg (chapter 6). These results are in agreement with the voluntary feed intake levels as published by Whittaker et al. (2000) (4.1 kg/d of a diet containing 60% sugar beet pulp) and Brouns et al. (1995) (4.1 kg/d of a diet containing 50% sugar beet pulp). The origin of the dietary fiber, however, seems important in the effect on feed intake. Brouns et al. (1995) gave gestating sows free access to six diets each containing a high level of a fibrous ingredient. Voluntary feed intake level of the sugar beet pulp diet was significantly lower than that of the other five high fiber diets (2.3 kg/d vs. 7.1 kg/d). It is not clear whether this reduction is the result from physical properties of the feed or from effects on metabolism during gestation. Sugar beet pulp has a high water-holding capacity (Bertin et al., 1988) which results in an increased gut fill, it contains high amounts of soluble NSP which can delay gastric emptying and nutrient absorption (Johansen et al., 1996; Guerin et al., 2001) and it changes the postprandial glucose response inducing long lasting effects on satiety (Vestergaard, 1997). In several studies, it was shown that high fiber diets reduce the frequency of stereotypic behavior and improve the welfare of gestating sows (Robert et al., 1993, 1997; Vestergaard, 1997). Therefore, in Dutch pig husbandry it is mandatory to give sows without piglets a diet with at least 14% crude fiber or at least 34% NSP (National Reference Center, 1998). Sows are supposed to be more satiated when high fiber diets are fed. Based on the results of Brouns et al. (1995), Vestergaard (1997), De Leeuw et al. (2004), and the results of the trial described in chapter 4, however, it is debatable whether crude fiber or NSP are responsible for the increased feeling of satiety. It seems more likely that the level of fermentable NSP is responsible for the increased feeling of satiety. De Leeuw et al. (2004) concluded that sugar beet pulp as a source of fermentable NSP stabilizes blood glucose and insulin levels and reduces physical activity. This may indicate an increased feeling of satiety. However, because in all studies with diets containing a high level of fermentable NSP sugar beet pulp was used as the ingredient with a high level of fermentable NSP, it is not known for certain whether a high level of fermentable NSP or a high level of sugar beet pulp is causing the increased feeling of satiety. Therefore, De Leeuw et al. (unpublished data) investigated if other ingredients (a combination of palm kernel, citruspulp, soybean hulls and sugar beet pulp) with a high level of fermentable NSP have the same effect on satiety as sugar beet pulp. Moreover, they tested different levels of fermentable NSP. It seems that, independent of the used ingredient, there is a dose-response relationship between the level of fermentable NSP in the diet and the stability of the blood glucose level. Besides, activity of the sows is decreasing with an increasing level of dietary fermentable NSP. However, sugar beet pulp seems to have an additional effect on stability of the blood glucose level and on activity. Maybe this can be explained by a higher fermentation rate of sugar beet pulp or by the high level of soluble NSP in sugar beet pulp, that can delay absorption of glucose and reduce gastric emptying rate (Guerin et al, 2001).

In periparturient sows, frequently constipation is seen, resulting in low feed intake levels after parturition and an increased risk for the development of mastitis, metritis and agalactia (MMA) (Tabeling et al., 2003). Parturition causes an increase in the dry matter content of feces and reduces defecation frequency (Tabeling et al., 2003) resulting in constipation. Feed restriction in the last days of gestation and change to a lactation diet with a low fiber content increase dry matter content of the feces. This reduces defecation frequency and thus can aggravate the problem of constipation (Tabeling et al., 2003). Therefore, they recommend to provide sows at least 2 kg/d of a diet containing 7% crude fiber (including a highly fermentable fiber to improve feces consistency) especially on the days near parturition. In our trials feed intake levels were not restricted before parturition. Moreover, sows were changed to the lactation diet on d 10 before parturition, so they were used to the lactation diet at the time of parturition. This is possibly the reason that problems with constipation and MMA were not observed in our trials.

Glucose tolerance

To meet the increasing demand for glucose by the fetuses, insulin sensitivity and glucose tolerance in sows decrease after d 85 of gestation (Père et al., 2000). The rate of glucose utilization by maternal tissues decreases, which allows for improved placental transfer of glucose. Sows with decreased glucose clearance rates produce offspring with heavier birth weight (Anderson et al., 1971). Such sows may be considered prediabetic (George et al., 1978). Diets with a low-glycemic-index can improve insulin sensitivity and glucose tolerance in healthy humans (Goff et al., 2003) and have been associated with a reduced risk for developing diabetes (Salmeron et al., 1997). The glycemic index is a classification of carbohydrate foods based on their acute blood glucose responses (Wolever, 2004). In general, diets with a low-glycemic-index are high in fermentable carbohydrates (Goff et al., 2003). Sugar beet pulp has a high level of fermentable carbohydrates. As in our study (chapter 5), the high NSP diet contained 40% sugar beet pulp, the diet probably had a low-glycemic-index. Maybe this explains the differences in basal glucose level, maximum increase in glucose and glucose area under the curve (AUC) between our study and the study of Kemp et al. (1996). Both studies were performed with late-gestating sows on the same experimental farm. In the study of Kemp et al. (1996) sows were fed a commercial starch rich diet whereas in our study sows were fed a diet with a high level of fermentable NSP. In our study, basal glucose concentration was 0.32 mmol/L higher and maximum increase in glucose and glucose AUC were 0.43 mmol/L and 23 (mmol/L).min lower, respectively, indicating that our sows are less glucose-intolerant than those used by Kemp et al. (1996). Thus, it seems that also in sows glucose tolerance can be improved by feeding sows a diet with a high level of NSP.

Conclusions

The main conclusions of this thesis are:

Digestibility:

- With regard to digestibility of nutrients, group-housed gestating sows completely adapt to a diet with a high level of fermentable NSP (i.e., NSP from sugar beet pulp) in two weeks. The time period necessary to adapt to a starch rich diet or a diet with a high level of fermentable NSP is similar.

Behavior:

- Feeding group-housed sows a diet with a high level of fermentable NSP during gestation reduces the level of stereotypic behavior in gestation compared to a starch diet. Feeding sows a diet with a high level of fermentable NSP during lactation has an additional reducing effect on the development of stereotypic behavior in subsequent gestation.
- In sows that are fed a high level of fermentable NSP diet during both gestation and lactation, the frequencies of total non-feeding oral activities and of sham chewing in gestation and lactation do not increase from parity 1 to 2. This is probably due to the composition of the lactation diet and not to the composition of the gestation diet.
- Feeding sows a diet with a high level of fermentable NSP during both gestation and lactation is a favorable feeding strategy from a viewpoint of animal welfare.
- Ad libitum feeding of group-housed gestating sows with a diet containing a high level of fermentable NSP is an interesting feeding strategy from a viewpoint of animal welfare because it reduces feeding motivation and results in less skin lesions.

Reproductive performance:

- Feeding gestating sows a diet with a high level of fermentable NSP (i.e. NSP from sugar beet pulp) restrictedly or ad libitum during three successive parities does not negatively affect reproductive performance compared to feeding gestating sows a conventional diet restrictedly.
- It is possible to feed sows a diet with a high level of fermentable NSP during both gestation and lactation without negative effects on reproductive performance.
- Feeding a diet with a high level of fermentable NSP from weaning until mating may increase the numbers of total and live-born piglets.
- The higher variation in body weight and backfat thickness in ad libitum fed gestating sows does not negatively affect reproductive performance.

Feed intake:

- Feed intake and feed intake pattern in gestating sows that are fed a diet with a high level of fermentable NSP ad libitum differ from those in gestating sows that are fed a conventional diet restrictedly. Mean daily voluntary feed intake in ad libitum fed gestating sows (4.2 kg) increases from weeks 2 to 6 of gestation and then decreases to week 15 of gestation.
- A daily intake of about 550 g starch plus sugar in late-gestating sows seems sufficient for optimal fetal growth since higher levels of starch do not increase birth weight of the piglets.
- Feeding additional energy (starch or fat) in late-gestating sows that are fed a high NSP diet restrictedly does not increase litter weight at birth or piglet survival but it does increase maternal gain.

Glucose tolerance:

- Feeding late-gestating sows additional energy from fat may induce glucose intolerance. Feeding late-gestating sows additional energy from starch does not induce glucose intolerance.

Practical implications

From a viewpoint of animal welfare, it is favorable to feed sows a diet with a high level of fermentable non-starch polysaccharides (NSP) during both gestation and lactation. Moreover, it is possible to feed sows a diet with a high level of fermentable NSP during both gestation and lactation over three successive parities without negative effects on reproductive performance. Body weight and backfat thickness of the sows, however, are negatively influenced by feeding sows a high level of dietary fermentable NSP during both gestation and lactation. Feeding a high starch diet during lactation increases feed intake and reduces backfat losses during lactation. Therefore, feeding sows a diet with a high level of fermentable NSP restrictedly during gestation and a high level of starch during lactation seems the most favorable feeding strategy.

Ad libitum feeding of gestating sows with a diet containing a high level of fermentable NSP is also an interesting feeding strategy from viewpoints of animal welfare and reproductive performance. Despite the higher feed intake during gestation, resulting in heavier and fatter sows at parturition and greater losses in body weight and backfat during lactation, ad libitum feeding of gestating sows during three successive reproduction cycles does not negatively affect reproductive performance.

In conclusion, both feeding gestating sows a diet with a high level of fermentable NSP restrictedly or ad libitum can be interesting feeding strategies to comply with the European obligation to feed sows without piglets some fiber every day.

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Summary

Introduction

Gestating sows are restricted in feed intake to maintain optimal body composition and productivity. Feed restriction is identified as one of the major factors associated with the development of stereotypic behavior in sows and therefore, there is a growing interest in feeding high fiber diets to sows. Fiber is known to reduce feeding motivation in restrictedly fed gestating sows by increasing satiation, which in return reduces the development of oral stereotypies. The botanical origin of dietary fiber can influence the effect on stereotypic behavior. There are indications that fermentable non-starch polysaccharides (NSP) in the diet are more involved in the feeling of satiety and in reducing stereotypic behavior than crude fiber or non-fermentable NSP. Feeding a diet with a high level of fermentable NSP during gestation reduces stereotypic behavior but it is still existing. Possibly, stereotypic behavior can be further reduced and animal welfare be further improved by feeding sows ad libitum during gestation or by feeding them a high NSP diet during both gestation and lactation. Improved welfare may also improve reproductive performance of sows. There are some indications that litter size may be improved when sows are fed diets with a high level of fermentable NSP during both gestation and lactation. Therefore, the main objective of this thesis was to investigate the long-term effects of feeding sows high levels of dietary fermentable NSP (i.e., NSP from sugar beet pulp) on behavior and reproductive performance.

Adaptation to nutrient digestion of a starch diet or a NSP diet in sows (chapter 2)

The currently used feed evaluation system in the Netherlands is based on fecal digestibility experiments with individually housed growing pigs. However, fecal digestibilities of dietary energy and nutrients are higher for sows than for growing pigs especially in diets with a high level of NSP. The time required for sows to adapt to a diet with a high level of fermentable NSP is not known. Therefore, the adaptation in nutrient digestibility to a starch-rich diet and a diet with a high level of fermentable NSP was studied in group-housed gestating sows during a period of 6 weeks. The experiment consisted of a 1-week adaptation period followed by a 5-week collection period. Fecal digestibilities were measured weekly by using the acid-insoluble ash marker method. Apparent fecal digestibilities of dry matter and organic matter of both diets were similar. Fecal digestibility of crude protein and crude fat was lower whereas that of NSP was higher in sows that were fed the high NSP diet. Calculated net energy values of both diets were similar. Diet by time interaction was not observed for any of the response variables indicating that sows adapt as quickly to a diet with a high level of fermentable NSP as to a starch-rich diet.

The experiment shows that, with regard to digestibility of nutrients, gestating sows completely adapt to a high NSP diet (i.e., NSP from sugar beet pulp) in 2 weeks and that the time period necessary to adapt to a starch-rich diet and a diet with a high level of fermentable NSP is similar.

Performance of sows fed high NSP levels during gestation and lactation (chapter 3)

This experiment was conducted to determine the long-term effects and carry-over effects of feeding high levels of fermentable NSP during gestation, during lactation or during both gestation and lactation on reproductive performance and development in body weight and backfat thickness in sows. Four-hundred and forty-four postpuberal gilts were allotted to a 2 x 2 x 2 factorial experiment. Treatments were diet composition during gestation (including weaning-to-estrus interval) (**G-Starch**: 274 g/kg of starch and 123 g/kg of fermentable NSP or **G-NSP**: 86 g/kg of starch and 300 g/kg of fermentable NSP), diet composition during lactation (**L-Starch**: 293 g/kg of starch and 113 g/kg of fermentable NSP or **L-NSP**: 189 g/kg of starch and 216 g/kg of fermentable NSP) and group-housing system during gestation (free access stalls or electronic feeding). Both gestation diets were formulated to be isoenergetic. Sows were followed over the first three parities. Body weight and backfat gains during gestation were lower in sows fed the G-NSP diet than in those fed the G-starch diet. The effects were more pronounced in the electronic feeding system than in the free access stalls. These results indicate an overestimation of the energy value of fermentable NSP. Body weight and backfat losses during lactation were less in sows fed the G-NSP diet during gestation than in those fed the G-starch diet. This can be explained by a 0.4 kg/d higher feed intake during lactation of the sows fed the G-NSP diet. Sows fed the L-NSP diet lost more backfat during lactation than sows fed the L-starch diet. This can be explained by a 0.4 kg/d lower feed intake during lactation of the sows fed the L-NSP diet. The number of total piglets born and live born piglets was 0.5 piglet higher in sows fed the G-NSP diet than in those fed the G-starch diet. It may be that feeding sows a diet with a high level of fermentable NSP from weaning until mating is responsible for the increase in the number of total and live-born piglets. Lactation diet did not affect the number of total piglets born or live born piglets.

This study shows that, although high NSP diets negatively influence BW and backfat thickness of the sows, it is possible to feed sows a diet with a high level of fermentable NSP diet during both gestation and lactation over three successive parities without negative effects on reproductive performance. Feeding sows a diet with a high level of fermentable NSP during gestation and a high level of starch during lactation seems the most favorable feeding strategy.

Stereotypic behavior of sows fed high NSP levels during gestation and lactation (chapter 4)

This experiment was conducted to determine the long-term effects and carry-over effects of feeding high levels of fermentable NSP during gestation, during lactation or during both gestation and lactation on development of stereotypic behavior in sows. Sows were followed over the first two parities. The same gestation and lactation diets were fed as in the experiment described in chapter 3. Behavioral measurements were carried out in weeks 3, 12 and 15 after start of the experiment or after weaning in parity 1 and 2 sows, respectively, three days before the expected date of parturition and one week before weaning in the first three hours after the morning meal using a scan-sampling technique. Feeding group-housed sows a high level of dietary fermentable NSP during gestation reduced the frequency of total non-feeding oral activities (= sham chewing + other non-feeding oral activities) in gestation compared with a starch diet. In both parity 1 and 2 sows, the greatest reduction was realised in week 15 and the smallest reduction in week 3. During lactation, the composition of the gestation diet did not affect the frequency of total non-feeding oral activities. Feeding sows a diet high in fermentable NSP during lactation reduced the frequency of total non-feeding oral activities in lactation in parity 2 sows but not in parity 1 sows compared with a starch diet. Moreover, it reduced the frequency of total non-feeding oral activities during subsequent gestation. In sows that were fed a high level of fermentable NSP diet during both gestation and lactation, the frequencies of total non-feeding oral activities in gestation and lactation did not increase from parity 1 to 2. This is probably due to the composition of the lactation diet and not to the composition of the gestation diet.

This study shows that diets high in fermentable NSP during gestation reduce the level of stereotypic behavior in gestation. Diets high in fermentable NSP during lactation have an additional reducing effect on the development of stereotypic behavior in subsequent gestation.

Additional starch or fat in high NSP diets

(chapter 5)

Piglet birth weight was lower in sows fed a high level of fermentable NSP during gestation than in sows fed a starch diet (chapter 3). A deficiency in glucogenic energy, especially at the end of gestation, in sows fed a high NSP diet might explain the lower birth weight of the piglets. In case of a shortage of glucogenic energy, feeding sows additional starch at the end of gestation may increase the birth weight of the piglets while feeding sows additional fat will not affect birth weight. Feeding sows additional energy at the end of gestation, however, may induce glucose intolerance in sows. Therefore, the effect of feeding additional starch or additional fat from day 85 of gestation on litter performance and glucose tolerance was studied in sows that were fed a high NSP diet. Three treatments were applied. Sows were fed 3.4 kg/d of a high NSP diet or the same quantity of the high NSP diet and an additional daily amount of 360 g starch, or the same quantity of the high NSP diet and an additional daily amount of 164 g fat. The supply of additional dietary starch or fat did not increase piglets birth weight and total litter weight at birth. A daily intake of about 550 g starch plus sugar in late-gestating sows seems sufficient for fetal growth. Piglet mortality after birth was not affected by dietary treatment. Body weight and backfat gains in the last month of gestation were higher in sows fed additional starch or fat than in sows fed the high NSP diet. Feed intake in lactation was highest in sows fed the high NSP diet, lowest in sows fed additional starch at the end of gestation and intermediate in sows fed additional fat. The differences in lactation feed intake did not result in differences in BW and backfat losses during lactation. Sows that were fed additional fat had the greatest glucose area under the curve indicating that these sows were less tolerant for glucose.

This study shows that feeding additional energy (starch or fat) in late-gestating sows that are fed a high NSP diet does not increase litter weight at birth nor piglet survival but it does increase maternal gain. Feeding sows additional energy from fat may induce glucose intolerance. Feeding sows additional energy from starch does not induce glucose intolerance.

Performance of ad libitum fed gestating sows

(chapter 6)

The objective of this experiment was to study the effects of feeding group-housed gestating sows a diet with a high level of fermentable NSP ad libitum on the development in individual feed intake characteristics and reproductive performance during three successive reproduction cycles. Performance of the ad libitum fed sows was compared to the performance of sows that were fed a conventional diet restrictedly. Feed intake characteristics during gestation were only measured in the ad libitum fed sows. The ad libitum fed sows ate 1.3 kg/d more during gestation than the restrictedly fed sows (4.2 versus 2.9 kg/d) resulting in higher body weight and backfat gains during gestation. Sows that were fed ad libitum during gestation lost more body weight and backfat during lactation than sows that were fed restrictedly during gestation. Feed intake during lactation, however, was similar in sows that were fed restrictedly or ad libitum during gestation. Reproductive performance was not affected by gestation feeding regime. Depending on the number of preceding reproduction cycles that a sow was fed ad libitum, the maximum voluntary feed intake was reached in parity 3, 4 or 5 and then remained stable in subsequent parities. Mean daily feed intake of the ad libitum fed sows increased from weeks 2 to 6 of gestation and then decreased to week 15 of gestation. On average, ad libitum fed sows spent 90 min/d eating whereas restrictedly fed sows spent 24 min/d eating. An increase in time spent eating is associated with a reduction in feeding motivation and in stereotypic behaviors. Skin lesions were recorded less in ad libitum fed gestating sows.

This study shows that it is possible to feed gestating sows a diet with a high level of fermentable NSP ad libitum during three successive reproduction cycles without negative effects on reproductive performance. Moreover, ad libitum feeding of gestating sows reduces feeding motivation and results in less skin lesions.

Conclusions

The main conclusions of this thesis are:

Digestibility:

- With regard to digestibility of nutrients, group-housed gestating sows completely adapt to a diet with a high level of fermentable NSP (i.e., NSP from sugar beet pulp) in two weeks. The time period necessary to adapt to a starch rich diet or a diet with a high level of fermentable NSP is similar.

Behavior:

- Feeding group-housed sows a diet with a high level of fermentable NSP during gestation reduces the level of stereotypic behavior in gestation compared to a starch diet. Feeding sows a diet with a high level of fermentable NSP during lactation has an additional reducing effect on the development of stereotypic behavior in subsequent gestation.

- In sows that are fed a high level of fermentable NSP diet during both gestation and lactation, the frequencies of total non-feeding oral activities and of sham chewing in gestation and lactation do not increase from parity 1 to 2. This is probably due to the composition of the lactation diet and not to the composition of the gestation diet.
- Feeding sows a diet with a high level of fermentable NSP during both gestation and lactation is a favorable feeding strategy from a viewpoint of animal welfare.
- Ad libitum feeding of group-housed gestating sows with a diet containing a high level of fermentable NSP is an interesting feeding strategy from a viewpoint of animal welfare because it reduces feeding motivation and results in less skin lesions.

Reproductive performance:

- Feeding gestating sows a diet with a high level of fermentable NSP (i.e. NSP from sugar beet pulp) restrictedly or ad libitum during three successive parities does not negatively affect reproductive performance compared to feeding gestating sows a conventional diet restrictedly.
- It is possible to feed sows a diet with a high level of fermentable NSP during both gestation and lactation without negative effects on reproductive performance.
- Feeding a diet with a high level of fermentable NSP from weaning until mating may increase the numbers of total and live-born piglets.
- The higher variation in body weight and backfat thickness in ad libitum fed gestating sows does not negatively affect reproductive performance.

Feed intake:

- Feed intake and feed intake pattern in gestating sows that are fed a diet with a high level of fermentable NSP ad libitum differ from those in gestating sows that are fed a conventional diet restrictedly. Mean daily voluntary feed intake in ad libitum fed gestating sows (4.2 kg) increases from weeks 2 to 6 of gestation and then decreases to week 15 of gestation.
- A daily intake of about 550 g starch plus sugar in late-gestating sows seems sufficient for optimal fetal growth since higher levels of starch do not increase birth weight of the piglets.
- Feeding additional energy (starch or fat) in late-gestating sows that are fed a high NSP diet restrictedly does not increase litter weight at birth or piglet survival but it does increase maternal gain.

Glucose tolerance:

- Feeding late-gestating sows additional energy from fat may induce glucose intolerance. Feeding late-gestating sows additional energy from starch does not induce glucose intolerance.

Samenvatting

Inleiding

Drachtige zeugen worden in het algemeen beperkt gevoerd om overmatige vervetting en reproductieproblemen te voorkomen. Het beperkt voeren van zeugen kan echter leiden tot de ontwikkeling van stereotiep gedrag en daarom is er een toenemende interesse in het verstrekken van vezelrijke voeders aan zeugen. Vezelrijke voeders zorgen voor een verzadigd gevoel bij de zeugen waardoor de voeropname motivatie gereduceerd wordt en de ontwikkeling van stereotiep gedrag afgeremd wordt. De botanische herkomst van de vezel lijkt echter een rol te spelen bij het effect op stereotiep gedrag. De fysische en chemische eigenschappen kunnen sterk verschillen per soort vezel. Een van de kenmerken die varieert per vezel is het gehalte aan verteerbare overige organische stof (VOOS). Er zijn aanwijzingen dat het gehalte aan VOOS in het voer (met name VOOS uit bietenpulp) een belangrijkere rol speelt in de reductie van stereotiep gedrag dan de gehalten aan ruwe celstof of aan overige organische stof (OOS). Bietenpulp heeft een hoog waterbindend vermogen waardoor zeugen mogelijk sneller een verzadigd gevoel hebben en bietenpulp vertraagt de maaglediging. Anderzijds blijft het glucosegehalte in het bloed langer op een hoog niveau als zeugen een voer met veel bietenpulp opnemen, waardoor de dieren zich gedurende langere tijd verzadigd voelen. Het verstrekken van een voer met een hoog VOOS-gehalte aan drachtige zeugen vermindert stereotiep gedrag maar neemt het niet volledig weg. Mogelijk kan het stereotiep gedrag nog verder gereduceerd en het welzijn nog verder verbeterd worden door drachtige zeugen onbeperkt te voeren of door zeugen tijdens zowel dracht als lactatie een VOOS-rijk voer te geven. Onbeperkte voedering met het gebruikelijke zeugenvoer leidt echter tot overmatige groei en vervetting van de zeugen. VOOS-rijke voeders lijken de voeropname tot een gewenst niveau te kunnen beperken. Een beter welzijn van de zeugen leidt mogelijk ook tot betere reproductieresultaten. Er zijn aanwijzingen dat het aantal levend geboren biggen hoger is als zeugen zowel tijdens de dracht als lactatie een VOOS-rijk voer krijgen.

Het belangrijkste doel van dit onderzoek was daarom na te gaan wat de lange termijn effecten zijn van het verstrekken van VOOS-rijke voeders (met name VOOS uit bietenpulp) aan zeugen op reproductie en gedrag.

Aanpassing in vertering aan een zetmeelrijk voer en aan een VOOS-rijk voer (hoofdstuk 2)

Om de hoeveelheid netto energie in varkensvoer te berekenen wordt in Nederland gebruik gemaakt van verteringscoëfficiënten die vastgesteld zijn bij individueel gehuisveste vleesvarkens. VOOS-rijke voeders worden door zeugen echter beter verteerd dan door vleesvarkens. Bovendien is er een verschil in vertering tussen individueel en groepsgehuisveste dieren. Het is niet bekend hoe lang het duurt voordat het maagdarmkanaal van zeugen zich aangepast heeft aan een VOOS-rijk voer. Daarom is in een verteringsonderzoek met drachtige zeugen in groepshuisvesting nagegaan hoe lang het duurt voordat het maagdarmkanaal zich aangepast heeft aan een zetmeelrijk of een VOOS-rijk voer. Na een adaptatieperiode van 1 week zijn gedurende vijf weken mestmonsters bij zeugen genomen. De verteringscoëfficiënten werden wekelijks bepaald met behulp van de indicatormethode (HCl-onoplosbare as werd als indicator toegevoegd aan het voer).

De schijnbare fecale verteringscoëfficiënten van de droge stof en organische stof waren vergelijkbaar in het zetmeelrijke en het VOOS-rijke voer. De schijnbare fecale verteringscoëfficiënten van eiwit en vet waren lager bij zeugen die het VOOS-rijke voer kregen. De schijnbare fecale verteringscoëfficiënt van OOS was hoger bij zeugen die het VOOS-rijke voer kregen. De berekende netto energiewaarde van de twee voeders was vergelijkbaar. Voor geen enkel kenmerk was er sprake van een interactie tussen voersoort en week van waarnemen. Dit betekent dat de zeugen zich even snel aanpassen aan een VOOS-rijk voer als aan een zetmeelrijk voer.

Uit het verteringsonderzoek blijkt dat, wat betreft de vertering van nutriënten, zeugen na twee weken aangepast zijn aan een VOOS-rijk voer (VOOS met name afkomstig uit bietenpulp). Bovendien zijn zeugen even snel aangepast aan een VOOS-rijk voer als aan een zetmeelrijk voer.

VOOS-rijk voer tijdens dracht en lactatie: effect op reproductie (hoofdstuk 3)

In dit onderzoek is nagegaan wat de lange termijn en carry-over effecten zijn van het verstrekken van VOOS-rijke voeders tijdens de dracht, tijdens de lactatie of tijdens de dracht en lactatie op de reproductieresultaten en ontwikkeling in gewicht en spekdikte bij zeugen. In totaal zijn 444 opfokzeugen ingezet die drie worpen gevolgd zijn. Het onderzoek is opgezet als en 2 x 2 x 2 factoriële proef. Proefbehandelingen waren:

1. Voersoort tijdens de dracht (inclusief gustperiode): zetmeelrijk voer (274 g/kg zetmeel en 123 g/kg VOOS) of VOOS-rijk voer (86 g/kg zetmeel en 300 g/kg VOOS).
2. Voersoort tijdens de lactatie: zetmeelrijk voer (293 g/kg zetmeel en 113 g/kg VOOS) of VOOS-rijk voer (189 g/kg zetmeel en 216 g/kg VOOS).
3. Huisvestingssysteem tijdens de dracht: voerligboxen met uitloop of groepshuisvesting met voerstation.

Beide drachtvoeders hadden een EW van 0,98 (uitgaande van een energetische waardering van VOOS van 13,5 MJ NE/kg) en de drachtige zeugen werden iso-energetisch gevoerd.

De zeugen die het VOOS-rijke drachtvoer kregen namen minder in gewicht en spekdikte toe tijdens de dracht dan de zeugen die het zetmeelrijke drachtvoer kregen. In groepshuisvesting met voerstation waren deze verschillen in gewichts- en spekdiktetoename groter dan in voerligboxen met uitloop. Dit duidt op een overschatting van de energetische waardering van VOOS. Tijdens de lactatie namen de zeugen die het VOOS-rijke drachtvoer kregen minder in gewicht en spekdikte af dan de zeugen die het zetmeelrijke drachtvoer kregen. Dit is het gevolg van een 0,4 kg/d hogere voeropname tijdens de lactatie van de zeugen die het VOOS-rijke drachtvoer kregen. Zeugen die het VOOS-rijke lactatievoer kregen verloren meer spek tijdens de lactatie dan zeugen die het zetmeelrijke lactatievoer kregen als gevolg van een 0,4 kg/d lagere voeropname. Het aantal levend geboren biggen per worp was 0,5 hoger bij zeugen die het VOOS-rijke drachtvoer kregen. Mogelijk dat het verstrekken van het VOOS-rijke drachtvoer in het interval spenen-dekken verantwoordelijk is voor het hogere aantal levend geboren biggen. De samenstelling van het lactatievoer had geen effect op het aantal levend geboren biggen.

Uit dit onderzoek blijkt dat het mogelijk is om zeugen gedurende drie opéénvolgende pariteiten zowel tijdens de dracht als tijdens de lactatie een VOOS-rijk voer te verstrekken zonder dat dit negatieve gevolgen heeft voor reproductie, ook al nemen de zeugen minder in gewicht en spekdikte toe. De combinatie van een VOOS-rijk voer tijdens de dracht en een zetmeelrijk voer tijdens de lactatie lijkt de meest gewenste voerstrategie.

VOOS-rijk voer tijdens dracht en lactatie: effect op gedrag (hoofdstuk 4)

In dit onderzoek is nagegaan wat de lange termijn en carry-over effecten zijn van het verstrekken van VOOS-rijke voeders tijdens de dracht, tijdens de lactatie of tijdens de dracht en lactatie op de ontwikkeling van oraal stereotiep gedrag bij zeugen. Het onderzoek is uitgevoerd bij zeugen in voerligboxen met uitloop. Zeugen zijn gedurende de eerste twee pariteiten gevolgd en kregen de dracht- en lactatievoeders verstrekt zoals beschreven in hoofdstuk 3. De gedragswaarnemingen zijn 's ochtends van 8.30 tot 11.30 u via intervalwaarnemingen uitgevoerd in de derde, twaalfde en vijftiende week na inzet in de proef c.q. spenen, drie dagen voor de verwachte werpdatum en 1 week voor het spenen. Zeugen die het VOOS-rijke drachtvoer kregen vertoonden duidelijk minder oraal stereotiep gedrag (= looskauwen + andere niet aan voeding gerelateerde orale gedragingen) tijdens de dracht dan zeugen die het zetmeelrijke drachtvoer kregen. De grootste reductie in oraal stereotiep gedrag werd gevonden in week 15 na inzet c.q. spenen en de kleinste reductie in week 3. De samenstelling van het drachtvoer beïnvloedde het oraal stereotiep gedrag tijdens de lactatie niet. Het VOOS-rijke lactatievoer verminderde het oraal stereotiep gedrag tijdens de daaropvolgende dracht en tijdens de tweede lactatie maar niet tijdens de eerste lactatie. Bij zeugen die zowel tijdens de dracht als tijdens de lactatie de VOOS-rijke voeders kregen, steeg de frequentie van oraal stereotiep gedrag niet van pariteit 1 naar pariteit 2. Dit is waarschijnlijk het gevolg van de samenstelling van het lactatievoer en niet van de samenstelling van het drachtvoer.

Uit dit onderzoek blijkt dat een VOOS-rijk drachtvoer het oraal stereotiep gedrag tijdens de dracht reduceert. Een VOOS-rijk lactatievoer reduceert de ontwikkeling van stereotiep gedrag tijdens de daaropvolgende dracht nog verder.

Extra zetmeel of vet in de laatste maand van de dracht
(hoofdstuk 5)

Het geboortegewicht van de levend geboren biggen was lager bij zeugen die het VOOS-rijke drachtvoer kregen dan bij zeugen die het zetmeelrijke drachtvoer kregen (hoofdstuk 3). Mogelijk hebben de zeugen die het VOOS-rijke drachtvoer kregen aan het eind van de dracht te weinig glucogene energie (energie uit zetmeel) opgenomen. Voor de ontwikkeling van de nog ongeboren biggen is het belangrijk dat de zeugen voldoende zetmeel opnemen met het voer. Als een tekort aan glucogene energie werkelijk de oorzaak is van het lagere geboortegewicht, zou het geven van extra energie uit zetmeel aan het eind van de dracht het geboortegewicht moeten verhogen. Het geven van extra energie uit vet (lipogene energie) zou geen effect moeten hebben op het geboortegewicht. Het geven van extra energie aan het eind van de dracht kan echter tot glucose-intolerantie leiden bij zeugen. Glucose-intolerantie bij zeugen kan tot te zware biggen leiden bij de geboorte en dit kan de biggensterfte verhogen. Daarom is bij zeugen die een VOOS-rijk drachtvoer kregen nagegaan wat het effect is van het verstrekken van extra zetmeel of extra vet in de laatste maand van de dracht op reproductie en glucose tolerantie. Vanaf 85 dagen dracht tot werpen waren er drie proefbehandelingen:

1. Zeugen kregen 3,4 kg/d van het VOOS-rijke drachtvoer.
2. Zeugen kregen 3,4 kg/d van het VOOS-rijke drachtvoer plus 360 g/d zetmeel.
3. Zeugen kregen 3,4 kg/d van het VOOS-rijke drachtvoer plus 164 g/d vet.

Het verstrekken van extra zetmeel of extra vet aan het einde van de dracht verhoogde het geboortegewicht van de biggen niet maar het gewicht van de zeugen wel. Een dagelijkse opname van circa 550 gram zetmeel plus suiker in de laatste maand van de dracht lijkt voldoende voor de ontwikkeling van de nog ongeboren biggen. Het geven van extra zetmeel of vet in de laatste maand van de dracht had geen effect op de biggensterfte na geboorte. De zeugen die het VOOS-rijke drachtvoer kregen in de laatste maand van de dracht namen het meeste voer op tijdens de lactatie. De zeugen die extra zetmeel kregen namen het minste voer op tijdens de lactatie. De verschillen in voeropname tijdens de lactatie resulteerde niet in verschillen in gewicht- en spekdikte afname tijdens de lactatie. Zeugen die extra vet kregen in de laatste maand van de dracht hadden de grootste oppervlakte onder de curve voor glucose. Dit duidt er op dat deze zeugen minder tolerant zijn voor glucose.

Uit dit onderzoek blijkt dat het verstrekken van extra zetmeel of vet in de laatste maand van de dracht aan zeugen die een VOOS-rijk drachtvoer krijgen het geboortegewicht van de biggen en de biggensterfte na geboorte niet verhoogt. Het geven van extra vet in de laatste maand van de dracht kan tot glucose-intolerantie bij zeugen leiden. Het geven van extra zetmeel in de laatste maand van de dracht leidt niet tot glucose-intolerantie bij zeugen.

Onbeperkt voeren van drachtige zeugen
(hoofdstuk 6)

In dit onderzoek is nagegaan wat het effect is op reproductie, gewichts- en spekdikteontwikkeling en ontwikkeling in voeropname en voeropnamekenmerken van het gedurende drie opéénvolgende pariteiten onbeperkt voeren van drachtige zeugen met een VOOS-rijk voer. De resultaten zijn vergeleken met die van zeugen die beperkt werden gevoerd met een gangbaar zeugenvoer. De voeropnamekenmerken zijn alleen gemeten bij de onbeperkt gevoerde zeugen. De onbeperkt gevoerde zeugen namen gemiddeld tijdens de dracht 1,3 kg voer per dag meer op dan de beperkt gevoerde zeugen (4,2 versus 2,9 kg/d). Hierdoor namen ze meer in gewicht en spekdikte toe tijdens de dracht. De zeugen die onbeperkt werden gevoerd tijdens de dracht verloren meer gewicht en spek tijdens de lactatie dan de zeugen die beperkt werden gevoerd tijdens de dracht. De voeropname tijdens de lactatie was echter vergelijkbaar bij zeugen die beperkt of onbeperkt waren gevoerd tijdens de dracht. De reproductieresultaten van de onbeperkt gevoerde zeugen waren vergelijkbaar met die van de beperkt gevoerde zeugen. Als zeugen vanaf de eerste dracht onbeperkt worden gevoerd, bereiken ze tijdens de derde dracht hun maximale voeropname. Als zeugen vanaf de derde, vierde of vijfde dracht onbeperkt worden gevoerd, bereiken ze de maximale voeropname tijdens de vijfde dracht. Vanaf de vijfde dracht neemt de voeropname niet meer toe. De voeropname van de onbeperkt gevoerde zeugen steeg van week 2 tot week 6 van de dracht om daarna tot het einde van de dracht geleidelijk af te nemen. De onbeperkt gevoerde zeugen waren gemiddeld 90 minuten per dag bezig met het opnemen van voer. De beperkt gevoerde zeugen hadden in gemiddeld 24 minuten hun dagelijkse portie voer op. Een toename in eettijd bij zeugen is geassocieerd met een reductie in voeropname motivatie en een reductie in stereotiep gedrag. Huidbeschadigingen kwamen minder voor bij de onbeperkt gevoerde drachtige zeugen.

Uit dit onderzoek blijkt dat het mogelijk is om drachtige zeugen gedurende drie opéénvolgende pariteiten onbeperkt te voeren zonder negatieve effecten op reproductie. Het onbeperkt voeren reduceert de voeropname motivatie van zeugen en vermindert het aantal zeugen met huidbeschadigingen.

Conclusies

De belangrijkste conclusies uit dit proefschrift zijn:

Vertering:

- Wat betreft de vertering van nutriënten zijn groepsgehuisveste drachtige zeugen na twee weken aangepast aan een VOOS-rijk voer (VOOS met name afkomstig uit bietenpulp). Bovendien zijn de zeugen even snel aangepast aan een VOOS-rijk voer als aan een zetmeelrijk voer.

Gedrag:

- Een VOOS-rijk drachtvoer reduceert het oraal stereotiep gedrag tijdens de dracht in vergelijking met een zetmeelrijk drachtvoer. Een VOOS-rijk lactatievoer reduceert de ontwikkeling van stereotiep gedrag tijdens de daaropvolgende dracht nog verder.
- Bij zeugen die zowel tijdens de dracht als tijdens de lactatie VOOS-rijke voeders krijgen, stijgt de frequentie van oraal stereotiep gedrag niet van pariteit 1 naar pariteit 2. Dit is waarschijnlijk het gevolg van de samenstelling van het lactatievoer en niet van de samenstelling van het drachtvoer.

- Het verstrekken van VOOS-rijke voeders tijdens zowel dracht als lactatie is vanuit welzijnsoogpunt de meest gewenste voerstrategie.
- Het onbeperkt voeren van drachtige zeugen met een VOOS-rijk voer is vanuit welzijnsoogpunt een gewenste voerstrategie omdat het de voeropname motivatie van zeugen reduceert en het aantal zeugen met huidbeschadigingen vermindert.

Reproductie:

- Het beperkt of onbeperkt voeren van drachtige zeugen met een VOOS-rijk voer gedurende drie opéénvolgende pariteiten heeft geen negatief effect op de reproductieresultaten in vergelijking tot het beperkt voeren van drachtige zeugen met een gangbaar zeugenvoer.
- Het is mogelijk om zeugen tijdens zowel de dracht als lactatie VOOS-rijke voeders te geven zonder negatieve effecten op reproductie.
- Het verstrekken van een VOOS-rijk voer van spenen tot dekken verhoogt mogelijk het aantal levend geboren biggen.
- De grotere variatie in gewicht en spekdikte bij onbeperkt gevoerde drachtige zeugen heeft geen negatief effect op de reproductieresultaten.

Voeropname:

- De voeropname en voeropnamekenmerken van onbeperkt gevoerde drachtige zeugen verschillen van die van beperkt gevoerde drachtige zeugen. De voeropname van de onbeperkt gevoerde zeugen (gemiddeld 4,2 kg/d) stijgt van week 2 tot week 6 van de dracht om daarna tot het einde van de dracht geleidelijk af te nemen.
- Een dagelijkse opname van 550 gram zetmeel plus suiker in de laatste maand van de dracht lijkt voldoende voor een optimale groei van de foeten. Een hogere zetmeel plus suiker opname verhoogt het geboortegewicht van de biggen niet.
- Het verstrekken van extra energie (zetmeel of vet) aan het eind van de dracht verhoogt het geboortegewicht van de biggen niet en leidt niet tot minder biggensterfte. Het verhoogt wel het gewicht van de zeugen.

Glucose tolerantie:

- Het verstrekken van extra energie uit vet in de laatste maand van de dracht kan tot glucose-intolerantie bij zeugen leiden. Het verstrekken van extra energie uit zetmeel leidt niet tot glucose-intolerantie bij zeugen.

Curriculum Vitae

Carola Maria Cornelia van der Peet-Schwering werd geboren op 22 augustus 1958 te Bergen (Limburg). In 1976 behaalde zij het VWO-A diploma aan het Elzendaalcollege te Boxmeer. In 1977 heeft zij staatsexamen gedaan in natuur- en scheikunde, waarna zij begonnen is met de studie Zoötechniek aan de toenmalige Landbouw Hogeschool in Wageningen. In januari 1984 haalde zij haar doctoraal diploma met als hoofdvakken veefokkerij en veehouderij. Tot 1 februari 1985 was zij wetenschappelijk medewerker bij de vakgroep tropische veeteelt van de Landbouw Hogeschool. Op 1 februari 1985 is zij begonnen als onderzoeker bij het toenmalige Proefstation voor de Varkenshouderij te Utrecht. Belangrijkste taak was het rapporteren van reeds afgesloten onderzoek. In juni 1986 is zij aangesteld als onderzoeker voeding bij het Proefstation voor de Varkenshouderij, dat inmiddels was gevestigd in Rosmalen. Belangrijkste onderzoeksthema's waaraan in de loop der jaren gewerkt is zijn: mogelijkheden om via voeding de mineralenuitscheiding en ammoniakemissie te verlagen, waterbehoefte vleesvarkens en zeugen, voeding vleesvarkens in relatie tot slacht- en vleeskwaliteit, ontwikkelen van een groeimodel voor vleesvarkens (Technisch Model Varkensvoeding) en voeding in relatie tot gezondheid biggen. Sinds 1999 is zij werkzaam als senior wetenschappelijk onderzoeker voeding bij het Praktijkonderzoek Varkenshouderij, inmiddels Praktijkonderzoek van de Animal Sciences Group van Wageningen UR, en is zij gestart met haar promotie onderzoek. Daarnaast was zij van 2001 tot 2003 projectmanager voeding varkens en pluimvee. Momenteel werkt ze aan diverse voedingsprojecten binnen de Animal Sciences Group.