

## Dietary Fiber Stabilizes Blood Glucose and Insulin Levels and Reduces Physical Activity in Sows (*Sus scrofa*)<sup>1,2</sup>

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**ABSTRACT** The aim of this study was to test whether a diet with a high level of fermentable dietary fiber can stabilize interprandial blood glucose and insulin levels, prevent declines below basal levels, and reduce physical activity in limited-fed breeding sows. Stable levels of glucose and insulin may prevent interprandial feelings of hunger and, consequently, increased activity. Catheterized sows ( $n = 10$ ) were fed twice daily (0700 and 1900 h) 900 g of a diet with either a low (L-sows) or a high level of fermentable dietary fiber (H-sows; sugarbeet pulp). Blood samples, taken between feeding times, were analyzed for glucose and insulin levels (basal and area under the curve) and stability of levels (variance and sum of absolute differences between levels in consecutive samples). The main focus was on samples taken after the postprandial peak. Behavior was videotaped for analysis of postures and posture changes. Basal glucose and insulin levels did not differ between treatments. H-sows had more stable levels than L-sows. Interprandial levels of H-sows were higher than or equal to basal levels. L-sows showed a decline in glucose below basal levels at 1400 h ( $P < 0.05$ ). Before 1400 h, no difference in the frequency of posture changes was observed between treatments. After 1400 h, the frequency of posture changes increased more in L-sows than in H-sows. We concluded that sugarbeet pulp as a source of fermentable dietary fiber stabilizes glucose and insulin levels and reduces physical activity in limited-fed sows several hours after feeding. This may indicate a prolonged feeling of satiety. *J. Nutr.* 134: 1481–1486, 2004.

**KEY WORDS:** • satiety • stress • fermentation • volatile fatty acids • pigs

Restricted nutrient intake of nonlactating sows is essential to prevent excessive fatness and reduced reproductive performance as a consequence. The restricted level at which sows mainly receive their diets meets their needs for maintenance and reproduction, but the diets often do not provide a sufficient feeling of satiety. This causes a high feeding motivation throughout the day, even immediately after feeding, resulting in increased levels of activity and the development of stereotyped behavior (1–3).

Incorporation of fibrous ingredients into the diet was shown to reduce activity and stereotyped behavior (4–6). The long-term effectiveness, however, seems to depend on the physico-chemical characteristics of the ingredients (7,8). Studies with concentrate diets containing sugarbeet pulp (SBP)<sup>4</sup> as the fiber

source showed that stereotyped or manipulative behavior was reduced not only immediately after feeding, but also several hours after feeding (9,10). This may be due to several positive characteristics of the SBP. Just after feeding, its high water-holding capacity (11) may play an important role in the reduction of feeding motivation. It can cause high gastric distension and consecutive stimulation of stretch receptors (12). In addition, SBP contains high amounts of soluble nonstarch polysaccharides (NSP), which can delay the passage rate of digesta and nutrient absorption (7,13). These NSP (pectin) are easily fermentable by bacteria in the distal part of the gastrointestinal tract. Volatile fatty acids (VFA; also referred to as SCFA) are produced. Because fermentation in the hindgut may be elevated several hours after feeding, VFA may be involved in the longer-term feeling of satiety (14). They are available as a source of energy at times when the glucose supply from the gut is decreasing (14–16). Many studies were done to investigate the effects of fibrous diets on glucose and insulin levels (7,8,17,18). These studies focused mainly on the postprandial glucose and insulin peaks and on mean levels of glucose and insulin. Reduced and delayed peaks were observed. In rats (19,20) and humans (21), it was shown that transient declines in glucose levels precede meal initiation (rats) or spoken meal request (humans). An intravenous glucose infusion to partially block the premeal decline delayed the subsequent meal (20). Sows usually do not have the opportunity to

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<sup>4</sup> Abbreviations used: AUC, area under the curve; CF, crude fiber; CL, crude lipid; CP, crude protein; fNSP, fermentable nonstarch polysaccharides; H-diet, diet with a high level of fNSP; H-sows, sows fed the H-diet; L-diet, diet with a low level of fNSP; L-sows, sows fed the L-diet; NSP, nonstarch polysaccharides; SAD, sum of absolute differences between levels in consecutive samples; SBP, sugarbeet pulp; VAR, variance; VFA, volatile fatty acids.

choose their meal time. Therefore, it may be important to stabilize interprandial glucose levels and prevent declines in glucose levels below basal levels to prevent feelings of hunger. We hypothesize that VFA are able to prevent interprandial transient declines of glucose levels because VFA can be used as an alternative energy source. According to Bergman (16), VFA may contribute ~20–30% of the energy requirements of pigs. This contribution could be considerably higher when dietary fiber levels in the diet increase. Acetic acid can be utilized by skeletal muscle and may, therefore, spare glucose. In addition, propionic acid is a glucogenic precursor. Butyric acid is utilized mainly by the large intestinal epithelium (16).

Therefore, the aim of this study was to determine whether a concentrate diet containing large amounts of easily fermentable carbohydrates (fermentable nonstarch polysaccharides; fNSP) can stabilize blood glucose and insulin levels after the postprandial peak and prevent possible interprandial declines below basal levels. In addition, we examined whether the fNSP-rich diet reduces physical activity.

## MATERIALS AND METHODS

**Animals and housing.** Empty first-parity sows ( $n = 12$ ; Topigs), bred at de Waaiboerhoeve in Lelystad (Animal Sciences Group of Wageningen UR, The Netherlands), were used in this experiment. They were individually housed in metabolism cages (180 × 80 cm) in the Metabolism Unit in Lelystad. There were 2 rows of 6 cages in the room and neighboring sows could not see each other. The climate in the room was kept constant. The temperature was set at 20.5°C and artificial lights were on from 0600 until 2000 h. Windows were blinded to prevent any effect of daylight on the behavior of the sows. During the dark period, dimmed artificial lights were on. The cages were equipped with an automatic feeding system and a water reservoir, connected to a nipple next to the feeder. Two metal funnels beneath the slatted floor allowed separate collection of excretions and spilled water. The protocol for this experiment was approved by the Ethical Review Committee of the Animal Sciences Group of Wageningen UR.

**Diets and feeding.** Sows were fed either a diet with a high level of fNSP (H-diet;  $n = 6$ ) or with a low level of fNSP (L-diet;  $n = 6$ ). Within each of 2 weight classes (high and low), sows were randomly assigned to 1 of the 2 diets. Siblings were assigned to different diets.

Diets were formulated according to the official Dutch recommendations (22), except for the NSP content in the L-diet, using the linear program Optisam. The diets were manufactured at a research feed mill (Arkervart-Twente). The composition is given in Table 1. Diets were isoenergetic in their metabolizable energy content. The H-diet contained SBP as the main fNSP source at the expense of barley, wheat, and cornstarch, which were the main sources of glucogenic energy in the L-diet. Representative samples of each diet, taken during production, were analyzed for dry matter, ash, crude protein (CP), crude lipid (CL), starch, and sugar. NSP were derived by subtracting the CP, CL, starch, and sugar contents from the organic matter content (22). fNSP were derived by subtracting the digestible CP, digestible CL, starch, and sugar content from the digestible organic matter content (22). Apparent fecal digestibility coefficients of nutrients are not presented in this paper.

Sows automatically received 900 g of feed at 0700 and 1900 h. The amount of feed provided per day was ~10% above maintenance requirements for energy, based on the average metabolic weight of the sows (weight<sup>0.75</sup>). Water availability was restricted to a maximum of 12 L/d.

**Surgery.** After 18 d of adaptation to their new housing and diets, sows were surgically fitted with catheters in the jugular vein and the carotid artery (23). Surgery took place on each of 4 consecutive days. During the 24 h preceding surgery, sows were deprived of feed. After i.m. premedication with Stresnil (20–30 mL; Janssen Pharmaceutica BV), atropine (8 mL; Vetimex Animal Health BV), and Finadyne (3 mL; Schering Plough BV), the anesthesia was induced i.v. with ketamine (20–40 mL; Alfasan). Anesthesia was maintained with

TABLE 1

Formulation and composition of the experimental diets

	L	H
Ingredient, g/kg		
Barley	130.0	—
Tapioca (starch, 625–675 g/kg)	191.3	123.4
Soybean meal (extracted; CF, 50–70 g/kg; CP, >440 g/kg)	80.0	80.0
Soybean hulls (CF, <310 g/kg)	70.0	124.0
Peas (CP, <220 g/kg)	70.0	70.0
Wheat middlings	150.0	—
Sunflower seed (extracted; CF, 160–200 g/kg)	60.0	37.4
Sugarbeet pulp (dehydrated; sugar, <100 g/kg)	—	450.0
Molasses (cane; sugar, >475 g/kg)	50.0	50.0
Animal fat	22.2	26.1
Cornstarch	150.0	20.0
Limestone	9.8	0.6
Salt	4.7	2.7
Cr <sub>2</sub> O <sub>3</sub> -Cornstarch mix (1:3)	1.0	1.0
Monocalcium phosphate · 1H <sub>2</sub> O	4.8	7.2
Vitamin and trace element mix <sup>1</sup>	5.0	5.0
D,L-Methionine	0.8	1.4
L-Threonine	0.4	0.9
L-Tryptophan	—	0.2
Analyzed composition, g/kg as fed		
Dry matter	858	866
Ash	58	67
Crude protein	123	120
Crude fat	36	36
Starch	343	123
Sugar	53	87
Nonstarch polysaccharides <sup>2</sup>	246	436
Fermentable nonstarch polysaccharides <sup>3</sup>	173	378
Metabolizable energy, <sup>4</sup> MJ/kg	12.7	12.6

<sup>1</sup> The vitamin-mineral premix supplied (per kg diet): retinyl, 3.44 mg; cholecalciferol, 0.05 mg; Vitamin E, 25 IU; menadione, 1 mg; thiamin, 0.75 mg; riboflavin, 4 mg; D-pantothenic acid, 13 mg; niacin, 15 mg; cyanocobalamin, 0.015 mg; folic acid, 1.3 mg; pyridoxine, 1 mg; choline, 300 mg; Fe as Fe<sub>2</sub>SO<sub>4</sub> · H<sub>2</sub>O, 150 mg; Cu as CuSO<sub>4</sub> · 5H<sub>2</sub>O, 20 mg; Zn as ZnO, 65 mg; Mn as MnO, 30 mg; Co as CoCO<sub>3</sub>, 0.15 mg; I as KI, 1 mg; Se as Na<sub>2</sub>SeO<sub>3</sub>, 0.2 mg.

<sup>2</sup> NSP were derived by subtracting the CP, CL, starch, and sugar content from the organic matter content (22).

<sup>3</sup> Fermentable NSP (fNSP) were derived by subtracting the digestible CP, digestible CL, starch, and sugar content from the digestible organic matter content (22).

<sup>4</sup> Calculated (22). A correction was made for the assumed energy-saving effect by reduced physical activity. This correction is advised for diets for growing pigs containing up to 15% sugarbeet pulp (22). We assumed the same energy saving per unit of fNSP derived from sugarbeet pulp in sows.

isoflurane (first 5%, later 1.5%) mixed with oxygen and nitrous oxide (1:2) via an endotracheal tube. Starting the day before surgery, Depomycine (10 mL; Mycofarm Nederland BV) was administered i.m. on 4 consecutive days. During the days after surgery, the feeding level was gradually increased to allow good recovery and adaptation of the gut to the diets. Measurements started ~1 mo after surgery. Sows returned to the experimental feeding level 5 d before measurements started. Catheters were flushed weekly with heparinized saline.

**Blood sampling.** Blood samples were taken on 1 d 0.25 h before meal-start and at 0.5, 1, 2, 3, 5, 7, 9, and 11 h after meal-start. Samples were taken with 9-mL syringes containing lithium-heparin (Monovette, Sarstedt BV) from the jugular vein after flushing the catheter with another syringe. After sampling, the catheter was filled with heparinized saline again. Blood samples were immediately put on ice and centrifuged for 10 min at 800 × g at 4°C. The plasma obtained was stored at -20°C until analysis.

A preliminary blood sample (1 h before meal-start) was taken to let the sows become used to the sampling procedure. This sample was not analyzed. All other samples were analyzed for glucose and insulin. Glucose was analyzed by the Boehringer Mannheim hexokinase method (Roche Diagnostics Nederland BV). Insulin was analyzed using a time-resolved fluoroimmunoassay (AutoDELFIA Insulin; Wallac Oy) with porcine standards.

Glucose and insulin were analyzed for levels and stability of their levels. Areas under the curve (AUCs) were calculated for the total period and for the periods before and after 1000 h separately. Samples taken before 1000 h were expected to include the postprandial peak (7,8,18). AUCs were approximated by using trapezoidal summation. Trapezoids were calculated as the length of the base (interval time between consecutive samples in h) times the average of the heights of the 2 sides (levels of consecutive samples). Stability of levels was determined by calculating the variance (VAR) and the sum of absolute differences between levels in consecutive samples (SAD) for the total period (including the presumed postprandial peak) and the period after 1000 h (excluding the presumed postprandial peak). Glucose and insulin levels were expressed as a percentage of their basal level within sows as well. The basal level was defined as the average of the level in the first and last sample (15 min before the morning feeding and 60 min before the afternoon feeding, respectively).

**Video-recording.** The behavior of the sows was recorded on videotape once during the light period (0600–2000 h) using a time-lapse video recorder. Time spent in standing (body supported by all 4 legs), lying (body not supported by any of the legs), and sitting (body supported by both front legs only) was determined and expressed as a percentage of the total recording time. The number of posture changes was determined as a measure of physical activity in each of seven 2-h periods.

**Statistical analysis.** Data were analyzed using 1-sided nonparametric tests in StatXact (24). Differences between treatments were tested with an unpaired permutation test for parameters of glucose and insulin levels (basal level, AUC) and stability (VAR, SAD), postures, and number of posture changes in each 2-h period. Within each treatment, glucose and insulin levels in each blood sample were compared with their basal levels with a paired permutation test. An increase or decrease in the number of posture changes over time was

determined within each dietary treatment by comparing the number of posture changes in each period with those in the previous period with a paired permutation test. Data are presented as means  $\pm$  SEM. Differences were considered significant at  $P \leq 0.05$ , rounded at the second decimal.

## RESULTS

Two sows (1 from each dietary treatment) were excluded from analyses for health reasons. All of catheters functioned well throughout the experiment and were perfectly placed as confirmed after section. Body weights of sows did not differ between treatments at the start of the main period of measurements ( $179 \pm 4.3$  kg; range: 163–203 kg).

**Glucose and insulin.** Basal blood glucose levels and AUCs over the total period and before and after 1000 h did not differ between treatments (Table 2). Indicators of glucose stability were influenced by diet. L-sows had a higher VAR and a higher SAD over the total period and after 1000 h than H-sows. L-sows had a clear postprandial glucose peak at 0730 h (Fig. 1). After 1000 h, glucose levels of L-sows tended to be above basal levels at 1200 h ( $P = 0.06$ ) and were significantly below basal levels at 1400 h. H-sows had a postprandial raise in glucose level and did not have a clear peak. Before 1000 h, H-sows tended to have glucose levels above basal levels at 0800 ( $P = 0.06$ ) and had glucose levels significantly above basal levels at 0900 h. After 1000 h, glucose levels of H-sows were above basal levels at 1200 h and 1600 h. Glucose levels did not drop below basal levels. In H-sows, glucose levels at 1800 h were higher than those at 0645 h.

Basal blood insulin levels did not differ between treatments (Table 2). L-sows had a larger AUC over the total period than H-sows. Before 1000 h, L-sows tended to have a larger AUC than H-sows ( $P = 0.07$ ). After 1000 h, there was no difference in AUC between treatments. L-sows had a higher VAR and SAD over the total period and after 1000 h than H-sows.

TABLE 2

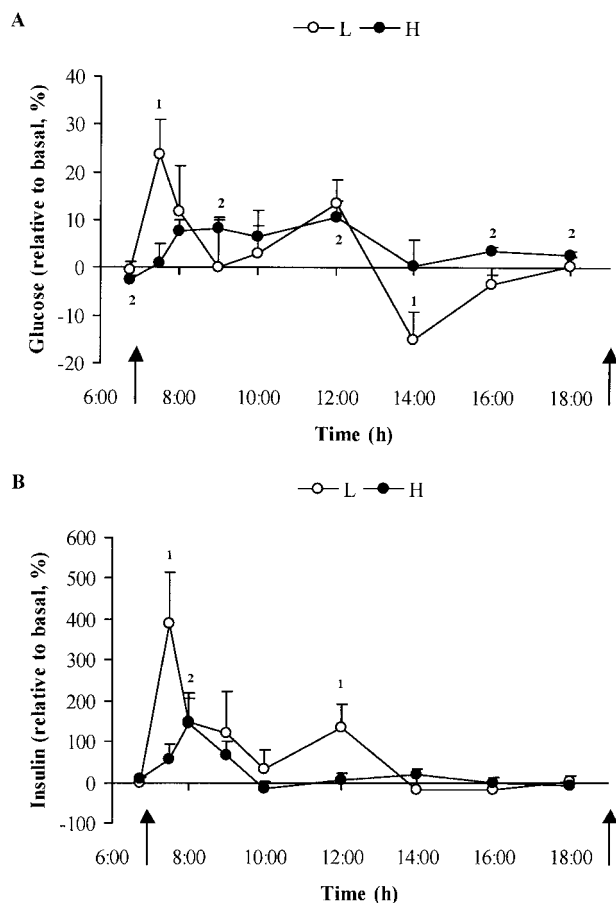
Indicators of glucose and insulin levels (basal, AUC) and stability (VAR, SAD) in sows fed either a low-fNDF diet (L) or a high-fNDF diet (H)<sup>1</sup>

	Diet		P-value
	L	H	
<b>Glucose</b>			
Basal, mmol/L	4.93 $\pm$ 0.15	4.75 $\pm$ 0.13	0.191
AUC total, <sup>2,3</sup> mmol $\cdot$ h/L	5.01 $\pm$ 0.13	4.99 $\pm$ 0.21	0.468
AUC $\leq$ 1000 h, mmol $\cdot$ h/L	5.29 $\pm$ 0.13	5.00 $\pm$ 0.18	0.103
AUC $\geq$ 1000 h, mmol $\cdot$ h/L	4.89 $\pm$ 0.17	4.98 $\pm$ 0.24	0.389
VAR total, (mmol/L) <sup>2</sup>	0.63 $\pm$ 0.26	0.15 $\pm$ 0.06	0.036
VAR $\geq$ 1000 h, (mmol/L) <sup>2</sup>	0.47 $\pm$ 0.14	0.13 $\pm$ 0.06	0.036
SAD total, mmol/L	6.33 $\pm$ 1.76	2.71 $\pm$ 0.52	0.048
SAD $\geq$ 1000 h, mmol/L	3.07 $\pm$ 0.82	1.26 $\pm$ 0.40	0.052
<b>Insulin</b>			
Basal, pmol/L	34.88 $\pm$ 7.25	31.87 $\pm$ 1.83	0.437
AUC total, <sup>2,3</sup> pmol $\cdot$ h/L	199.71 $\pm$ 43.47	131.78 $\pm$ 10.53	0.048
AUC $\leq$ 1000 h, pmol $\cdot$ h/L	80.28 $\pm$ 18.10	51.16 $\pm$ 6.23	0.068
AUC $\geq$ 1000 h, pmol $\cdot$ h/L	119.43 $\pm$ 29.87	80.62 $\pm$ 6.83	0.147
VAR total, (pmol/L) <sup>2</sup>	2580.36 $\pm$ 853.33	485.67 $\pm$ 209.08	0.012
VAR $\geq$ 1000 h, (pmol/L) <sup>2</sup>	1199.30 $\pm$ 578.40	93.41 $\pm$ 55.25	0.012
SAD total, pmol/L	365.10 $\pm$ 75.98	149.52 $\pm$ 25.50	0.008
SAD $\geq$ 1000 h, pmol/L	123.65 $\pm$ 39.01	43.76 $\pm$ 11.32	0.040

<sup>1</sup> Values are means  $\pm$  SEM,  $n = 5$ .

<sup>2</sup> Total, all samples;  $\leq$ 1000 h, samples taken up to and including 1000 h;  $\geq$ 1000 h, samples taken after and including 1000 h.

<sup>3</sup> AUC averaged per h (arbitrary units).



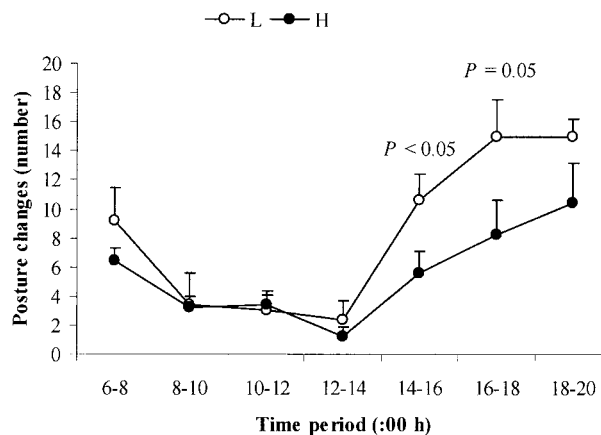
**FIGURE 1** Glucose (A) and insulin (B) levels in sows fed either a low-fNSP diet (L) or a high-fNSP diet (H) relative to basal levels. Results are expressed as means  $\pm$  SEM,  $n = 5$ . Arrows represent feeding times. <sup>1</sup>The level of L-sows differs from basal,  $P \leq 0.05$ ; <sup>2</sup>the level of H-sows differs from basal,  $P \leq 0.05$ .

L-sows had a postprandial insulin peak at 0730 h (Fig. 1). After 1000 h, the insulin levels of L-sows were above basal levels at 1200 h. No drop below basal levels was observed. H-sows had a postprandial peak at 0800 h. At 0730 and 0900 h, glucose levels of H-sows tended to be above basal levels ( $P = 0.09$ ). After 0900 h, insulin levels of H-sows returned to and remained at basal levels.

**Behavior.** No differences were observed between treatments in the number of posture changes before 1400 h (Fig. 2). The number of posture changes tended to decrease in both H- ( $P = 0.06$ ) and L-sows ( $P = 0.09$ ) after the first 2-h period, and remained stable until 1400 h. The number of posture changes made by L-sows increased in the period 1400–1600 h ( $P < 0.05$ ) and further increased in the period 1600–1800 h ( $P = 0.05$ ). The number of posture changes of H-sows tended to increase in these periods ( $P = 0.09$ ). In both periods, L-sows changed posture more frequently than H-sows. In the period 1800–2000 h, L-sows tended to change posture more frequently than H-sows ( $P = 0.1$ ). No differences were observed between treatments in the total time spent lying and sitting (Table 3). H-sows stood somewhat more than L-sows, but this difference was not significant ( $P = 0.155$ ).

## DISCUSSION

We hypothesized that VFA, which are produced during fermentation by the microflora in the hindgut and subse-



**FIGURE 2** Number of posture changes made by sows fed either a low-fNSP diet (L) or a high-fNSP diet (H) during each 2-h period in the 14-h light period. Results are expressed as means  $\pm$  SEM,  $n = 5$ .  $P$ -values show differences between treatments,  $P \leq 0.05$ .

quently absorbed, may be involved in satiation of the sow several hours after feeding. They can potentially prevent transient declines in blood glucose levels at a time when the amount of glucose in the small intestine available for absorption is reduced (14). Indeed, in this study, glucose levels of H-sows were more stable, not only immediately after feeding, but also several hours later. No drops in glucose below basal levels were observed in H-sows. This is in contrast to L-sows, which had a large drop in the glucose level at 1400 h (15% below basal level). Because meal initiation is often preceded by a transient decline in glucose level in rats and humans (19–21; 6–8% decline in rats, 10% in humans, compared with basal levels), glucose levels may have been temporarily too low and may have caused a feeling of hunger and subsequent feeding motivation. During unrestricted feeding, L-sows had an increase in glucose level at the same time (1400 h; unpublished data). We speculate that between 1200 and 1400 h, sows indeed were hungry and started eating. This likely caused the higher glucose levels at 1400 h during unrestricted feeding.

The postprandial rise in glucose and insulin levels appeared slightly later in H-sows than in L-sows. This was also found by others (7,8,17,18) and may be caused in part by a longer eating time. High-fiber diets are eaten more slowly and are chewed more than low-fiber diets (25–27). Another reason may be the delayed nutrient absorption mentioned earlier. In other studies, postprandial responses of glucose and especially insulin were reduced when a high-fiber diet was fed (7,8,18,25). In the present study, this difference was also found, but it was not significant. Reduced responses can be caused by the lower

**TABLE 3**

Percentage of time spent standing, lying, and sitting by sows fed either a low-fNSP diet (L) or a high-fNSP diet (H)<sup>1</sup>

	Diet		$P$ -value
	L	H	
Standing	14.8 $\pm$ 3.8	21.0 $\pm$ 4.4	0.155
Lying	77.7 $\pm$ 5.7	74.5 $\pm$ 3.8	0.345
Sitting	7.5 $\pm$ 2.2	4.5 $\pm$ 1.9	0.190

<sup>1</sup> Values are means  $\pm$  SEM,  $n = 5$ .

amount of glucogenic energy (starch) in the H-diet. The experimental diets were isoenergetic. Starchy products in the L-diet were replaced by SBP as the fNSP source in the H-diet. In addition, high-fiber diets improve glucose tolerance and insulin sensitivity (28). When calculating the stability indicators of glucose and insulin during the total period in the present study, the postprandial response is involved. More accurate information on the effects of fNSP may be obtained by excluding the postprandial peak. In this way, the effects of increased VFA production several hours after feeding (14) may become more prominent. In the present study, the effect of diet on the stability indicators of glucose and insulin after the postprandial peak was comparable to that of the total period.

Results for insulin were largely comparable to those for glucose. This was expected because the release of insulin by the pancreas is stimulated by glucose. The variation in insulin levels during the day was very large compared with glucose. This could be expected because it is an important function of insulin to maintain constant blood glucose levels. In contrast to glucose, however, no drops in insulin below basal levels were observed in L-sows. At 1400 h, insulin levels were equal to basal levels.

We can ask whether basal levels of glucose and insulin as they were defined in the present study represent ideal levels. Levels just before feeding could be below ideal levels. Basal glucose levels observed in the present study were comparable to or higher than those observed in other studies, whereas basal insulin levels were lower (8,17,18). In these studies, basal insulin levels were ~50–70 pmol/L. The difference between studies may be due to different methods of analysis. In the present study, no difference was observed in basal levels between the 2 dietary treatments. This indicates that it is reasonable to compare relative glucose and insulin levels of H-sows with those of L-sows.

H-sows stood somewhat more than L-sows ( $P = 0.155$ ). This may be explained by the longer time spent eating by H-sows. After 1400 h, an increase in physical activity was observed. This was most pronounced in L-sows. This is in accordance with the drop in glucose level at 1400 h, likely indicative of an increased feeling of hunger at that time. The increase in physical activity, however, cannot be attributed solely to the drop in glucose level. For example, glucose levels of L-sows were restored after 1400 h, whereas physical activity did not decrease, but increased. It should be noted that glucose and insulin levels can be influenced by physical activity as well. Increased activity causes an increased demand for energy by cells; therefore, it may cause a (temporary) reduction in the blood glucose level. In the present study, however, the increase in physical activity did not appear earlier than the drop in glucose level. Thus, the drop in glucose level is most likely not caused by increased physical activity. In this respect, it should be noted that the physical activity of sows was restricted by housing them in cages. In group-housing systems, the influence of physical activity and interactions with pen mates on glucose levels may be more pronounced. In agreement with the present study, others also found lower activity when the feed allowance was high or a high-fiber diet was provided (3,6,10,27,29). In most of these experiments, stereotyped behavior, which develops over time, was also determined. High-fiber diets appeared to cause less stereotyped behavior than low-fiber diets. Some authors found that the differences in behavior were more pronounced several hours after feeding than immediately after feeding (10). Others found these effects only several hours after feeding (9). The short duration of the present experiment did not allow intensive behavior observations. It is possible, however, that the

development of stereotyped behavior may have been less pronounced in H-sows, compared with L-sows. It is likely that VFA, produced during fermentation of dietary fiber in SBP, play a role in the stabilization of glucose and insulin levels and the reduction of physical activity and stereotyped behavior several hours after feeding. It cannot be excluded, however, that other properties or other effects of SBP on digestive processes or on components being produced could play a role. Schrama et al. (30) observed reduced physical activity in growing pigs that were fed a diet with SBP. This seemed to be related to fermentation rather than to bulkiness (31).

In this study, SBP was chosen as an easily fermentable fNSP source. Other fNSP-rich ingredients may have effects on glucose and insulin comparable to those of SBP. The effectiveness may depend, however, on fermentation characteristics (e.g., rate of fermentation) and the effect of fermentation on passage rate of digesta.

We conclude that SBP as a source of fermentable dietary fiber stabilizes glucose and insulin levels in sows and reduces physical activity several hours after feeding. This may be indicative of a prolonged feeling of satiety. Future studies should confirm whether VFA, which are produced during fermentation, are responsible for this effect.

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