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Apparent Ileal and Total-Tract Nutrient Digestion by Pigs as Affected by Dietary Nondigestible Oligosaccharides[1]

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ABSTRACT: The effects of two types of nondigestible oligosaccharides (NDO), fructooligosaccharides (FOS), and transgalactooligosaccharides (TOS) were studied on growing and weanling pigs' nutrient digestion. Dietary NDO were included at the expense of purified cellulose. Twenty-five 57-d-old growing pigs, averaging 15.9 ± .6 kg on d 0 of the experiment, were fed a corn-based control diet or the control with 6.8 or 13.5 g of FOS/kg or 4.0 or 8.0 g of TOS/kg (five pigs per diet). Feces were collected on d 28 to 32, and small-intestinal digesta were collected (slaughter technique) on d 42 to 47 of the experiment. Feeds, feces, and digesta were analyzed for DM, inorganic matter, CP, ether extract, and crude fiber. Dietary NDO did not significantly affect apparent fecal and small intestinal digestion of nutrients in growing pigs. After being fed a NDO-free diet through d 10 after weaning, 38-d-old weanling pigs (n = 20), averaging 10.4 ± .8 kg on d 0 of the experiment, were fed a control diet (based on cornstarch, casein, and oat husk meal) or the control with 10 or 40 g of FOS or TOS/kg (four pigs per diet). Feces and urine were collected on d 13 to 17, and ileal digesta were collected via a postvalve T-cecum cannula on d 33 to 37 of the experiment. Feeds, feces, and digesta were analyzed for DM, inorganic matter, CP, ether extract, starch, NDF, ADF, ADL, Ca, P, Mg, Fe, Cu, and Zn. Nonstarch neutral-detergent soluble carbohydrates (NNSC) completed the mass balance for the carbohydrates. Urine was analyzed for N and minerals. The apparent fecal digestion of NNSC increased in the NDO-supplemented diets. The TOS-fed pigs tended ($P < .10$) to have a higher apparent fecal digestion of CP than the FOS-fed and control pigs but excreted more N via the urine ($P < .01$). Nitrogen and mineral balances were not affected. The FOS was nearly completely degraded prececally. Mean fiber digestion was lower at the fecal compared with the ileal level, as was the extent of NDO effects. This indicates that fiber digestion requires more than 2 wk to adapt to dietary NDO. Apparent ileal digestion of hemicellulose increased for the NDO-supplemented diets ($P < .05$), but that of NNSC decreased ($P < .001$). Thus, under the well-controlled conditions of this experiment, dietary NDO hardly affected nutrient digestion in well-kept growing and weanling pigs. However, digestion of dietary nonstarch carbohydrates may be affected.

Key Words: Oligosaccharides, Pigs, Digestion, Minerals

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Introduction

Most carbohydrates in pig diets are enzymatically hydrolyzed to absorbable monomers as glucose (from starch). However, some carbohydrates escape enzymatic digestion in the small intestine and form a substrate for the gastrointestinal microflora. These include nondigestible oligosaccharides (**NDO**), which are found in various feedstuffs. α-Galactooligosaccharides (**GOS**) can be found in soybeans, lupines, and peas (Saini, 1989) and are α-linked galactose units to the glucose moiety of sucrose. Fructooligosaccharides (**FOS**) can be found in most cereals, including barley, wheat, and rye (Henry and Saini, 1989), and are β-linked fructose units to the fructose moiety of sucrose.

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Transgalactooligosaccharides (**TOS**), not found in feedstuffs, are β-linked galactose units to the galactose moiety of lactose. The NDO are mixtures of molecules with different chain lengths.

The GOS have long been known as antinutritional factors. They may reduce dietary metabolizable energy (Leske et al., 1993) and can induce diarrhea, extensive flatulence, and discomfort in nonruminants (Saini, 1989). However, FOS and TOS may improve growth performances in young pigs (Hidaka et al., 1985; Katta et al., 1993). Information on the effects of dietary NDO on nutrient digestion is scarce. Dietary TOS (2 g/kg) and galactosyl lactose (a TOS component; 5 g/kg) did not affect ileal digestion of DM and amino acids in weanling pigs (Gabert et al., 1995; Mathew et al., 1997). Considerable levels of NDO in the control diets (from cereals and soybean meal) may have diluted or masked the effects of NDO added. Data on the effects of NDO on mineral absorption in pigs are lacking; FOS (50 g/kg diet) increased Ca and Mg absorption from the hindgut of rats (Ohta et al., 1995).

We studied the effects of FOS and TOS on apparent fecal and ileal nutrient digestion in growing and weanling pigs, using low-NDO control diets. In addition, nitrogen and mineral balances were determined in the weanling pigs.

Materials and Methods

Diets, Animals, and Housing

General. Raftilose P95®, a FOS-rich powder (Orafti, Tienen, Belgium) and Oligostroop® (Borculo Whey Products, Borculo, The Netherlands), a TOS-rich syrup, supplied the NDO. These NDO-rich products contain some digestible sugars as well: fructose, glucose, and sucrose for Raftilose P95®; and galactose, glucose, and lactose for Oligostroop®. These sugars were exchanged at the expense of glucose (Dextrose®; Avebe, Veendam, The Netherlands), and the true NDO were exchanged at the expense of purified cellulose (Arbocel®; MCA, Zutphen, The Netherlands). Diets did not contain additional copper, antibiotics, or probiotics. Chromium oxide was used as a digestibility marker. Feeds were sampled while preparing daily allowances.

Castrated pigs (Great Yorkshire × Landrace sires × Great Yorkshire dams) were individually housed in metabolism cages. The feeding level was to 2.6 times energy required for maintenance, assumed to be 459 kJ ME/kg$^{.75}$. The diets met or exceeded the known nutrient and mineral requirements for young pigs (NRC, 1988). The pigs were weighed to adjust individual daily feed allowance before and between collection periods. Ethics approval was given by the Animal Ethics Committee of Wageningen Agricultural University.

Growing Pigs. Table 1 gives the ingredients and analyzed chemical composition of the diets fed to the growing pigs. Corn was analyzed via high-performance anion exchange chromatography (**HPAEC**; Rocklin and Pohl, 1983) and contained 300 mg of GOS/kg (K.J.M. Van Laere, unpublished data). Thus, the control (**CON**) diet contained .19 g of GOS/kg. Raftilose P95® was included at 7.5 and 15 g/kg and Oligostroop® at 10 and 20 g/kg, resulting in (**F-L**) 6.8 and (**F-H**) 13.5 g of NDO/kg of diet for FOS and (**T-L**) 4 and (**T-H**) 8 g of NDO/kg of diet for TOS, respectively.

The diets were fed to 25 57-d-old pigs, averaging 15.9 ± .6 kg on d 0 of the experiment. Five pigs were used per diet. The pigs had been fed the diets for 3 wk (Houdijk et al., 1998a), when they were being moved to the cages. The pigs were allowed a 7-d adaptation period to the cages before feces were collected. Feeds were offered twice daily as a slurry (1:3 feed:water, prepared 15 min before feeding).

Weanling Pigs. Table 2 gives the ingredients and analyzed chemical composition of the diets fed to the weanling pigs. Oat husk meal was used to study fiber digestion; this fiber source did not contain FOS or TOS, as analyzed by HPAEC (K.J.M. Van Laere, unpublished data). Raftilose P95 was included at (**F10**) 11.1 and (**F40**) 44.3 g/kg, and Oligostroop was included at (**T10**) 22.4 and (**T40**) 89.6 g/kg of diet. These inclusion levels resulted in 10 and 40 g of NDO/kg of diet; this batch of Oligostroop contained more TOS than that used with the growing pigs. The mass balance was completed by minor changes in the amount of cornstarch.

Thirty 30-d-old pigs were obtained. Before being weaned at 28 d of age, the pigs received an NDO-free creep feed from d 10 of age onward, without antibiotics or additional copper. After being weaned and transported to the experimental unit, the pigs were allowed an 8-d adaptation period during which they received the same NDO-free diet. Then 20 pigs (selected on BW and health) were ranked on BW and divided into four weight classes, averaging 10.4 ± .8 kg. Pigs from each weight class were randomly allocated to the experimental diets (four pigs per diet). Before feces collection, the pigs were allowed a 13-d adaptation period to the experimental diets, which included a gradual replacement of the creep feed during 3 d. Feeds were offered twice daily; water was available for 1 h during feeding.

Sample Collections

General. After the adaptation period, feces were quantitatively collected for 24 h/d on five successive days using big fecal bags, sized 20 × 30 cm, for the growing pigs (Van Kleef et al., 1994), and small bags sized 14 × 18 cm, for the weanling pigs (Combihesive®, Squibb B.V., Rijswijk, The Netherlands). The bags were replaced twice daily, weighed, and stored at

–20°C pending analysis. Weanling pig urine was collected via funnels underneath the cages through filters into buckets with 5 mL 6.0 *N* HCl to avoid volatilization of nitrogenous compounds. The urine production was recorded daily and stored at 4°C pending analysis. The small-intestinal digesta were collected using different methods for growing and weanling pigs.

Growing Pigs. Nine to 13 d after feces collection, the pigs were anesthetized with O_2/N_2O and halothane, 3.0 ± .1 h after the morning meal. The abdomen was opened, and the last 7 m of the small intestine (**SI2**) was isolated with clamps to prevent digesta movement. The SI2 was removed, and the pigs were killed. The SI2 content was determined, and the digesta obtained were stored at –20°C pending analysis.

Weanling Pigs. After feces collection, the pigs were surgically fitted with a postvalve T-cecum cannula (Van Leeuwen et al., 1991). After recovery of at least 10 d, ileal digesta were collected during two periods of two successive days, which were separated by 1 d. Plastic bags, sized 15 × 20 cm, were attached to the cannula, which had been open for at least 1 h before the morning meal. During 12 h following the morning meal, the bags were replaced hourly and weighed. Digesta were stored at –20°C pending analysis.

Chemical Analysis and Calculations

Feed, feces, and digesta were analyzed for DM (ISO, 1983), inorganic matter (**IM**; ISO, 1978), CP (6.25 × Kjeldahl N; ISO, 1979), ether extract (**EE**; ISO, 1996), and crude fiber (**CF**; NEN, 1988). The

Table 1. Composition of the diets fed to the growing pigs

Item	Type: / Level:	Diet[a] CON	FOS L	FOS H	TOS L	TOS H
		g/kg as fed				
Ingredient						
Raftilose P95®		—	7.5	15.0	—	—
Oligostroop®		—	—	—	10.0	20.0
Glucose		117.8	117.4	117.0	113.2	108.5
Cellulose		30.0	22.9	15.8	24.6	19.3
Corn		633.6	633.6	633.6	633.6	633.6
Protein sources[b]		150.0	150.0	150.0	150.0	150.0
Soy oil		10.0	10.0	10.0	10.0	10.0
Fumaric acid		10.0	10.0	10.0	10.0	10.0
Mineral mix[c]		32.4	32.4	32.4	32.4	32.4
Amino acids[d]		5.2	5.2	5.2	5.2	5.2
Premix[e]		10.0	10.0	10.0	10.0	10.0
Chromium oxide[f]		1.0	1.0	1.0	1.0	1.0
DM content[g]						
Period I		893.8	895.7	894.6	899.3	894.1
Period II		889.8	884.2	884.5	888.3	892.2
Analyzed DM composition[h]						
Inorganic matter		60.9	60.3	60.7	60.7	61.1
Crude protein		190.6	190.9	190.1	189.8	191.1
Ether extract		49.0	48.7	49.2	48.7	49.3
Crude fiber		40.4	34.4	29.2	35.5	32.0
N-free extract		659.1	665.6	670.7	665.2	666.5

[a]CON: no nondigestible oligosaccharides; FOS: fructooligosaccharides-rich Raftilose P95® at 7.5 (L) and 15.0 (H) g/kg diet; TOS: transgalactooligosaccharides-rich Oligostroop® at 10.0 (L) and 20.0 (H) g/kg diet.

[b]Casein, fish meal, and animal meal: 50 g/kg diet each.

[c]This mineral mix provided (per kg feed) 2.0 g NaCl, 8.0 g $CaCO_3$, 9.4 g CaH_2PO_4, 2.0 g MgO, and 11.0 g $KHCO_3$.

[d]Added synthetic amino acids (per kg feed) were 2.6 g L-lysine HCl, 1.1 g DL-methionine, .8 g L-threonine, and .7 g L-tryptophane.

[e]The vitamin/mineral mix provided (per kg feed): 9,000 IU vitamin A, 1,800 IU vitamin D_3, 40 mg vitamin E, 3 mg vitamin K, 2 mg thiamine, 5 mg riboflavin, 12 mg d-panthothenic acid, 1 mg folic acid, 3 mg pyridoxine, 30 mg niacin, 40 μg cobalamin, 1,000 mg choline chloride, 50 mg vitamin C, .1 mg biotin, 2.5 mg $CoSO_4{\cdot}7H_2O$, .2 mg Na_2SeO_3-$5H_2O$, .5 mg KI, 400 mg $FeSO_4{\cdot}7H_2O$, 60 mg $CuSO_4{\cdot}5H_2O$, 70 mg MnO_2, and 300 mg $ZnSO_4$.

[f]In diets of period II only (at the expense of corn).

[g]Period I (feces collection) and Period II (digesta collection) after 32 to 36 and 42 to 46 d on the diets, respectively.

[h]For analyses, see Material and Methods section.

DM − IM equaled OM; OM − CP − EE − CF equaled N-free extract (**NFE**). Additional analysis for weanling pig samples were ADF, ADL (both according to Van Soest, 1973), NDF, and starch (**St**; both as described by Goelema et al., 1998). The NDF − ADF equaled hemicellulose (**Hemi**), and ADF − ADL equaled cellulose (**Cel**). The ADL was analyzed in feeds only. The OM − CP − EE − NDF − St equaled nonstarch neutral-detergent soluble carbohydrates (**NNSC**), which should include NDO. Indeed, the differences between NNSC of the experimental diets closely reflected the inclusion levels of NDO (Table 2). Most minerals (Ca, Mg, Fe, Cu, Zn, and Cr) were analyzed using atomic absorption spectophotometry (De Ruig, 1986). Phosphorus was analyzed via spectophotometry (AOAC, 1975). Urine was analyzed for N and minerals.

Apparent fecal (FD) and ileal digestion (ID) were calculated according to the following Eq. [1] and [2], respectively. The N and mineral balances were described by intake, total excretion (fecal + urinary), and retention (intake − total excretion). Urinary

Table 2. Composition of the diets fed to the weanling pigs

Item	Type: / Level:	Diet[a] CON	FOS 10	FOS 40	TOS 10	TOS 40
		g/kg as fed				
Ingredient						
Raftilose P95®		—	11.1	44.3	—	—
Oligostroop®		—	—	—	22.4	89.6
Cellulose		42.0	32.0	1.8	32.0	1.8
Glucose		150.0	149.4	147.7	142.9	121.7
Cornstarch		470.75	470.25	468.95	465.45	449.65
Casein		185.0	185.0	185.0	185.0	185.0
Oat husk meal		60.0	60.0	60.0	60.0	60.0
Soy oil		25.0	25.0	25.0	25.0	25.0
Amino acids[b]		3.0	3.0	3.0	3.0	3.0
Minerals[c]		54.0	54.0	54.0	54.0	54.0
Premix[d]		10.0	10.0	10.0	10.0	10.0
Chromium oxide		.25	.25	.25	.25	.25
DM content[e]						
Period I		888.1	886.9	886.6	880.5	879.2
Period II		887.3	890.6	893.2	889.3	889.7
Analyzed DM composition[f]						
Inorganic matter		50.0	50.3	49.8	50.6	51.4
Crude protein		189.7	191.8	190.1	192.0	198.8
Ether extract		21.1	20.5	19.3	20.3	21.4
Hemicellulose		19.9	20.8	23.1	21.0	23.2
Cellulose		55.3	44.9	19.5	46.0	21.1
Lignin		6.1	6.6	7.4	6.2	6.4
Starch		469.2	467.6	459.1	465.2	452.3
NNSC		188.7	197.5	231.7	198.7	225.4
Ca		9.9	9.9	9.9	10.0	9.9
P		5.9	5.8	5.8	5.9	5.9
Mg, mg/kg		468.9	496.8	484.5	462.6	444.8
Fe, mg/kg		159.2	170.3	162.5	162.8	159.4
Cu, mg/kg		18.4	15.7	18.9	18.3	16.6
Zn, mg/kg		85.8	89.9	93.9	89.8	83.7

[a]CON: no nondigestible oligosaccharides (NDO); FOS: fructooligosaccharides; TOS: transgalactooligosaccharides; both NDO at 10.0 or 40.0 g/kg of diet.

[b]Amino acids (g/kg feed): 1.7 L-cysteine, .8 L-threonine, and .5 L-tryptophane.

[c]Minerals (g/kg feed): 5.0 NaCl, 10.0 $CaCO_3$, 20.0 $CaHPO_4$, .5 MgO, 16.5 $KHCO_3$, and 2.0 $NaHCO_3$.

[d]Premix (per kg feed): 9,000 IU vitamin A, 1,800 IU vitamin D_3, 40 mg vitamin E, 3 mg vitamin K, 2 mg thiamine, 5 mg riboflavin, 12 mg d-panthothenic acid, 1 mg folic acid, 3 mg pyridoxine, 30 mg niacin, 40 μg cobalamin, 1,000 mg choline chloride, 50 mg vitamin C, .1 mg biotin, 2.5 mg $CoSO_4{\cdot}7H_2O$, .2 mg $Na_2SeO_3{\cdot}5H_2O$, .5 mg KI, 400 mg $FeSO_4{\cdot}7H_2O$, 40 mg $CuSO_4{\cdot}5H_2O$, 70 mg MnO_2, and 200 mg $ZnSO_4$.

[e]Dietary DM in Period I (feces collection) and Period II (digesta collection) after 13 to 17 and 33 to 37 d on the diets, respectively.

[f]For analyses, see Materials and Methods section. NNSC: nonstarch neutral-detergent soluble carbohydrates.

excretion was also expressed as a percentage of total excretion.

$$\text{FD-a} = [(DI_a - DFE_a)/(DI_a)] \times 100 \qquad [1]$$

where DI_a = daily intake of nutrient a (g) and DFE_a = daily excretion of nutrient a via the feces (g).

$$\text{ID-a} = \{1 - [(D_a \times F_{Cr})/(D_{Cr} \times F_a)]\} \times 100 \qquad [2]$$

where D_a = concentration nutrient a in ileal digesta (g/kg), D_{Cr} = concentration chromium in ileal digesta (mg/kg), F_a = concentration nutrient a in feed (g/kg), and F_{Cr} = concentration chromium in feed (mg/kg).

Statistical Analysis

The FD was analyzed for 22 pigs (CON, 5; F-L, 4; F-H, 4; T-L, 5; and T-H, 4) and the ID for 18 pigs (CON, 5; F-L, 3; F-H, 3; T-L, 4; and T-H, 3) in the experiment with growing pigs. The FD and balances were analyzed for 17 weanling pigs (CON, 4; F10, 4; F40, 4; T10, 3; and T40, 2) and the ID for 16 weanling pigs (CON, 3; F10, 3; F40, 3; T10, 4; and T40, 3). The excluded pigs had diarrhea; when possible, reserve pigs were included. Hindgut contribution to FD was not calculated from FD and ID, because these variables were determined with different feed intake and different time on the diets.

An analysis of variance was conducted using the model given by Eq. [3]. Results are expressed as least squares means and pooled SEM of D_i. Predetermined orthogonal contrasts were used to locate the effects of dietary NDO. Type (FOS vs TOS), level (L vs H with growing pigs or 10 vs 40 g/kg with weanling pigs), type × level, and the effect of NDO inclusion per se could be distinguished. The contrasts were considered to be significant when $P < .05$. The Tukey-Kramer multiple comparisons test was used to clarify observed contrasts. However, contrast statements are much more powerful to locate effects than are multiple comparisons (Lowry, 1992).

$$y_{ij} = \mu + D_i + \epsilon_{ij} \qquad [3]$$

where y_{ij} = observation, μ = general mean, D_i = effect of diet (i = 1, . . . , 5), and ϵ_{ij} = residual error.

Results

Growing Pigs. Table 3 shows apparent FD and ID in the growing pigs at average BW of 34.9 ± .8 kg and 45.5 ± 1.3 kg, respectively. Dietary NDO did not significantly affect the FD. An interaction ($P < .001$) was observed for the ID-CF; an increase of dietary TOS but not of FOS significantly increased ID-CF. Dietary NDO did not affect the ID of the other nutrients.

Weanling Pigs. Table 4 shows apparent FD and ID in the weanling pigs at average BW of 15.6 ± .3 kg and 20.3 ± .3 kg, respectively. The NDO-fed pigs produced less ($P < .10$) feces than the control pigs. Further, pigs fed the 40 g NDO/kg diets produced less ($P < .10$) feces than pigs fed the 10 g of NDO/kg diets and had higher ($P < .05$) FD-OM. The FOS-fed pigs had lower ($P < .10$) FD-CP than the TOS-fed pigs. The FD-Cel was less ($P < .10$) in the NDO-fed pigs than in the control pigs. Starch (**St**) was practically completely digested in all pigs, but the FD-St was greater ($P < .10$) in NDO-fed pigs than in the control pigs. The NDO-fed pigs had higher FD-NNSC than the control pigs, and this was higher for the 40 g of NDO/kg diets than for the 10 g of NDO/kg diets ($P < .001$).

Ileal digesta production increased with the increased level of FOS and decreased with the increased level of TOS ($P < .10$). The NDO-fed pigs had higher ID of Hemi ($P < .05$) and Cel ($P < .001$) but lower ID of NNSC ($P < .001$) than the control pigs. The ID of OM, Hemi, and Cel was higher for the 40 g than for the 10 g of NDO/kg diets ($P < .001$); this effect was the opposite for the ID-St ($P < .05$) and ID-NNSC ($P < .001$). Further, the FOS-fed pigs had lower ID-NNSC than the TOS-fed pigs ($P < .01$). However, interactions were observed for ID-OM, ID-NNSC ($P < .05$), and ID-IM ($P < .10$). On the average, dietary NDO did not affect ID of minerals, even though interactions were observed for ID-Cu ($P < .01$) and ID-Zn ($P < .10$). The FOS-fed pigs had lower ID-Zn than the TOS-fed pigs ($P < .10$).

Table 5 shows the balances for N, Ca, and P; Table 6 shows the balances for Mg, Fe, Cu, and Zn. The TOS-fed pigs excreted relatively more ($P < .01$) N via the urine than the FOS-fed pigs and the control pigs. Dietary NDO did not significantly affect retention of N and minerals on a grams-per-day basis (Tables 5 and 6) or when expressed as percentage of intake (data not shown). However, some effects were observed for mineral intake. Magnesium intake was higher in the FOS-fed pigs than in the TOS-fed pigs, and pigs fed the 10 g of NDO/kg diets had higher Mg and lower Fe intake than pigs fed the 40 g of NDO/kg diets ($P < .10$), the latter being more pronounced in FOS- than in TOS-supplemented diets ($P < .10$). The NDO-fed pigs had a negative Fe retention, which did not significantly differ from the control pigs. The NDO-fed pigs had lower Cu intake ($P < .05$), but their Cu balance was not affected.

Discussion

Several NDO may potentially be regarded as prebiotics, recently defined as nondigestible food ingredients that beneficially affect the host by selectively stimulating the growth and(or) activity of one or a limited number of bacteria in the colon, and, thus, improve host health (Gibson and Roberfroid, 1995).

In animal nutrition, prebiotics may be used as feed additives with similar beneficial claims. However, information on effects of NDO in pigs is limited, especially with regard to nutrient digestion.

We included NDO up to 40 g/kg diet at the expense of purified cellulose. Therefore, the total amount of potential fermentable components was comparable between diets, but its fermentability shifted from slow (cellulose) to rapid (NDO). The FOS and TOS fermentation rates are only slightly lower than that of glucose (Houdijk et al., 1998b), and fermentation of purified cellulose is low (Sunvold et al., 1995). The NDO inclusion is, thus, confounded with cellulose removal. A placebo effect has likely been limited; cellulose did not significantly affect ID and FD of crude protein, amino acids, Na, K, Mg, and P in weanling and growing pigs; only FD-Ca, but not ID-Ca, was significantly lowered (Den Hartog et al., 1988; Li et al., 1994).

Dietary NDO did not affect nutrient FD in the growing pigs, but, in the weanling pigs, FD-DM increased with increasing levels of dietary NDO. Younger pigs may be more sensitive to changes in fermentable dietary components, even though a more likely explanation is the higher NDO levels used. An increase of the FD-DM may have resulted directly from replacing Arbocel with NDO. Assuming FD-Cel from oat husk meal was 10% (CVB, 1995), the FD-Arbocel for the control diet was 60%. Given that NDO were not recovered from feces of NDO-fed pigs, the FD-NDO can be assumed 100% (Houdijk et al., 1998a). This agrees with the increase of FD-NNSC for NDO-supplemented diets. Because the FD-Cel for the NDO-supplemented diets was reduced, the FD-Arbocel may also have been reduced. Corrected for this, calculated FD-DM was 90.4, 92.5, 91.0, and 92.5%, for the F10, F40, T10, and T40 diet, respectively. These are very close to the FD-DM observed, thus the true effect of NDO on FD-DM may have been limited. Indeed, FOS and TOS did not affect FD-DM in rats (Berggren et al., 1993; Kikuchi et al., 1996) or in pigs with TOS exchanged at the expense of starch (R. Kamelaar, unpublished data).

Table 3. Feed intake, feces production, distal small-intestinal digesta, and apparent fecal and ileal digestion of nutrients in growing pigs fed diets with or without nondigestible oligosaccharides

	Diet[a]					
Type:	CON	FOS		TOS		
Item / Level:		L	H	L	H	SEM
Feed intake and feces production, g/d						
Feed[b]	1,228	1,174	1,194	1,148	1,102	48
Feces	561	444	476	501	433	57
Apparent fecal digestion, %						
Dry matter	86.6	86.9	86.8	86.5	86.9	.6
Inorganic matter	54.6	56.2	53.5	53.4	51.8	1.4
Organic matter	88.6	88.9	89.0	88.6	89.1	.6
Crude protein	83.3	83.4	82.7	82.2	83.4	1.0
Ether extract	82.8	81.7	82.7	82.1	81.6	2.1
Crude fiber	44.2	43.5	35.8	40.9	44.4	3.7
N-free extract	93.4	93.4	93.5	93.5	93.5	.3
Feed intake, g/d, and distal small-intestinal digesta, g						
Feed[c]	1,410	1,353	1,393	1,358	1,297	68
Digesta	473	535	485	570	419	63
Apparent ileal digestion, %						
Dry matter	74.4	71.8	73.7	73.6	72.9	2.1
Inorganic matter	37.3	28.5	36.9	32.5	32.0	4.9
Organic matter	76.8	74.6	76.1	76.3	75.6	1.9
Crude protein	64.4	54.4	58.9	60.4	50.9	6.6
Ether extract	82.3	80.0	80.6	82.0	78.0	4.7
Crude fiber[d]	13.0[xy]	8.5[x]	7.4[x]	2.3[x]	20.6[y]	2.4
N-free extract	83.6	83.4	83.6	84.4	85.1	1.2

[a]CON: diet without nondigestible oligosaccharides (NDO); FOS: fructooligosaccharides-rich Raftilose P95® at 7.5 (L) and 15.0 (H) g/kg diet; TOS: transgalactooligosaccharides-rich Oligostroop® at 10.0 (L) or 20.0 (H) g/kg diet. NDO at the expense of cellulose (wt/wt).

[b]Diets fed for 28 to 32 d.

[x,y]Least squares means lacking common superscripts differ significantly ($P < .05$ by Tukey-Kramer).

[c]Diets fed for 42 to 47 d.

[d]Contrasts level (H vs L): $P < .001$ and type × level: $P < .001$; other contrasts throughout the table were not significant.

Dietary NDO per se did not affect the FD-CP. The absence of effects on FD-CP was also observed with lactulose in minipigs (Ahrens and Schön, 1988) and GOS in dogs (Zuo et al., 1996) and in rats (Fleming and Lee, 1983). However, feces from the FOS-fed pigs contained more CP than feces from the TOS-fed pigs (65.0 vs 55.1 g/kg, SEM 2.1, $P < .05$) and the control pigs (55.6 g/kg). The TOS-fed pigs excreted less of their nitrogen via the feces and more via the urine compared with the FOS-fed pigs and the control pigs. Therefore, the FD-CP was higher for the TOS-fed pigs than for the FOS-fed pigs ($P < .05$) and the control pigs, but apparent nitrogen retention was not affected. Apparently, the increased amount of nitrogen absorbed from the intestinal lumen of our TOS-fed pigs was not used and excreted via the urine.

Dietary NDO did not significantly affect nutrient ID in the growing pigs. This was partly due to the relatively large variation observed, especially for CP, which may have been caused by the sampling size used in the slaughter technique. It was expected that digestion of this (calculated) highly digestible diet had completed relatively proximal in the small intestine. Apparently, digestion had not been completed for digesta obtained from the proximal part of the section used for sampling. In addition, transit time may vary

Table 4. Feed intake, feces and ileal digesta production, and apparent fecal and ileal digestion in weanling pigs fed diets with or without nondigestible oligosaccharides

	Diets[a]						Orthogonal contrasts[b]			
Type:	CON	FOS		TOS						
Item Level:		10	40	10	40	SEM	NDO	Type	Level	Type × level
Feed intake and feces production, g/d										
Feed[c]	608	622	553	587	595	24	NS	NS	NS	NS
Feces	116	117	82	100	90	10	†	NS	†	NS
Apparent fecal digestion, %										
DM[d]	90.9	90.5	92.4	91.3	92.6	.7	NS	NS	*	NS
IM	78.3	77.6	75.4	76.5	77.6	2.9	NS	NS	NS	NS
OM	91.5	91.2	93.3	92.1	93.4	.6	NS	NS	*	NS
CP	93.7	93.9	93.6	95.1	94.6	.6	NS	†	NS	NS
EE	78.4	79.2	80.4	79.2	83.1	2.3	NS	NS	NS	NS
Hemi	5.3	1.8	21.9	11.2	15.9	8.1	NS	NS	NS	NS
Cel	49.3	29.4	26.2	41.8	24.1	9.6	†	NS	NS	NS
St	99.98	99.98	99.99	99.99	99.99	.01	†	NS	NS	NS
NNSC	94.1^{z}	95.6^{yz}	96.8^{xy}	95.1^{z}	97.2^{x}	.4	***	NS	***	NS
Feed intake and ileal digesta production, g/d										
Feed[e]	763	793	747	753	727	19	NS	NS	†	NS
Digesta	575	599	777	699	596	71	NS	NS	NS	†
Apparent ileal digestion, %										
DM[d]	87.7^{y}	87.4^{y}	88.0^{xy}	86.7^{y}	90.4^{x}	.5	NS	NS	***	*
IM	74.9	76.0	72.2	73.7	77.6	2.2	NS	NS	NS	†
OM	88.4^{y}	88.0^{y}	88.9^{y}	87.4^{y}	91.1^{x}	.5	NS	NS	***	*
CP	89.4	87.7	87.6	86.8	89.1	1.4	NS	NS	NS	NS
EE	86.8	85.2	85.3	84.5	89.6	2.2	NS	NS	NS	NS
Hemi	10.4^{z}	14.5^{yz}	49.7^{xy}	8.8^{z}	60.0^{x}	7.9	*	NS	***	NS
Cel	25.5^{y}	22.4^{y}	64.9^{x}	16.8^{y}	75.9^{x}	4.7	***	NS	***	NS
St	99.7	99.7	99.6	99.7	99.6	.03	NS	NS	*	NS
NNSC	89.1^{x}	86.3^{xy}	77.6^{z}	86.9^{xy}	83.2^{y}	.9	***	**	***	*
Ca	78.4	79.2	80.4	80.5	80.9	3.1	NS	NS	NS	NS
P	85.5	84.1	86.5	86.4	86.7	2.2	NS	NS	NS	NS
Mg	34.6	35.7	36.8	33.1	39.5	4.6	NS	NS	NS	NS
Fe	–4.1	–5.9	–39.0	–6.0	–12.3	14.3	NS	NS	NS	NS
Cu	43.5	34.0	44.3	42.9	37.1	2.4	NS	NS	NS	**
Zn	28.8	20.1	30.7	34.2	30.3	3.5	NS	†	NS	†

[a]CON: diets without nondigestible oligosaccharides (NDO); FOS: fructooligosaccharides; TOS: transgalactooligosaccharides; both NDO at 10 or 40 g/kg diet. NDO at the expense of cellulose (w/w).

[b]NS: $P > .10$, †: $P < .10$, *: $P < .05$, **: $P < .01$, ***: $P < .001$.

[c]Diets fed for 13 to 18 d.

[d]DM: dry matter; IM: inorganic matter; OM: organic matter; CP: crude protein (6.25∗Kjeldahl-N); EE: ether extract; Hemi: hemicellulose; Cel: cellulose; St: Starch; NNSC: OM − CP − EE − St − NDF.

[e]Diets fed for 33 to 37 d.

[x,y,z]Least squares means lacking common superscripts differ significantly ($P < .05$ by Tukey-Kramer).

Table 5. Nitrogen, calcium, and phosphorus balance in weanling pigs fed diets with or without nondigestible oligosaccharides

	Diet[a]					
Type:	CON	FOS		TOS		
Item Level:		10	40	10	40	SEM
Nitrogen, g/d						
Intake[b]	16.36	16.94	14.90	15.86	16.64	.65
Total excretion[b]	3.78	3.72	3.50	3.56	4.12	.21
Retention	12.58	13.21	11.39	12.30	12.51	.59
Excretion via urine[c], %	72.6	72.3	72.9	78.3	78.4	1.8
Fecal digestion[d], %	93.7	93.9	93.6	95.1	94.6	.6
Calcium, g/d						
Intake	5.34	5.45	4.83	5.14	5.16	.21
Total excretion	1.61	1.63	1.59	1.66	1.57	.24
Retention	3.73	3.81	3.24	3.48	3.59	.37
Excretion via urine, %	13.9	12.0	3.6	9.9	7.8	4.2
Fecal digestion, %	73.3	73.4	67.5	70.2	71.6	5.7
Phosphorus, g/d						
Intake	3.18	3.17	2.83	3.03	3.09	.12
Total excretion	.66	.67	.65	.64	.57	.10
Retention	2.52	2.51	2.19	2.39	2.52	.18
Excretion via urine, %	1.2	1.6	3.1	2.0	1.8	.7
Fecal digestion, %	79.3	79.2	77.5	79.2	81.6	3.8

[a]CON: diets without nondigestible oligosaccharides (NDO); FOS: fructooligosaccharides; TOS: transgalactooligosaccharides; both NDO at 10 or 40 g/kg diet. NDO at the expense of cellulose (w/w). Diets were fed for 13 to 18 d.
[b]Contrast type × level: $P < .10$.
[c]Contrast FOS vs TOS: $P < .01$.
[d]Contrast FOS vs TOS: $P < .10$.

between animals, which further attributed to the variation observed for nutrient ID in the growing pigs. In the weanling pigs, the ID-DM for diet T40 was higher than that of the other diets, resulting in the significant contrasts observed. Dietary treatments did not significantly affect the ID-EE and ID-CP. The latter is in agreement with data on TOS (Gabert et al., 1995) and galactosyllactose (Mathew et al., 1997). Because type and level of dietary NDO only tended to interact for the ID-IM, differences in ID-DM between the FOS- and TOS-fed pigs were mainly related to the carbohydrate fraction.

Starch was nearly completely digested prececally; nonstarch polysaccharides (**NSP**) may partly be degraded prececally in pigs. Up to 44 g of NSP from various wheat and oat diets were metabolized prececally in 45- to 50-kg pigs, including 4.9 to 6.3 g of cellulose from the oat diets (Bach Knudsen and Hansen, 1991). Similarly, prececal loss of cellulose from a rutabaga-based diet was reported in 85- to 90-kg pigs, additionally showing significant concentrations of cellulolytic anaerobes in ileal digesta (Chesson et al., 1985). In our pigs, prececally metabolized cellulose ranged from 3.5 to 11.9 g/d and did not differ between diets. Therefore, the increased ID-Cel resulted from differences in cellulose intake. Similar effects were observed for the TOS diets but not for the FOS diets for the growing pigs. Differences may be due to different CF intake and the possible separation of the digestibility marker and fiber fraction at the time of digesta collection (Graham and Åman, 1986).

Dietary NDO increased the ID-Hemi, indicating an increased prececal degradation and(or) solubility of hemicellulose. Fiber solubility is critical in the determination of hemicellulose as a NDF component. The hemicellulose mainly originated from oat husk meal. The main fibers from oats are (Bach Knudsen and Hansen, 1991) cellulose (insoluble), arabinoxylan (partly soluble, 25%), and β-glucan (largely soluble, 85%). *Bacteroides ovatus* may degrade arabinoxylan to oligosaccharides; *Bifidobacterium longum* may ferment arabinoxylan (Van Laere et al., 1997). These species can also ferment FOS and TOS (Hartemink and Rombouts, 1997). Prececal bacterial action may reduce the molecular weight of β-glucan 7- to 35-fold (Johansen et al., 1993). Both processes may have been enhanced prececally in NDO-fed pigs as a result of an increased bacterial activity.

The FOS- and TOS-fed pigs had different ID-NNSC. This difference may have originated from the diet and endogenous secretions. The first may indicate that the ID-FOS was less than the ID-TOS. However, the ID-FOS averaged 92.3 ± 1.4% in this experiment (HPAEC, data not shown); in another study, the ID-TOS averaged 30% (R. Kamelaar, unpublished results). The FOS may also have stimulated a greater ileal flow of mucin or soluble bacterial products than

TOS. Indeed, the FOS-fed pigs had more bacteria in their ileal digesta than the TOS-fed pigs (Houdijk et al., 1997). Further, the ID-NNSC may have decreased due to an increased hemicellulose solubility. More details on ileally recovered carbohydrates are needed to satisfactorily explain the differences in ID-Hemi and ID-NNSC values observed.

Our experiments indicate that the effects of NDO on nutrient digestion of highly digestible diets are small. This apparently contrasts with data on GOS, which have long been known to be detrimental for animal performance (Saini, 1989). Even though several techniques have been used to remove GOS, only ethanol extraction satisfactorily improved nutritional quality (Coon et al., 1990). Velasse's negative effect on nutrient digestion was not compensated by the addition of α-galactosidase, although the ID-GOS increased from 57 to 93% (Veldman et al., 1993). Replacing high- with low-oligosaccharide soybean meal lowered GOS from 31 to 4 g/kg diet, but nutrient digestion was not improved in dogs (Zuo et al., 1996). This may indicate that extraction not only removes GOS but also other more detrimental factors; GOS may act as antinutritional factors only when intake exceeds a certain threshold (Benno et al., 1993).

Dietary NDO did not affect the mineral FD or retention. Rat studies showed improvement of mineral absorption with FOS (Ohta et al., 1995) and TOS (Chonan and Watanuki, 1995), but also with other NDO, including lactulose and raffinose (Brommage et al., 1993). The extent of improvement depended on the type of mineral, mineral deficiency, and type of NDO. The absence of effects of dietary NDO in our study is in agreement with the absence of effects of inulin on fecal mineral availability in pigs (Vanhoof and De Schrijver, 1996). The effects observed in Mg, Fe, and Cu intake likely resulted from the combination of differences in feed intake realized and dietary minerals analyzed. The decreased Cu intake for the NDO-fed pigs seemed to be regulated partly at the renal level (lower excretion of Cu via the urine). Most effects of dietary NDO on mineral ID were not significant. This is in agreement with the lack of significant effects of FOS and inulin on ileal secretion

Table 6. Magnesium, iron, copper, and zinc balance in weanling pigs fed diets with or without nondigestible oligosaccharides

Item	Diet[a] Type:	CON	FOS		TOS		SEM
	Level:		10	40	10	40	
Magnesium, mg/d							
Intake[bc]		253.0	274.3	237.4	238.9	232.7	10.2
Total excretion		119.6	117.7	96.9	98.8	93.0	10.5
Retention		133.3	156.6	140.4	140.1	139.7	11.9
Excretion via urine, %		6.2	6.4	3.4	8.3	7.5	1.7
Fecal digestion, %		55.6	60.0	60.1	61.8	62.9	3.9
Iron, mg/d							
Intake[cd]		85.9	94.0	79.6	84.1	83.4	3.5
Total excretion		83.3	96.7	92.1	93.9	89.6	11.8
Retention		2.6	−2.7	−12.5	−9.7	−6.2	14.0
Excretion via urine, %		.7	.7	.6	.5	.5	.1
Fecal digestion, %		3.3	−3.2	−17.1	−8.1	−8.9	16.4
Copper, mg/d							
Intake[d]		9.9	8.7	9.2	9.4	8.7	.4
Total excretion[e]		7.4	7.0	6.0	6.6	6.4	.6
Retention		2.5	1.7	3.2	2.8	2.3	.7
Excretion via urine, %[f]		4.8	3.7	3.6	3.7	3.2	.6
Fecal digestion, %		29.5	22.3	36.0	33.3	28.0	6.9
Zinc, mg/d							
Intake		46.3	49.6	46.0	46.4	43.8	1.9
Total excretion		40.2	37.6	34.7	39.4	32.4	3.1
Retention		6.0	12.0	11.3	7.0	11.4	4.4
Excretion via urine, %		2.5	3.5	3.1	3.6	3.0	.7
Fecal digestion, %		14.2	26.6	25.8	19.9	27.2	9.3

[a]CON: diets without nondigestible oligosaccharides (NDO); FOS: fructooligosaccharides; TOS: transgalactooligosaccharides; both NDO at 10 or 40 g/kg of diet. NDO at the expense of cellulose (wt/wt). Diets were fed for 13 to 18 d.

[b]Contrast FOS vs TOS: $P < .10$.

[c]Contrast 10 vs 40 g NDO/kg diet: $P < .10$.

[d]Contrast type × level: $P < .10$.

[e]Contrast CON vs NDO-supplemented diets: $P < .05$.

[f]Contrast CON vs NDO-supplemented diets: $P < .10$.

of minerals in ileostomy patients and pigs (Vanhoof and De Schrijver, 1996; Ellegard et al., 1997). The effects observed for ID-Zn were probably due to different Zn intakes, which were 63.1 and 57.5 mg/d (SEM 1.8, $P < .01$) for the FOS- and TOS-fed pigs, respectively. Similarly with Cu, the interaction between type and level of dietary NDO was significant for Cu intake (data not shown). The Cu intake and ID-Cu were correlated ($r = .53$, $P < .05$), indicating that the pigs were fed close to their requirements for Cu.

The absence of NDO effects on mineral balances in pigs contrasts with rat studies. The NDO are usually included at 50 to 100 g/kg diet and are often the only fermentable soluble carbohydrates in rat diets. Consequently, a higher degree and prolonged fermentation may result, as indicated by a lowered cecal, colonic, and fecal pH (Ohta et al., 1994). In our diets, NDO were included at lower levels and were accompanied by soluble fermentable carbohydrates from oat husk meal; the differences in degree of fermentation created may have been limited. Given that the fecal pH of NDO-fed pigs was not lowered, NDO-fermentation may have been completed proximally (Houdijk et al., 1998a). Thus, dietary NDO may have affected luminal conditions for enhanced mineral absorption to a lower extent than in the rat studies cited. Another important factor is the mineral content in the diet. Dietary factors influencing mineral absorption may not be recognized if mineral levels are above requirements. Compared with the mineral requirements of 10- to 20-kg ad libitum-fed pigs (NRC, 1988), only iron and copper were slightly in excess. Whether mineral requirements for restricted and ad libitum-fed pigs are comparable is not known; the relatively high digestion and the positive correlation between intake and the FD, ranging from $r = .45$ ($P < .10$) for P to $r = .62$ ($P < .001$) for Fe, except for Mg, indicated that for most minerals the intake was near the requirements.

The fecal and ileal data should not be compared quantitatively in the experiments described. In addition to time differences between fecal and ileal observations, mean ID-Cel and ID-Hemi were higher than FD-Cel and FD-Hemi. Further, dietary NDO affected ID-Hemi and ID-Cel to a larger extent than FD-Hemi and FD-Cel. This indicates that porcine fiber digestion needs to adapt to dietary NDO and that this was not completed within 13 d on the experimental diets.

Implications

Dietary fructooligosaccharides and transgalactooligosaccharides, included up to 40 g/kg of diet and exchanged at the expense of purified cellulose, hardly affect apparent nutrient digestion and nitrogen and mineral balances in well-kept pigs fed highly digestible diets. Pigs may need more than 2 wk to fully adapt to nondigestible oligosaccharides. The apparent prececal hemicellulose digestion may be enhanced after feeding diets supplemented with nondigestible oligosaccharides for 5 wk. Fructooligosaccharide fermentation is nearly completed prececally. Nitrogen excretion may partly shift from feces to the urine for diets rich in transgalactooligosaccharides. Knowlegde about the composition of ileally recovered nonstarch carbohydrates is needed to assess the meaning of the lower apparent ileal digestion of nonstarch neutral detergent soluble carbohydrates observed for the diets supplemented with fructooligosaccharides and transgalactooligosaccharides.

Literature Cited

Ahrens, F., and J. Schön. 1988. The influenze of dietary non-absorbable carbohydrates on caecal fermentation and whole tract protein digestibility. In: L. Buraczewska, S. Buraczewski, B. Pastuszewska, and T. Zebrowska (Ed.) Digestive Physiology in the Pig. pp 167–171. COBRPO, Jablonna, Poland.

AOAC. 1975. Official Methods of Analysis (12th Ed.). Association of Official Analytical Chemists, Arlington, VA.

Bach Knudsen, K. E., and I. Hansen. 1991. Gastrointestinal implications in pigs of wheat and oat fractions. 1. Digestibility and bulking properties of polysaccharides and other major constituents. Br. J. Nutr. 65:217–232.

Benno, Y., K. Endo, N. Shiragami, K. Sayama, and T. Mitsuoka. 1993. Effects of raffinose intake on the human fecal microflora. Bif. Microfl. 6:59–63.

Berggren, A. M., I.M.E. Bjorck, G. L. Nyman, and B. O. Eggum. 1993. Short chain fatty acid content and pH in caecum of rats given various sources of carbohydrates. J. Sci. Food Agric. 63: 397–406.

Brommage, R., C. Binacua, S. Antille, and A. L. Carrié. 1993. Intestinal calcium absorption in rats is stimulated by dietary lactulose and other resistant sugars. J. Nutr. 123:2186–2194.

Chesson, A., A. J. Richardson, and J. A. Robertson. 1985. Fibre digestion and bacteriology of the digestive tract of pigs fed cereal and vegetable fibre. In: A. Just, H. Jørgensen and J. A. Fernandez (Ed.) Proceedings of the 3rd International Seminar on Digestive Physiology in the Pig, Frederiksberg Bogtrykkeri, Copenhagen, Denmark. pp 272–275.

Chonan, O., and M. Watanuki. 1995. Effect of galactooligosaccharides on calcium absorption in rats. J. Nutr. Sci. Vit. 41:95–104.

Coon, C. N., K. L. Leske, O. Akavanichan, and T. K. Cheng. 1990. Effect of oligosaccharide-free soybean meal on the true metabolizable energy and fibre digestion in adult roosters. Poult. Sci. 69:787–793.

CVB. 1995. [Chemical composition, digestibility, and feeding value of feedstuffs]. Veevoedertabel, Centraal Veevoederbureau, Lelystad, The Netherlands (in Dutch).

De Ruig, W. G. 1986. Atomic absorption spectrometric determination of calcium, copper, iron, magnesium, manganese, potassium, sodium, and zinc in animal feeding stuffs: Interlaboratory collaborative studies. J. Assoc. Off. Anal. Chem. 69: 1009–1013.

Den Hartog, L. A., J. Huisman, W.J.G. Thielen, G.H.A. van Schayk, H. Boer, and E. J. van Weerden. 1988. The effect of including various structural polysaccharides in pig diets on ileal and faecal digestibility of amino acids and minerals. Livest. Prod. Sci. 18:157–170.

Ellegard, L., H. Andersson, and I. Bosaeus. 1997. Inulin and oligofructose do not influence the absorption of cholesterol, or the excretion of cholesterol, Ca, Mg, Zn, Fe, or bile acids but increases energy excretion in ileostomy subjects. Eur. J. Clin. Nutr. 51:1–5.

Fleming, S. E., and B. Lee. 1983. Growth performance and intestinal transit time of rats fed purified and natural dietary fibers. J. Nutr. 113:592–601.

Gabert, V. M., W. C. Sauer, R. Mosenthin, M. Schmitz, and F. Ahrens. 1995. The effect of oligosaccharides and lactitol on the ileal digestibilities of amino acids, monosaccharides and bacterial populations and metabolites in the small intestine of weanling pigs. Can. J. Anim. Sci. 75:99–107.

Gibson, G. R., and B. M. Roberfroid. 1995. Dietary modulation of the human colonic microbiota: Introducing the concept of prebiotics. J. Nutr. 125:1401–1412.

Goelema, J. O., M.A.M. Spreeuwenberg, G. Hof, A.F.B. van der Poel, and S. Tamminga. 1998. Effect of pressure toasting on the rumen degradability and intestinal digestibility of whole and broken peas, lupins and faba beans and a mixture of these feedstuffs. Anim. Feed Sci. Technol. (in press).

Graham, H., and P. Åman. 1986. Circadian variation in composition of duodenal and ileal digesta from pigs fitted with T-canulas. Anim. Prod. 43:133–140.

Hartemink, R., and F. M. Rombouts. 1997. Gas formation from oligosaccharides by the intestinal microflora. In: R. Hartemink (Compiler) Non-digestible Oligosaccharides: Healthy Food for the Colon? pp 57–66. Modern BV, Bennekom, The Netherlands.

Henry, R. J., and H. S. Saini. 1989. Characterization of cereal sugars and oligosaccharides. Cereal Chem. 66:362–365.

Hidaka, H., T. Eida, T. Hashimoto, and T. Nakazawa. 1985. Feeds for domestic animals and method for breeding them. Eur. Pat. Appl. 133547A2:1–10.

Houdijk, J.G.M., M. W. Bosch, M.W.A. Verstegen, and H. J. Berenpas. 1998a. Effects of dietary oligosaccharides on the growth performance and faecal characteristics of young growing pigs. Anim. Feed Sci. Technol. 71:35–48.

Houdijk, J.G.M., R. Hartemink, and M.W.A. Verstegen. 1997. Dietary non-digestible oligosaccharides affect ileal microflora in young pigs. In: J.A.M. van Arendonk (Ed.) 48th Annual meeting of the European Association for Animal Production. p 87. Wageningen Pers, Wageningen, The Netherlands (Abstr.).

Houdijk, J.G.M., B. A. Williams, S. Tamminga, and M.W.A. Verstegen. 1998b. Effect of non-digestible oligosaccharides in diets for weaner pigs on *in vitro* fermentation. Proceedings of the British Society of Animal Science. BSAS, Penicuik, U.K. p 30.

ISO. 1978. Animal feeding stuffs–Determination of crude ash (ISO 5984). International Organization for Standardization, Genève, Switzerland.

ISO. 1979. Animal feeding stuffs–Determination of nitrogen content and calculation of crude protein content (ISO 5983). International Organization for Standardization, Genève, Switzerland.

ISO. 1983. Animal feeding stuffs–Determination of moisture content (ISO 6496). International Organization for Standardization, Genève, Switzerland.

ISO. 1996. Animal feeding stuffs–Determination of fat content, category B (ISO/DIS 6492). International Organization for Standardization, Genève, Switzerland.

Johansen, H. N., P .J. Wood, and K. E. Bach Knudsen. 1993. Molecular weight changes in the (1-3)(1-4)-β-d-glucan of oats incurred by the digestive processes in the upper gastrointestinal tract of pigs. J. Agric. Food Chem. 41:2347–2352.

Katta, Y., K. Ohkuma, M. Satouchi, R. Takahashi, and T. Yamamoto. 1993. Feed for livestock. European-Patent-Application 549478A1:1–14.

Kikuchi, H., C. Andrieux, M. Riottot, M. Bensaada, F. Popot, P. Beaumatin, and O. Szylit. 1996. Effect of two levels of transgalactosylated oligosaccharide intake in rats associated with human faecal microflora on bacterial glycolytic activity, end products of fermentation and bacterial steroid transformation. J. Appl. Bacteriol. 80:439–446.

Leske, K. L., C. J. Jevne, and C. N. Coon. 1993. Effect of oligosaccharide additions on nitrogen-corrected true metabolizable energy of soy protein concentrate. Poult. Sci. 72:664–668.

Li, S., W. C. Sauer, and R. T. Hardin. 1994. Effect of dietary fibre level on amino acid digestibility in young pigs. Can. J. Anim. Sci. 74:327–333.

Lowry, S. R. 1992. Use and misuse of multiple comparisons in animal experiments. J. Anim. Sci. 70:1971–1977.

Mathew, A. G., C. M. Robbins, S. E. Chattin, and J. D. Quigley, III. 1997. Influence of galactosyl lactose on energy and protein digestibility, enteric microflora, and performance of weanling pigs. J. Anim. Sci. 75:1009–1016.

NEN. 1988. Cereals, pulses and animal feeding stuffs–Determination of crude fibre content by the abbreviated method (NEN 5417). Standards of the Netherlands Normalization Institute, Delft, The Netherlands.

NRC. 1988. Nutritional Requirement of Swine. National Academy Press, Washington, DC.

Ohta, A., M. Ohtsuki, S. Baba, T. Adachi, T. Sakata, and E. Sakaguchi. 1995. Calcium and magnesium absorption from the colon and rectum are increased in rats fed fructooligosaccharides. J. Nutr. 125:2417–2424.

Ohta, A., M. Ohtsuki, T. Takizawa, H. Inaba, T. Adachi, and S. Kimura. 1994. Effects of fructooligosaccharides on the absorption of magnesium and calcium by cecectomized rats. Int. J. Vit. Nutr. Res. 64:316–323.

Rocklin, R. D., and C. A. Pohl. 1983. Determination of carbohydrates by anion-exchange chromatography with pulsed amperometric detection. J. Liq. Chromatogr. 6:1577–1590.

Saini, H. S. 1989. Legume seed oligosaccharides. In: J. Huisman, A.F.B. Van der Poel, and I. E. Liener (Ed.) Recent Advances of Research in Antinutritional Factores in Legume Seeds. pp 329–341. Pudoc, Wageningen, The Netherlands.

Sunvold, G. D., H. S. Hussein, G. C. Fahey, Jr., N. R. Merchen, and G. A. Reinhart. 1995. In vitro fermentation of cellulose, beet pulp, citrus pulp, and citrus pectin using fecal inoculum from cats, dogs, horses, humans, and pigs and ruminal fluid from cattle. J. Anim. Sci. 73:3639–3648.

Van Kleef, D. J., K. Deuring, and P. van Leeuwen. 1994. A new method of faeces collection in the pig. Lab. Anim. 28:78–79.

Van Laere, K.J.M., M. Bosveld, H. A. Schols, G. Beldman, and A.G.J. Voragen. 1997. Fermentative degradation of plant cell wall derived oligosaccharides by intestinal bacteria. In: R. Hartemink (Compiler) Non-digestible Oligosaccharides: Healthy Food for the Colon? pp 37–46. Modern BV, Bennekom, The Netherlands.

Van Leeuwen, P., D. J. van Kleef, G.J.M. van Kempen, J. Huisman, and M.W.A. Verstegen. 1991. The post valve T-caecum cannulation technique in pigs applicated to determine the digestibility of amino acid in maize, groundnut and sunflower meal. J. Anim. Physiol. Anim. Nutr. 65:183–193.

Van Soest, P. J. 1973. Collaborative study of acid-detergent fibre and lignin. J. Assoc. Off. Anal. Chem. 56:781–784.

Vanhoof, K., and R. De Schrijver. 1996. Availability of minerals in rats and pigs fed non-purified diets containing inulin. Nutr. Res. 16:1017–1022.

Veldman, A., W.A.G. Veen, D. Barug, and P. A. van Paridon. 1993. Effect of alpha-galactosides and alpha-galactosidase in feed on ileal piglet digestive physiology. J. Anim. Physiol. Anim. Nutr. 69:57–65.

Zuo, Y., G. C. Fahey, Jr., N. R. Merchen, and N. L. Bajjalieh. 1996. Digestion responses to low oligosaccharide soybean meal by ileally-cannulated dogs. J. Anim. Sci. 74:2441–2449.