

Effect of Non-starch Polysaccharides on Mucin Secretion and Endogenous Amino Acid Losses in Pigs

P. C. H. Morel*, R. M. Padilla¹ and G. Ravindran

Institute of Food, Nutrition and Human Health, Massey University, Palmerston North, New Zealand

ABSTRACT : This study was undertaken to examine the influence of soluble non-starch polysaccharides on growth performance, mucin secretion, and endogenous amino acid flows in weaner pigs. Different levels (0, 4 and 7.5%) of purified corn arabinoxylan (AX) or barley β -glucan extract (BG) were substituted for cellulose in a purified diet based on starch, sucrose and enzymatically hydrolyzed casein. All diets contained titanium oxide as an indigestible marker. Each experimental diet was fed to five, 6-wk old weaner pigs for 21 days. Average daily gain ($p < 0.05$) and feed conversion ratio ($p < 0.01$) were improved with dietary inclusion of 7.5% AX and BG, indicating high degradation rates of AX and BG in pigs. Crude mucin contents and endogenous nitrogen flow were increased ($p < 0.05$) with increased levels of AX, but not with BG. Numerical increases in endogenous amino acid flow (EAAF) were observed with increased levels of AX but no definite trend with BG. Endogenous amino acid flow in pigs fed mixed NSP diets (4% BG and 3.5% cellulose) was significantly higher ($p < 0.05$) than those fed 7.5% BG diets. Among diets containing pure sources of soluble non-starch polysaccharides, endogenous amino acid flows were highest in 7.5% AX ($p < 0.05$), intermediate in BG, and lowest in control diet. Increased flows ($p < 0.01$) of threonine, proline and serine in pigs fed 7.5% AX diets are consistent with the increased flow of crude mucin determined in this treatment. In conclusion, mucin and endogenous amino acid flows were increased with dietary inclusion of AX, which could be related to its physicochemical property, particularly its high water-holding capacity. In contrast, β -glucan, due to its high degradation rate in pig, may be considered as unimportant factor in inducing mucin and endogenous amino acid secretions, at least at levels such as those used in this study. (*Asian-Aust. J. Anim. Sci.* 2003, Vol 16, No. 9 : 1332-1338)

Key Words : Non-starch Polysaccharides, Mucin, Endogenous Amino Acid Losses, Pigs

INTRODUCTION

Soluble and insoluble non-starch polysaccharides (NSP), found in viscous cereals such as wheat and barley, play an important role in monogastric nutrition because of their effects on endogenous protein secretion and nutrient digestion. Pigs do not produce the endogenous enzymes required to breakdown the cell wall NSP. A number of researchers (Fernandez and Jorgensen, 1986; Graham et al., 1986; Yin, 1994; Jorgensen et al., 1996) have shown that addition of dietary fiber to the diet results in reductions in the apparent ileal digestibility of starch, crude protein, fat and minerals. These reductions can be associated with changes in the rate of absorption of nutrients or increased endogenous secretions. Several studies have demonstrated that endogenous nitrogen losses in the distal ileum of pigs are influenced by various dietary factors, including the type and level of fiber (Sauer and Ozimik, 1986; Leterme et al., 1998; de Lange et al., 1989; Zebrowska and Kowalczyk, 2000) but how fiber components influences the increase in endogenous secretion remains unclear. It is, however, hypothesized that fiber may directly stimulate secretion of nitrogenous compounds into the digestive tract (Zebrowska

and Low, 1987) and reduce endogenous amino acid reabsorption (Bergner et al., 1981).

Mucous secretion from the gastro-intestinal tract consists *inter alia* of mucin with a high molecular weight glycoprotein responsible for the gelling nature of the mucus (Satchithanandam, 1990; Lien et al., 2001). Mucin appeared to have been scarcely digested prior to the large intestine (Lien et al., 1997), and its presence provides an aqueous "coat" along the gastro-intestinal tract that provides a surface barrier to intestinal absorption of nutrients. The determination of mucin in ileal digesta is of nutritional importance because it may represent a considerable portion of endogenous amino acid losses (Lien et al., 2001). However, studies examining the effects of individual dietary constituents on mucin secretion are limited. Especially the influence of dietary fiber is of interest since it may induce structural and morphological changes in the digestive tract leading to increased mucin secretion (Vahouny and Cassidy, 1986). In the present study, the effects of feeding different levels and types of soluble (arabinoxylan, β -glucan) and insoluble (cellulose) NSP on mucin secretion and endogenous nitrogen and amino acid flows were investigated. The peptide alimentation method of Moughan et al. (1992), which is based on the feeding of diets containing enzymatically-hydrolyzed casein (EHC) as the sole of protein, was employed to estimate endogenous flows.

* Corresponding Author: P. C. H. Morel. Tel: +64-6-350-5338, Fax: +64-6-350-5684, E-mail: P.C.Morel@massey.ac.nz

¹ DOSCST, Mati, Davao Oriental, 8200 Phillipines.

Received February 12, 2002; Accepted May 9, 2003

Table 1. Ingredient composition (g/100 g as fed basis) of the experimental diets

Ingredient	Control diet	4% AX	7.5% AX	4% BG	7.5% BG
Wheat starch	56.15	56.15	56.15	56.15	56.15
Casein or enzymatically-hydrolyzed casein ¹	15.00	15.00	15.00	15.00	15.00
Coconut oil	10.00	10.00	10.00	10.00	10.00
Sugar	7.00	7.00	7.00	7.00	7.00
Cellulose	7.50	3.50	-	3.50	-
Corn arabinoxylan	-	4.00	7.50	-	-
Glucagel™	-	-	-	4.00	7.50
Dicalcium phosphate	3.00	3.00	3.00	3.00	3.00
DL methionine	0.35	0.35	0.35	0.35	0.35
Threonine	0.20	0.20	0.20	0.20	0.20
Salt	0.15	0.15	0.15	0.15	0.15
Vitamin and mineral premix	0.25	0.25	0.25	0.25	0.25
Titanium oxide	0.40	0.40	0.40	0.40	0.40

AX=Arabinoxylan; BG=β-glucan.

¹ Casein was included in casein diets and enzymatically-hydrolyzed casein in EHC diets. Casein diets were fed from day 1 to day 15 of the experiment and the EHC diets from day 16 to 22 of the experiment.

Table 2. Analyzed composition (g/100 g as fed basis) of the experimental diets

	Control	4% AX	7.5% AX	4% BG	7.5% BG
Dry matter	90.02	90.86	91.29	90.81	90.45
Nitrogen	2.21	2.40	2.40	2.33	2.43
Amino acid					
Aspartic acid ¹	0.95	0.98	0.98	1.01	1.01
Threonine	0.53	0.58	0.60	0.63	0.56
Serine	0.63	0.62	0.68	0.64	0.66
Glutamic acid ¹	2.76	2.77	2.94	2.81	2.86
Proline	1.33	1.33	1.40	1.36	1.35
Glycine	0.24	0.26	0.28	0.26	0.27
Alanine	0.39	0.40	0.43	0.42	0.42
Valine	0.82	0.82	0.85	0.84	0.85
Isoleucine	0.66	0.68	0.70	0.68	0.68
Leucine	1.19	1.21	1.25	1.22	1.24
Tyrosine	0.33	0.34	0.36	0.35	0.35
Phenylalanine	0.61	0.62	0.64	0.63	0.63
Histidine	0.35	0.35	0.39	0.37	0.39
Lysine	1.05	1.00	1.07	1.03	1.03
Arginine	0.45	0.45	0.48	0.48	0.49
Non-starch polysaccharide (NSP)					
Insoluble NSP	7.83	1.37	-	1.50	-
Soluble NSP	0.71	5.33	4.00	3.20	4.70
Total NSP	8.09	6.70	4.00	4.70	4.70

AX=Arabinoxylan; BG=β-glucan. ¹ Glutamic acid and aspartic acid values also included glutamine and asparagines, respectively.

MATERIALS AND METHODS

Animal, diets and feeding schedule

A total of 25 LW×LR male and female weaner pigs (6 week old; 14.3 kg±3.2 kg), selected from five litters, were used in this study. The animals were housed in individual smooth edge metal cages under heat lamps, with access to fresh water at all times. Five piglets, one from each litter, were randomly allocated to each of five experimental diets. Different levels of purified corn arabinoxylan (AX) and barley β-glucan extract (BG) were substituted for cellulose in a purified diet based on wheat starch and sucrose with casein (CAS) or EHC (New Zealand Pharmaceuticals Ltd.,

Palmerston North, New Zealand) as the sole source of protein. The EHC-based diets contained titanium oxide as indigestible marker. The ingredient and analyzed composition of the experimental diets are presented in Table 1 and 2, respectively. The β-glucan was sourced from a commercial brand (Glucagel™; Gracelink Ltd., Lower Hutt, New Zealand), and the arabinoxylan was extracted from corn and supplied by Limagrain SA Clermont-Ferrand, France.

The casein-based diets were fed from day 1 to 15 of the experiment and the EHC-based diets from day 16 to 22. The daily amount of feed offered began at 400 g/day and was increased every four days by 50 g. The pigs were fed the

Table 3. Least-square means for liveweights (LW), daily feed intake (DFI), average daily gain (ADG) and feed conversion ratio (FCR) of pigs fed different type of NSP

	Diets					SEM	Litter	Diet
	Control	4% AX	7.5% AX	4% BG	7.5% BG			
No. of pigs	4	4	3	5	5			
LW start (kg)	14.4	13.9	15.1	14.1	14.7	0.58	NS	NS
LW end (kg)	17.9 ^a	17.7 ^a	21.0 ^b	18.1 ^a	20.3 ^b	0.72	*	*
ADG (g/d)	161 ^a	177 ^a	272 ^b	184 ^a	260 ^a	14	*	**
DFI (g/d)	539	527	610	548	580	24	NS	NS
FCR (g/g)	3.3 ^a	3.1 ^a	2.2 ^b	3.0 ^a	2.3 ^b	0.13	*	***

AX=Arabinoxylan; BG= β -glucan. ^{a, b} Values with different superscripts within row are significantly different.

NS, $p > 0.05$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

experimental diets twice daily (09:00 and 17:00 h) for the first 16 days, and five times daily (08:00, 10:00, 12:00, 14:00 and 16:00 h) for five days. On day 22, feed was offered at five times at hourly intervals prior to the collection of digesta samples.

Sample collection and chemical analysis

On day 22, an hour after the last feed, the piglets were anaesthetized with a mixture of Fluothane (4%, Imperial Chemical Industries Ltd., Cheshire, England) and oxygen, and euthanased by intracardiac injection of sodium pentobarbitone. The gastrointestinal tract was exposed and digesta samples from the jejunum and ileum were collected, immediately frozen and freeze-dried. Diet samples were analyzed for soluble and insoluble NSP, nitrogen, amino acids and titanium. Jejunal digesta samples were analyzed for crude mucin, nitrogen and titanium. Ileal digesta samples were subjected to the centrifugation-ultrafiltration method (Moughan et al., 1992; Hodgkinson et al., 2000) and analyzed for nitrogen, amino acids and titanium.

Nitrogen content was determined using a LECO FP-2000 analyzer (LECO Corporation, 3000 Lakeview Ave. St. Joseph 49085-2396, USA) by the Dumas process (Granger, 1997). Titanium contents were determined according to the method of Short et al. (1996). The total, soluble and insoluble non-starch polysaccharides (NSP) were analyzed using an assay kit (Englyst FiberzYM Kit GLC; Englyst Carbohydrate Services Limited, Cambridge, U.K.), which is based on the procedures described by Englyst et al. (1994).

Amino acids were determined following hydrolysis of duplicate samples (5-7 mg) in 1 ml of 6 mol/L glass distilled hydrochloric acid containing 0.1% phenol in glass tubes sealed under vacuum, for 24 h at $110 \pm 2^\circ\text{C}$. Amino acid concentrations were measured using a Waters ion exchange High Performance Liquid Chromatography system calibrated against a reference amino acid mixture of known concentration. The peaks of the chromatogram were integrated using the dedicated software Maxima 820 (Waters, Millipore, Milford, MA), which identify the amino acid by retention time against a reference amino acid mixture. Norleucine and Lysozyme were used as internal

and external standards, respectively, and the weights of each amino acid were calculated using free amino acid molecular weights. Cysteine and methionine were determined by oxidation of duplicate samples (3-4 mg) with 1 ml performic acid (1 part 30% hydrogen peroxide to 9 parts 88% formic acid) for 16 h at 0°C . The samples were then neutralized with 0.15 ml of 50% (w/w) hydrogen bromide prior to acid hydrolysis.

The method used to measure crude mucin was adapted from the method of Lien et al. (1997).

Calculations

The ileal endogenous flows of mucin, nitrogen and amino acids at the terminal ileum were calculated as grams lost per ingestion of 1 kilogram of feed dry matter (DM) was calculated using the following formula (Moughan et al., 1992).

$$\begin{aligned} &\text{Endogenous flow (g/kg DM intake)} \\ &= \text{Concentration of mucin, nitrogen or amino acid} \\ &\quad \text{in ileal digesta} \times \frac{\text{diet titanium}}{\text{ileal digesta titanium}} \end{aligned}$$

Statistical analysis

A linear model with litter of origin as random effect and diet as fixed effect was fitted to the data (GLM procedure, SAS Institute 2002). Differences between diets were tested using a LSD test. The relationship between endogenous losses and crude mucin flows was investigated by fitting a linear model with diet as a fixed effect and crude mucin flow or crude mucin nitrogen flow as covariates as well as the interaction between fixed effect and covariate to the endogenous nitrogen flow data.

RESULTS

Data from one pig were excluded from the analysis due to poor growth performance, and the crude mucin content of digesta from three pigs could not be determined because of insufficient amounts of digesta.

Table 4. Least-square means for jejunum crude mucin, and ileal endogenous flow in pigs fed different types and levels of non-starch polysaccharides

	Dietary treatment					SEM
	Control	4% AX	7.5% AX	4% BG	7.5% BG	
Crude mucin (CM)						
CM (g/kg DDM)	17.0 ^a	42.2 ^{bc}	61.8 ^c	32.5 ^{ab}	23.8 ^{ab}	6.3
CMN (g/kg DDM)	0.78	1.17	1.62	1.84	1.0	0.4
CM flow (g/kg DMI)	9.5 ^a	16.7 ^{ab}	23.3 ^b	12.2 ^a	10.0 ^a	3.2
CMN flow (g/kg DMI)	0.46	0.49	0.64	0.69	0.43	0.2
Endogenous flow (g/kg DMI)						
Nitrogen	2.27 ^a	2.58 ^{ab}	3.75 ^{bc}	4.03 ^c	2.79 ^{ab}	0.37
Aspartic acid ¹	0.90 ^a	0.99 ^a	1.53 ^{bc}	1.51 ^c	1.11 ^{ab}	0.14
Threonine	0.80 ^a	0.92 ^{ab}	1.27 ^{bc}	1.32 ^b	0.85 ^a	0.12
Serine	0.66 ^a	0.79 ^a	1.18 ^b	1.10 ^b	0.78 ^a	0.10
Glutamic acid ¹	1.86 ^a	1.82 ^a	3.27 ^b	2.20 ^a	2.21 ^a	0.30
Proline	0.83 ^a	0.92 ^a	1.73 ^b	1.25 ^{ab}	0.90 ^a	0.17
Glycine	1.47 ^{ab}	1.60 ^{abc}	2.05 ^{bc}	2.21 ^c	1.28 ^a	0.23
Alanine	0.48 ^a	0.58 ^a	0.89 ^{bc}	0.90 ^c	0.63 ^{ab}	0.09
Valine	0.59 ^a	0.65 ^a	0.92 ^{ab}	1.03 ^b	0.67 ^a	0.10
Isoleucine	0.35 ^a	0.43 ^{ab}	0.65 ^c	0.61 ^{bc}	0.48 ^{abc}	0.06
Leucine	0.60 ^a	0.66 ^a	0.99 ^{ab}	1.61 ^b	0.70 ^a	0.13
Tyrosine	0.27 ^a	0.30 ^{ab}	0.48 ^{bc}	0.55 ^c	0.32 ^{ab}	0.06
Phenylalanine	0.26 ^a	0.29 ^a	0.43 ^{ab}	0.56 ^b	0.32 ^a	0.06
Histidine	0.27 ^a	0.32 ^a	0.50 ^b	0.47 ^b	0.32 ^a	0.04
Lysine	0.28 ^a	0.40 ^a	0.65 ^b	0.64 ^b	0.44 ^{ab}	0.07
Arginine	0.30 ^a	0.36 ^a	0.55 ^{ab}	0.69 ^b	0.42 ^a	0.08
Total amino acids	9.91 ^a	11.04 ^a	17.09 ^b	16.20 ^b	11.43 ^a	1.52

AX=Arabinoxylan; BG=β-glucan. ^{a, b, c} Values with different superscripts within row are significantly different ($p < 0.05$).

¹ Aspartic acid includes asparagines and glutamic acid includes glutamine.

Growth performances

The growth performances of pigs fed different types of dietary fibers are presented in Table 3. The litter of origin influenced final live weight ($p < 0.05$), average daily gain (ADG $p < 0.05$), and feed conversion ratio (FCR, $p < 0.05$) indicating genetic and maternal effects. Pigs fed diets containing 7.5% AX and 7.5% BG had better ADG ($p < 0.01$) and FCR ($p < 0.001$) than those fed diets containing 7.5% cellulose or 3.5% cellulose and 4% AX or BG. No differences in feed intake were observed among dietary treatments.

Crude mucin content and flow

The jejunal crude mucin content, expressed in mg/g digesta DM, was not influenced by the addition of BG but increased ($p < 0.01$) in 4% and 7.5% AX treatments (Table 4). No difference in crude mucin nitrogen content was found between diets. The ileal crude mucin flow, expressed in mg/g DM intake, increased ($p < 0.05$) with the dietary inclusion of 4% and 7.5% AX but were similar in pigs fed the cellulose and BG diets. No difference in the crude mucin nitrogen was observed between diets.

Endogenous nitrogen and amino acid flow

Endogenous nitrogen flow increased ($p < 0.05$) as the dietary levels of AX increased (Table 4). When comparing

the purified NSP sources, endogenous flow of nitrogen was significantly higher ($p < 0.05$) with the dietary inclusion of 7.5% AX, intermediate with 7.5% BG and lowest with 7.5% cellulose. Dietary inclusion of mixed NSP (4% BG and 3.5% cellulose) resulted in a higher ($p < 0.05$) endogenous nitrogen flow.

Ileal endogenous flow of amino acids (Table 4) were higher ($p < 0.05$) for pigs fed diets containing 7.5% AX and mixed NSP (4% BG and 3.5% cellulose). The endogenous flows of all amino acids, except glycine, valine, leucine, phenylalanine and arginine, were greater ($p < 0.05$) in pigs fed 7.5% AX diets compared to those fed diets with 7.5% cellulose. The endogenous flows of aspartic, threonine, serine, glycine, alanine, valine, leucine, tyrosine, phenylalanine, histidine and arginine were higher ($p < 0.05$) in pigs fed mixed NSP (4% BG and 3.5% cellulose) diets, as compared with those fed 7.5% BG and 7.5% cellulose diets. Endogenous amino acid flows were similar ($p > 0.05$) in pigs fed with 7.5% AX and mixed NSP (4% BG and 3.5% cellulose), except for glutamic acid. Among the three pure NSP sources, greater endogenous amino acid flows were observed in pigs fed with 7.5% AX, intermediate flow for 7.5% BG and lowest for pigs fed with 7.5% cellulose. The endogenous flows of most amino acids were higher ($p < 0.05$) in pigs fed mixed NSP (4% BG and 3.5% cellulose) diet compared to those fed the 7.5% BG diet. The

Table 5. Relationship between jejunal crude mucin flow and crude mucin nitrogen flow and ileal endogenous nitrogen flow for pig fed different type of non-starch polysaccharides

Diet	Intercept	slope	RSD, R ²
CM flow (g/kg DMI)			
Control	1.47	0.0842	0.53, 0.78
4% AX	1.18		
7.5% AX	1.7		
4% BG	3.0		
7.5% BG	1.95		
CMN flow (g/kg DMI)			
Control	1.71	1.318	0.56, 0.76
4% AX	1.98		
7.5% AX	2.90		
4% BG	3.12		
7.5% BG	2.23		

AX=Arabinoxylan; BG= β -glucan.

RSD=Residual standard deviation. R²=Coefficient of determination.

above general trends in endogenous flows of individual amino acids were reflected in the flow of total amino acids.

Relationship between endogenous losses and crude mucin flows

The results of the covariate analysis showed that ileal endogenous nitrogen flow increased as jejunal crude mucin flow or crude mucin nitrogen flow increased. The slopes were the same for each diet but the intercepts were different (Table 5). The correlation between ileal endogenous nitrogen flow and jejunal crude mucin flow or crude mucin nitrogen flow were 0.56 and 0.66, respectively.

DISCUSSION

Growth performance

Pigs fed a diet with 7.5% AX or 7.5% BG had better average daily gain ($p < 0.01$) and feed conversion ratio ($p < 0.001$) than pigs fed a diet with 7.5% cellulose. The significant improvements observed in ADG and FCR associated with AX and BG diets were unexpected and in contrast to the reports that production parameters are negatively related to intake of soluble NSP from wheat and barley (Cadogan et al., 2000; Yin et al., 2001). These findings may be related to the differences in degradability between purified com AX and BG extract and native soluble AX and BG found in wheat and barley.

Crude mucin

Mucin is a high molecular weight glycoprotein substance that contains a large amount of carbohydrates connected by O-glycosidic bonds to an inner peptide backbone. Mucus is thought to play a major role that provides a protective lining for the gastrointestinal tract against harsh gut environment and entry of gut bacteria (Pestova et al., 2000; Lien et al., 2001). Despite the

importance of mucin in gastrointestinal health, limited information is available on the effects of diet, particularly dietary fiber, on mucin secretion.

In this experiment, dietary addition of 4% and 7.5% AX increased ileal crude mucin content by 148% and 263%, respectively. Cassidy et al. (1981) similarly observed that mucus secretion was elevated by supplementing diets with soluble fiber. The presence of soluble fiber may cause damages in intestinal mucosa, which may respond by reestablishing both the mucus and epithelial layer (Lien et al., 2001). This consequently leads to increased mucin secretions.

The flow of crude mucin was significantly increased with increasing levels of AX added to pig diets. It is considered that proteolysis and physical abrasion were the primary factors influencing the presence of mucin in the gastro-intestinal tract (Montagne et al., 2000), and presence of different types of dietary fiber may increase the activity and distribution of proteolytic enzymes in the lumen of the small intestine that, in turn, enhances increase in mucin flow. Leterme et al. (1998) showed that the linear increase in mucus flow in pigs that consumed diet high in pea fiber was positively related to water holding-capacity in the diet, rather than the feed intake. Thus, the increase in flow of crude mucin in the current trial, as shown by inclusion of arabinoxylan, can be partly explained by the ability of arabinoxylan to absorb water ten times its weight (Choct, 1997).

These results show that the type of dietary fiber may elicit varied actions to influence increase in mucin flow, which remains to be further investigated. The recovery of mucin in the ileal digesta can provide important insights into the effects of dietary constituents on the gastrointestinal tract.

Endogenous losses

Ileal endogenous nitrogen and amino acids flows were significantly increased with dietary inclusion of mixed NSP (4% BG and 3.5% cellulose) and with 7.5% AX. The increased endogenous nitrogen flow in pigs fed with mixed NSP (4% BG and 3.5% cellulose) is difficult to explain. The process where AX stimulates endogenous amino acid secretion is poorly understood, but two mechanisms may be proposed. First, the increase in endogenous flow in pigs fed with 7.5% AX is probably due to its physicochemical property. Arabinoxylan is known for its water-holding capacity, and this feature has been shown to be responsible for the increase in ileal endogenous nitrogen secretion in pigs fed diets containing pea fiber (Leterme et al., 1996; 1998). Second, in the current study, endogenous nitrogen flow was related to both the crude mucin and crude mucin nitrogen flows ($R^2 = 0.31$ and 0.44 , respectively). The increased endogenous nitrogen flow in pigs fed with 7.5%

AX may therefore also be explained by the increased secretion and flow of mucin (see Table 5), which contain nitrogenous components (Lien et al., 2001).

The lack of significant differences in endogenous nitrogen and amino acid flows in pigs fed 7.5% BG is probably suggestive of significant degradation of β -glucan in the small intestine. Arabinoxylan had a highly branched structure requiring several enzymes for complete degradation. In contrast, β -glucan due to its linear polymer can be easily degraded by the exo- and endo-enzymes (Bach Knudsen and Canibe, 2000). Leterme et al. (2000) reported that 49-90% of the total β -glucan is hydrolyzed in the small intestine by microbial and endogenous barley β -glucanase. Thacker (2000) showed the high degradation rate of β -glucan making it unlikely a factor in promoting anti-nutritive characters in pigs. Moreover, pig digesta has high water content, precluding any marked depressive effects of β -glucan (Campbell et al., 1992).

The endogenous nitrogen flows of 4.03 g/kg DMI and 3.75 g/kg DMI for pigs fed with mixed NSP (4% BG and 3.5% cellulose) and 7.5% AX diets, respectively, were lower than the value of 4.4 g/kg DMI reported by de Lange et al. (1990) in pigs fed diets based on wheat and barley. The endogenous flow in pigs fed the 7.5% cellulose diet in this trial (2.27 g/kg DMI) was relatively lower than the value of 2.85 g/kg DMI reported by Hodgkinson et al., (2000) and the values of 2.7-3.7 g/kg DMI reported by Butts et al., (1993a, b). Interestingly, in these studies, the assay diets contained lower levels of (3% to 5%) cellulose.

Glycine, glutamic acid, proline, threonine and aspartic acid predominated the endogenous flow amounting to more than 50% of the total endogenous amino acid flow, which is consistent with previous published data (Moughan et al., 1992; Butts et al., 1993a; Hodgkinson et al., 2000). The increase in the endogenous flows of threonine, serine and proline associated with dietary inclusion of 7.5% arabinoxylan may be explained by the predominance of these amino acids in mucin (Lien et al., 2001), which was increased with dietary inclusion of 7.5% arabinoxylan.

In conclusion, mucin and endogenous amino acid flows were increased with dietary inclusion of AX. It is possible that the branched structure and water holding capacity of AX molecules hamper digestion and absorption process and consequently leads to increased crude mucin secretion and endogenous nitrogen flow. In contrast, it appears that BG may not be an anti-nutritional factor in pigs as it is probably degraded by the microflora colonising the gut. Therefore, β -glucan may be considered as an unimportant factor in inducing mucin and endogenous amino acid secretions, at least at dietary levels such as those used in this study.

It should be noted, however, that the relationship between chemical composition, physical properties and physiological effects of dietary fiber along the

gastrointestinal tract is not a simple one. Clearly, more research is needed to better understand the dynamics of NSP in affecting nutrient digestion and absorption in pigs.

ACKNOWLEDGEMENTS

We are grateful to the New Zealand Foundation for Research Science and Technology for funding this work and to Dr G. Coles at Crop and Food Research, Lincoln for providing the purified corn arabinoxylan and the barley beta-glucan extract.

REFERENCES

- Bach Knudsen, K. E. and N. Canibe. 2000. Breakdown of plant carbohydrates in the digestive tract of pigs fed on wheat-or oat-based rolls. *J. Sci. Food Agr.* 80:1253-1261.
- Bergner, H., M. Luck and J. Muller. 1981. Investigation of the sorption of amino acids to diet components. Sorption of amino acids from wheat straw meal, alkali lignin and cellulose. *Arch. Anim. Nutr.* 31:265-271.
- Butts, C. A., P. J. Moughan, W. C. Smith and D. H. Carr. 1993a. Endogenous lysine and other amino acid flows at the terminal ileum of the growing pig (20 kg bodyweight): The effect of protein-free, synthetic amino acid, peptide and protein alimentation. *J. Sci. Food Agr.* 61:31-40.
- Butts, C. A., P. J. Moughan, W. C. Smith, G. W. Reynolds and D. J. Garrick. 1993b. The effect of food dry matter intake on endogenous ileal amino acid excretion determined under peptide alimentation in the 50 kg liveweight pig. *J. Sci Food Agr.* 62:235-243.
- Cadogan, D. J., G. G. Partridge and P. H. Simmins. 2000. Effect of xylanases addition in feed containing either pre-characterized wheat and wheat by-products on the performance of growing pigs. *Proceedings of the British Society of Animal Science.* 21.
- Campbell, G. L. and M. R. Bedford. 1992. Enzyme applications for monogastric feeds: A review. *Can. J. Anim. Sci.* 72:449-466.
- Cassidy, M. M., F. G. Lightfoot, B. S. Lauretta, E. Grau, J. A. Story, D. Kritchewsky and G. V. Vahouny. 1981. Effect of chronic intake of dietary fibres on the ultra-structural topography of rat jejunum and colon. *Am. J. Clin. Nutr.* 34:218-228.
- Choct, M. 1997. Non-starch polysaccharides: chemical structure and nutritional significance. *Feed Milling International.* June 1997. pp. 13-19.
- de Lange, C. F. M., W. C. Sauer, R. Mosenthin and W. B. Souffrant. 1989. The effects of feeding different protein-free diets on the recovery and amino acid composition of endogenous protein collected from the distal ileum and faeces of pigs. *J. Anim. Sci.* 67:746-754.
- de Lange, C. F. M., W. B. Souffrant and W. C. Sauer. 1990. Real ileal and protein ileal digestibilities in feedstuff for growing pigs as determined with the ^{15}N -isotope dilution technique. *J. Anim. Sci.* 68:409-428.
- Englyst H. N., M. E. Quigley and G. J. Hudson. 1994. Determination of dietary fibre as non-starch polysaccharides with gas-liquid chromatographic, high-performance chromatographic or spectrophotometric measurement of

- constituent sugars. *Analyst*. 119:1497-1509.
- Fernandez, J. A. and J. N. Jorgensen. 1986. Digestibilities and absorption of nutrients as affected by fibre content in the diet of the pig. Quantitative aspects. *Livest. Prod. Sci.* 15:53-71.
- Graham, H., K. Hesselman and P. Amman. 1986. Influence of wheat bran and sugar- beet pulp of the digestibility of dietary components in a cereal-based pig diet. *J. Nutr.* 116:242-251.
- Granger, D. 1997. Kjeldahl versus Dumas-which gives the right answer? *Chem. New Zealand*, p. 7.
- Hodgkinson, S. M., P. J. Moughan, G. W. Reynolds and K. A. C. James. 2000. The effect of dietary peptide concentration on endogenous ileal amino acid loss in the growing pig. *Br. J. Nutr.* 83:412-430.
- Jorgensen, H., X. Q. Zhao and B. O. Eggum. 1996. The influence of dietary fibre and environmental temperature on the development of the gastro-intestinal tract, digestibility, degree of fermentation of the hindgut and energy metabolism in pigs. *Br. J. Nutr.* 75:365-378.
- Leterme, P., E. Froidmont, F. Rossi and A. Thewis. 2000. Effect of barley fibres and barley intake on the ileal endogenous nitrogen losses in piglets. *J. Cereal Sci.* 31:229-239.
- Leterme, P., E. Froidmont, F. Rossi and A. Thewis. 1998. The high water-holding capacity of pea inner fibres affects the ileal flow of endogenous amino acids in pigs. *J. Agr. Food Chem.* 46:1927-1934.
- Leterme, P., T. Monmart, A. Thewis and P. Morandi. 1996. Effect of oral and parenteral N nutrition vs. N-free nutrition on the endogenous amino acid flow at the ileum of the pigs. *J. Sci. Food Agr.* 71:265-271.
- Lien, K. A., W. C. Sauer and J. M. He. 2001. Dietary influence on the secretion into and degradation of mucin in the digestive tract of monogastric animals and humans. *J. Anim. Feed Sci.* 10(2):223-245.
- Lien, K. A., W. C. Sauer and M. Fenton. 1997. Mucin output of ileal digesta of pigs fed a protein-free diet. *Z. Ernahrungswiss.* 36:182-190.
- Montagne, L., R. Toullec, M. Fornal and J. P. Lalles. 2000. Influence of dietary protein level and origin on the flow of mucin along the small intestine of the preruminant calf. *J. Dairy Sci.* 83:2820-2828.
- Moughan, P. J., G. Schuttert and M. Leenaars. 1992. Endogenous amino acid flow in stomach and small intestine of the young growing pigs. *J. Sci. Food Agr.* 60:437-442.
- Pestova, M. I., R. E. Clift, R. J. Vickers, M. A. Franklin and A. G. Mathew. 2000. Effects of weaning and dietary galactose supplementation on digesta glycoproteins in pigs. *J. Sci. Food Agr.* 80:1981-1924.
- SAS Institute. 2002. SAS for Window, version 8.02, SAS Institute. Cary, NC.
- Satchithanandam, S., M. Vargofcak-Apker, R. J. Calvert, A. R. Leeds and M. M. Cassidy. 1990. Alteration of gastro-intestinal mucin by fibre feeding in rats. *J. Nutr.* 120:1179-1184.
- Sauer, W. C. and L. Ozimec. 1986. Digestibility of amino acids in swine: results and their practical application. A review. *Livest. Prod. Sci.* 15:367-388.
- Short, F. J., P. Gorton, J. Wiseman and K. N. Boorman. 1996. Determination of titanium dioxide added as an inert marker in chicken digestibility studies. *Anim. Feed Sci. Tech.* 59:215-221.
- Thacker, P. A. 2000. Recent advances in the use of enzymes with special reference to β -glucanases and pentonases in swine rations. *Asian-Aust. J. Anim. Sci.* 13:376-385.
- Vahouny, G.V. and Cassidy, M.M. 1986. Dietary fibre and intestinal adaptation. In: *Dietary Fiber: Basic and Clinical Aspects*. (Ed. G. V. Vahouny and D. Kritchevsky), Plenum Press, New York. pp. 181-209.
- Yin, Y-L., S. K. Baidoo, H. Schulze and P. H. Simmins. 2001. Effects of supplementing diets containing hulls barley varieties having different levels of non-starch polysaccharides with β -glucanase and xylanases on the physiological status of the gastrointestinal tract and nutrient digestibility of weaned piglets. *Livest. Prod. Sci.* 71:97-107.
- Yin, Y. L. 1994. Nutrients value of feedstuff and diets for pigs: I. Apparent post-ileal digestibility and interrelationships between dietary constituents and faecal and ileal digestibility. *Anim. Feed Sci. Tech.* 45:243-255.
- Zebrowska, T. and J. Kowalczyk. 2000. Endogenous nitrogen losses in monogastrics and ruminants as affected by nutritional factors. *Asian-Aust. J. Anim. Sci.* 13:210-218.
- Zebrowska, T. and A. G. Low. 1987. The influence of diet based on whole wheat, wheat flour and wheat bran on exocrine pancreatic secretion of pigs. *J. Nutr.* 117:1212-1216.