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Fermentation affects mineral flux in the gastrointestinal tract of pigs fed diets supplemented with different viscous and fermentable non-starch polysaccharides (NSP) ☆

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ABSTRACT

The impact of NSP differing in viscosity and fermentability on intestinal mineral flux in pigs is largely unknown. Therefore, the effects of 5% low fermentable, low viscous cellulose (CEL), low fermentable, high viscous carboxymethylcellulose (CMC), high fermentable, low viscous oat β-glucan (LG) and high fermentable, high viscous oat β-glucan (HG) on ileal and faecal recovery and postileal flux of Ca and Zn were studied in 8 ileal-cannulated barrows (30 kg BW) according to a double 4×4 Latin square. Ileal and faecal recovery of Ca and Zn was lowest ($P<0.05$) for CMC and highest for HG. For all treatments faecal recovery of Zn was 1.5 to 2 times higher ($P<0.05$) than ileal recoveries, indicating a net secretion into the large intestine. Absorption of Ca and Zn secretion was non-linearly related ($P<0.01$) to postileal DM digestibility suggesting a relationship between fermentation and mineral flux in the large intestine. In conclusion, colonic fermentation of NSP or other dietary components affects the local mineral flux in pigs, possibly due to microbial requirements for minerals. Viscosity of NSP did not appear to be an important component to explain effects of NSP sources.

1. Introduction

By-products from the food and bio-processing industry are increasingly included as alternative feedstuffs in diets for pigs. Due to the removal of the starch fraction from cereal grains, non-starch polysaccharides (NSP), protein and minerals accumulate in the residuals (Slominski et al., 2004). Dietary NSP can influence the processes of mineral absorption in the small intestine (Bach Kristensen et al., 2005). However, little is known about the consequences of fermentation of complex NSP in the gastrointestinal tract of pigs on mineral flux. In rats, interactions between fermentable carbohydrates, activity of the intestinal microbiota and absorption of minerals have been described (Demigné et al., 1989). During microbial breakdown of NSP, several nutrients, such as minerals, may be released from bindings with NSP components such as phytate (Larsen and Sandström, 1993). These nutrients may be absorbed or utilized by the microbiota of the pig's large intestine. Increased mineral demands to meet bacterial requirements may reduce the intestinal mineral availability for the host. Therefore, the present experiment aimed to compare the effects of NSP differing in viscosity and fermentability on ileal and faecal recovery of Ca and Zn and their flux into the large intestine of grower pigs.

2. Material and methods

2.1. Animals and diets

A semi-purified basal diet consisting of 70% cornstarch and 16% casein was formulated to meet or to exceed the nutrient requirements for growing pigs according to NRC (1998). Titanium dioxide (TiO_2) was added as digestibility

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Table 1
Recovery of Ca and Zn in ileal digesta and faeces of pigs fed diets supplemented with cellulose (CEL), carboxymethylcellulose (CMC), low viscous oat β-glucan (LG) and high viscous oat β-glucan (HG).

Diet	Low fermentable		High fermentable		SEM	*P*-value
	Low viscous	High viscous	Low viscous	High viscous		
	CEL	CMC	LG	HG		
Calcium						
Intake (g/kg DM)	8.4	8.4	8.4	11.0	–	–
Ileal recovery (g/kg DM intake)	11.7[a]	4.8[c]	8.1[b]	12.0[a]	1.13	0.002
Faecal recovery (g/kg DM intake)	8.4[a]	3.7[b]	7.7[a]	9.3[a]	0.66	0.001
Zinc						
Intake (mg/kg DM)	124	154	157	157	–	–
Ileal recovery (mg/kg DM intake)	91[a]	82[a]	126[b]	147[b]	10.8	0.003
Faecal recovery (mg/kg DM intake)	220[a]	132[b]	205[a]	219[a]	21.1	0.064

[abc]LSmeans within a row with different superscripts are significantly different at $P<0.05$.

marker. The basal diet was supplemented with 5% purified sources of NSP: low fermentable, low viscous cellulose (CEL); low fermentable, high viscous carboxymethylcellulose (CMC); high fermentable, low viscous oat β-glucan (LG); or high fermentable, high viscous oat β-glucan (HG). Eight ileal-cannulated cross-bred barrows (Duroc × Large White; BW 30 ± 1.3 kg) were fed one of the experimental diets in a double 4 × 4 Latin square. The pigs were allowed to consume the experimental diets at a rate of 3 × the maintenance requirement for energy (3 × 110 kcal DE/kg $BW^{0.75}$; NRC, 1998). Pigs were fed twice daily two equal meals at 0800 and 1600. All procedures in this study were approved by the Animal Care and Use Committee for Livestock at the University of Alberta.

2.2. Experimental procedure and chemical analysis

The four experimental periods consisted of a 10-d adaptation period followed by 3-d collection of faeces and 4-d collection of ileal digesta. Prior to analyses, faeces and digesta were thawed, homogenized, sub-sampled, and freeze-dried. Feed, digesta, and faeces were analyzed for dry matter (DM), TiO_2, and Ca and Zn using atomic absorption spectrometry (AOAC, 1995). Recovery of Ca and Zn in ileal digesta and faeces was calculated as described by Metzler et al. (2009).

2.3. Statistical analysis

Data were analyzed by ANOVA using the PROC MIXED of SAS. Fixed effects included animal and treatment effect. Period and animal within a square were considered as random effects, assuming a compound symmetry variance–covariance structure (type = cs). A probability level of $P \leq 0.05$ was defined as

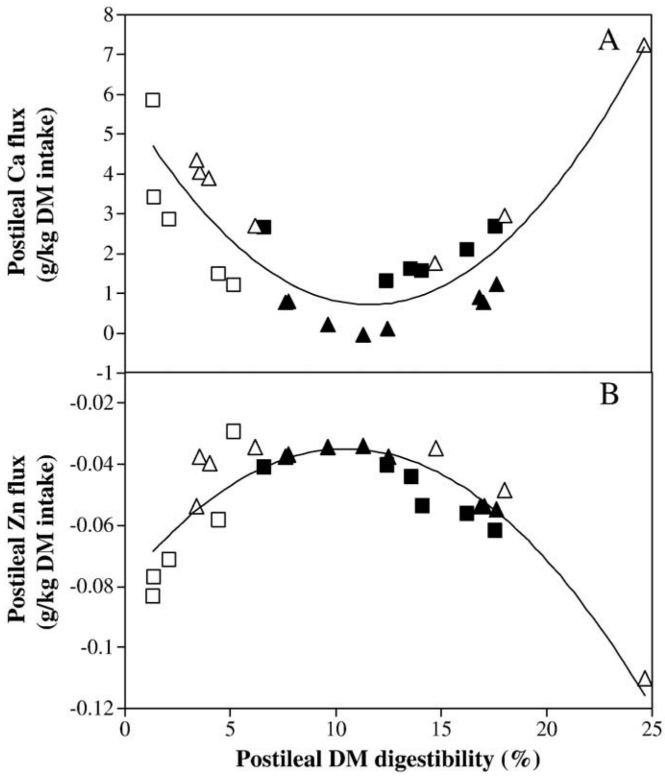

Fig. 1. Relation between postileal Ca (A) and Zn (B) flux and postileal DM digestibility of pigs fed diets supplemented with cellulose (■), carboxymethylcellulose (□), low viscous oat ß-glucan (Δ), and high viscous oat ß-glucan (▲).

significant difference. The relationship between postileal mineral flux and postileal DM digestibility (pDM) was studied using the weighted linear and non-linear regression analysis (PROC REG, SAS). The predicted values of the dependent variable were adjusted according to the above-explained model (i.e., animal and period effects) and regressed to pDM (independent variable) according to St-Pierre (2001).

3. Results

Supplementation of CMC reduced ($P<0.05$) ileal Ca recovery compared to CEL, LG and HG and reduced ($P<0.05$) ileal Zn recovery compared to LG and HG (Table 1). Faecal Ca and Zn recovery was lower ($P<0.05$) with CMC compared to CEL, LG and HG supplementation. Increasing pDM was associated with a curvilinear decrease in postileal Ca absorption with lowest Ca absorption at intermediate pDM levels: $Ca = 5.377 - 0.808 \times pDM + 0.0354 \times pDM^2$ ($R^2 = 0.74$; root mean square error = 0.859; $P<0.001$) (Fig. 1A). Similarly, the increase of pDM was related curvilinearly to a reduction of postileal Zn secretion with lowest Zn secretion at intermediate pDM levels: $Zn = -0.0738 + 0.0076 \times pDM - 0.0004 \times pDM^2$ ($R^2 = 0.83$; root mean square error = 0.008; $P<0.001$) (Fig. 1B).

4. Discussion

Purified sources of NSP differing in viscosity and fermentability were included in a semi-purified diet to assess their effects on ileal and faecal recovery of Ca and Zn. The NSP had a significant impact on the Ca and Zn flux in the small intestine, the main site of mineral absorption. Low viscous, low fermentable CEL increased the ileal recovery of Ca and Zn compared to CMC, likely due to its high cation-binding capacity (Idouraine et al., 1996) and faster small intestinal transit (Montagne et al., 2003). Interestingly, CMC and HG, both high viscous NSP, affected ileal mineral absorption differently in such a way that CMC caused a markedly lower ileal recovery of Ca and Zn compared to HG. Viscous CMC may increase the retention time in the stomach (Fledderus et al., 2007), thereby enhancing the release of minerals due to their exposure to the acidic environment of the stomach and their subsequent absorption in the small intestine (Powell et al., 1994). In contrast, the increased intestinal viscosity caused by HG as a soluble NSP likely impaired absorption of nutrients due to changes in gut motility and mixing of digesta (Montagne et al., 2003).

More Zn was excreted in faeces for the CEL, CMC, LG and HG diets than in ileal digesta indicating a net secretion into the large intestine (Table 1). This amount corresponded to 195, 75, 118 and 107% of the daily Zn requirement of 20 to 50 kg pigs (NRC, 1998) with CEL, CMC, LG and HG, respectively. Calcium, in turn, was absorbed postileally corresponding to 50, 17, 6 and 41% of the Ca requirement of 20 to 50 kg pigs (NRC, 1998) with CEL, CMC, LG and HG, respectively. Overall, flux of Ca and Zn were non-linearly related to the digestibility of DM in the large intestine. Fermentation in the large intestine may affect the mineral flux in several ways including increased solubility of mineral salts and enhanced absorption of minerals and short-chain fatty acids. Moreover, bacterial mineral needs for fermentation (Demigné et al., 1989), buffering properties of Ca to neutralise excessive acidification due to microbial activity in the gut lumen (Bovee-Oudenhoven et al., 1997), and increased endogenous mineral losses caused by higher mucus secretion and cell abrasion caused by the NSP (Jin et al., 1994) may also affect mineral flux. Finally, homeostatic regulation and interactions between minerals may have interfered in the postileal flux of Ca and Zn.

In conclusion, NSP varying in their viscosity and fermentability differently affected the Ca and Zn recovery in the small and large intestines. Colonic fermentation of NSP appeared to have an impact on the flux of Ca and Zn which may be related to bacterial mineral requirements. Viscosity did not affect ileal and faecal mineral recovery and mineral flux in the large intestine consistently among minerals.

Conflict of interest

None of the authors has a conflict of interest.

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