Livestock Science 134 (2010) 79–81

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Effects of viscosity and fermentability of purified non-starch polysaccharides on ileal and total tract nutrient digestibility in ileal-cannulated grower pigs☆

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ARTICLE INFO

Keywords:
Digestibility
NSP
Pig

ABSTRACT

Non-starch polysaccharides (NSP) reduce digestibility, but relative contributions of their functional properties viscosity (V) and fermentability (F) are not known. Thus, 8 ileal-cannulated pigs were fed 4 diets based on cornstarch and casein and supplemented with purified NSP sources, either 5% low F, low V cellulose (CEL), low F, high V carboxymethylcellulose (CMC), high F, low V oat β-glucan (LG), or high F, high V oat β-glucan (HG) in a double 4×4 Latin square. Apparent ileal (AID) and total tract digestibility (ATTD) were calculated using TiO_2 as indicator. The AID of energy, crude protein (CP) and dry matter (DM) was highest ($P<0.001$) for high viscous CMC. The ATTD of energy and DM was highest for CMC ($P<0.05$) and ATTD of CP did not differ among diets. The AID and ATTD of ash was only positive for CMC ($P<0.05$) indicating secretion of minerals with other NSP. Post-ileal DM digestibility, an indicator of fermentation, was highest ($P<0.0001$) for CEL and HG. The relationship of AID of energy to post-ileal DM digestibility was stronger ($R^2=0.85$; $P<0.001$) than the relation with digesta V ($R^2=0.45$; $P<0.001$). In conclusion, negative effects of NSP on AID of energy and CP are explained better by increased fermentability than by increased digesta viscosity.

1. Introduction

Non-starch polysaccharides (NSP) are an important feedstuff component. The NSP are not digested by porcine enzymes but are instead fermented along the gut (Jensen, 1999), mostly in the large intestine, and may affect digestibility of other macronutrients (Owusu-Asiedu et al., 2006). Physiological effects of NSP are attributable to two functional properties, viscosity and fermentability (Dikeman and Fahey, 2006). Soluble NSP increase digesta viscosity and thereby reduce nutrient digestibility in the small intestine. Non-digested nutrients and fermentable NSP pass into the large intestine and are subsequently fermented by microbial populations, thereby producing short chain fatty acids. Viscosity exerts its effects mainly in the small intestine and, in contrast, fermentability is associated with the large intestine (Dikeman and Fahey, 2006).

Most studies reporting roles of NSP were based on feeding feeds rich in NSP as intact plant cell walls; thus, functional properties such as solubility, viscosity, and fermentability cannot be studied as independent factors. Thus, purified NSP were fed to study specific contributions of viscosity and fermentability with the hypothesis that both reduce nutrient digestibility independently. The objectives were to understand effects of purified NSP differing in viscosity and fermentability on nutrient digestibility.

2. Materials and methods

2.1. Surgery, diets and feeding

The animal protocol was approved by the Animal Care and Use Committee for Livestock at the University of Alberta. Eight barrows (20 to 24 kg BW) were fitted with a T-cannula

☆ This paper is part of the special issue entitled "11th International Symposium on Digestive Physiology of Pigs".

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doi:10.1016/j.livsci.2010.06.103

Table 1
Post-ileal DM digestibility, ileal viscosity, apparent ileal digestibility (AID) and total tract digestibility (ATTD) of nutrients in pigs fed diets containing 5% cellulose (CEL), carboxymethylcellulose (CMC), low viscous oat β-glucan (LG), or high viscous oat β-glucan (HG).

Item	Low fermentable		High fermentable		SEM	*P*-value
	Low viscous CEL	High viscous CMC	Low viscous LG	High viscous HG		
Post-ileal DM digestibility, %	13.82[a]	1.30[b]	10.30[a]	12.83[a]	1.89	0.001
Ileal viscosity, mPa·s, (log)	2.48[c]	4.08[a]	3.23[b]	3.29[b]	0.17	0.001
AID, %						
Ash	−41.75[c]	33.98[a]	0.90[b]	−26.00[c]	8.02	0.001
CP	72.78[c]	85.63[a]	77.74[b]	72.77[c]	1.84	0.001
DM	69.76[c]	86.49[a]	75.94[b]	72.59[c]	1.28	0.001
Energy	76.05[b]	89.61[a]	79.96[b]	77.54[b]	1.15	0.001
Starch	98.50	97.71	96.12	98.65	1.28	0.336
ATTD, %						
Ash	−49.31[b]	40.21[a]	−26.31[b]	−35.57[b]	15.9	0.001
CP	84.98	88.79	86.31	83.16	1.55	0.073
DM	83.58[b]	87.94[a]	88.17[a]	85.43[ab]	1.30	0.018
Energy	89.57[b]	90.53[ab]	92.55[a]	89.85[b]	0.80	0.047

[abc]Means within the same row with the same letter were not different ($P>0.05$).

at the distal ileum. Ten d post-surgery, 2 pigs were fed 1 of 4 diets in a double 4×4 Latin square design obtaining 8 observations per diet. The four diets contained 70% corn starch, 16% casein, 1% canola oil, vitamin and mineral premixes, and 0.3% TiO_2 as an indigestible marker. Diets contained 5% of NSP sources (corrected for impurities) of four types differing in viscosity and fermentability: either 5% low F, low V cellulose (CEL), low F, high V carboxymethylcellulose (CMC), high F, low V oat β-glucan (LG) or high F, high V oat β-glucan (HG). Daily feed allowance was adjusted to 3× maintenance of energy (3×110 kcal DE/kg $BW^{0.75}$) that was fed in 2 equal meals at 0800 and 1600 with free access to water.

2.2. Experimental procedure and analyses

Each 17-d period had a 10-d of acclimation to diets, followed by a 3-d faeces collection and a 4-d ileal digesta collection. Feed, freeze-dried faeces and digesta were ground in a mill over a 1-mm screen and analyzed for gross energy, DM, CP (N×6.25), starch, TiO_2, and ash using standard methods. The AID and ATTD of energy, DM and CP were calculated using TiO_2 concentrations of feed, digesta, and faeces using the indicator method. Post-ileal DM digestibility was the difference between ATTD and AID of DM. Digesta viscosity was measured with a DV-I Viscometer (Brookfield, Middleboro, MA); values were converted to a log scale to reach a normal distribution. Data were analyzed by ANOVA using a mixed model containing diet (n = 4) as fixed effect and experimental period (n = 4) and pig (n = 8) as random effects; means were reported as least-squares means. Differences were considered significant if $P \leq 0.05$ and trends if $0.05 < P < 0.10$. Relations between AID of energy and post-ileal DM digestibility and viscosity were analyzed using the weighted linear and non-linear regression analysis with predicted values of the dependent variable adjusted (St-Pierre, 2001).

3. Results

The NSP source affected ($P<0.001$; Table 1) post-ileal DM digestibility; the CMC diet was the least fermentable in the large intestine ($P<0.05$) compared to the other three NSP diets. The NSP source affected ($P<0.001$) ileal viscosity; CMC caused the highest viscosity ($P<0.05$) followed by HG and LG, and CEL was least viscous ($P<0.05$).

Moreover, NSP source affected AID of ash ($P<0.001$; Table 1), which was negative for CEL and HG, close to zero for LG, and positive and highest ($P<0.05$) for CMC. The AID of CP and DM was also highest ($P<0.05$) for CMC, followed by LG compared to CEL and HG. The AID of energy was 10 to 12 units higher ($P<0.05$) for CMC than other NSP sources. Starch digestion was almost completed at the ileum and was not affected by NSP source.

The NSP source affected ($P<0.001$; Table 1) ATTD of ash, which was positive only for CMC. The NSP source affected ($P<0.05$) ATTD of energy and DM and tended to affect ($P<0.10$) ATTD of CP. The relation between AID of energy and post-ileal DM digestibility was strong, inverse, and curvilinear ($R^2 = 0.85$, $P<0.001$) (Fig. 1). The relation between AID of energy and ileal viscosity was curvilinear and weaker ($R^2 = 0.45$, $P<0.001$; Fig. 2) than the relation with fermentation.

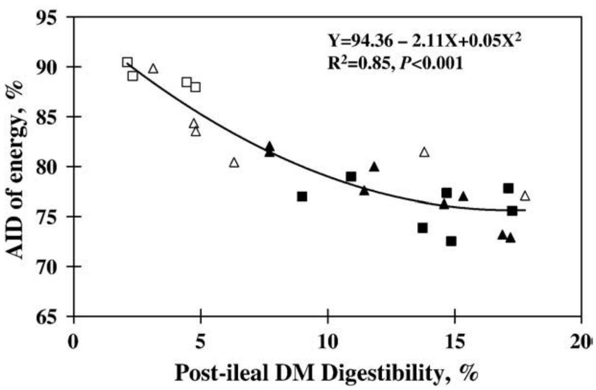

Fig. 1. Relation between AID of energy and post-ileal DM digestibility (fermentation) of pigs fed diets containing either cellulose (■), carboxymethylcellulose (□), low viscous oat β-glucan (△), or high viscous oat β-glucan (▲).

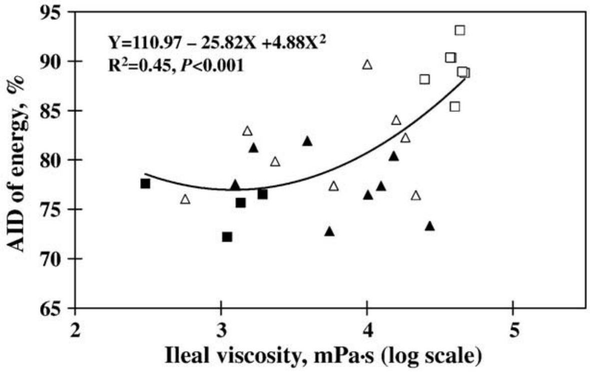

Fig. 2. Relation between AID of energy and ileal digesta viscosity of pigs fed diets containing either cellulose (■), carboxymethylcellulose (□), low viscous oat β-glucan (△), or high viscous oat β-glucan (▲).

4. Discussion

In the present study, post-ileal DM digestibility was an indicator of *in vivo* fermentation and differed from assumptions made while NSP sources were selected to model fermentability. The CEL diet had a high fermentability in the large intestine not due to CEL itself but increased flow and fermentation of nutrients other than CEL from the small into the large intestine. Therefore, data were not analyzed as a factorial arrangement, but instead as individual NSP sources.

The AID and ATTD of ash was negative after feeding the NSP sources except CMC, similar to recent findings in sows (Serena et al., 2008). The negative digestibility could be due to endogenous secretions of minerals or mineral requirements for microbial activity (Metzler et al., 2009). In agreement with our results, AID of CP was also high in weaned pigs fed high viscous CMC (Fledderus et al., 2007). The CMC decreased rate of gastric emptying (Rainbird and Low, 1986) and thereby prolonged contact between digestive enzymes and substrates, and eventually increased CP and energy digestibility. In contrast to CMC, CEL as insoluble NSP decreased the mean retention time in the ileum (Wilfart et al., 2007). Thus, decreased contact time between digestive enzymes and substrates explains the lower DM digestibility in the CEL group. The AID of CP and energy was lower for HG and LG compared to CMC likely due to increased viscosity, changes in gut motility, and mixing of digesta (Montagne et al., 2003); this physiological behaviour overrode an expected increase in digestibility due to slow passage rate.

The strong negative relation between AID of energy and post-ileal DM digestibility might be due to specific NSP sources causing unique patterns of AID of nutrients. For example, more nutrients were digested for CMC and LG diets, resulting in a higher AID of energy. In contrast, for CEL and HG diets, AID of nutrients was lower thereby increasing fermentable substrate entering the large intestine that was indeed fermented. On the other hand, the relation between AID of energy and viscosity was positive but not as strong as the relation with fermentation, because high viscosity increased AID of energy only for CMC but not proportionally for HG and LG diets. Thus changes in AID of energy cannot be explained entirely by viscosity.

In the present study, high viscous CMC had the highest AID of nutrients presumably by delayed gastric emptying and slower digesta passage. In contrast to CMC, effects of LG and HG on AID of nutrients were likely linked to negative effects of digesta viscosity on gut motility and digesta mixing, thereby impairing nutrient digestion and absorption. Faster digesta passage reduced AID of nutrients in the CEL group compared to CMC and thus increased nutrient flow into the large intestine for fermentation. In conclusion, negative effects of NSP on AID of energy and CP are explained better by increased fermentability than by increased digesta viscosity.

Conflict of interest

None of the authors has a conflict of interest.

Acknowledgements

S. Hooda received an Alberta Ingenuity PhD Student Scholarship. Danisco Animal Nutrition, Provimi, Alberta Pulse Growers, and Agriculture and Food Council of Alberta provided funding.

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