Ileal carbohydrate digestion in broiler chickens and humans

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Summary

Ileal digestibility trials conducted with the marker technique gives accurate information about the degradation of carbohydrates in the upper gastro intestinal tract. The marker technique gives negative digestibility values for the indigestible fibre polysaccharides, which reflects the actual accumulation of these components that occurs in the small intestine of monogastric animals. For easily absorbed components such as starch, which is almost completely absorbed in the small intestine, the marker technique gives excellent results, which also are corroborated by quantitative digestibility trials with human ileostomists.

Introduction

Plant Carbohydrates may be divided into two major groups, storage and structural. Starch is the principal storage carbohydrate in cereal grains and in many legumes and is presumably the only polysaccharide formed in the plastids. Starch is the major energy source in cereal based monogastric diets and is easily degraded and efficiently absorbed in the digestive tract.

Structural non-starch polysaccharides may also serve as storage carbohydrates and are as such stored in the cell vacuoles or outside the plasmalemma (Meier and Reid, 1982). Such storage polysaccharides may be found e.g. in some seeds, roots, tubers and leaves. Although not available for absorption in the small intestine non-starch polysaccharides of storage or structural type may still to a very large extent determine the nutritive value of monogastric diets by virtue of their physiological effects. Also, the way in which they build up the cell wall architecture may be of great importance. Structural polysaccharides are commonly referred to as dietary fibre. Dietary fibre is defined physiologically as plant polysaccharides plus lignin, which are resistant to hydrolysis by the digestive enzymes of man (Trowel1 et al. 1976). It has however been suggested to exclude lignin (the non-carbohydrate component) from the dietary fibre definition, although lignin in some cases may be a major cell wall constituent.

Supplementation with enzyme preparations to degrade dietary fibre polysaccharide is today a common practice to increase the nutritive and productive value of monogastric diets. Anti-nutritional effects of the dietary fibre are thereby reduced, or eliminated, leading to considerable performance improvements in animals fed diets that are rich in e.g. arabinoxylans or mixed 'linked' β–glucans.

The current paper will discuss the digestion of starch and structural polysaccharides in monogastric animals, including humans.

Experiments

In two experiments using the Cr_2O_3 marker technique the effects on carbohydrate digestion were studied in broiler chickens fed diets containing deacetylated chitin, also referred to as chitosan (Trial 1). In Trial 2, a rye bran based diet, with or without supplementation of a dietary fibre degrading enzyme, was fed to broiler chickens. In addition, a total collection study with ileostomy subjects (Trial 3) receiving a high fibre diet containing rye was conducted in order to study the effects on quantitative digestion and excretion of carbohydrate components.

Dietary fibres were analysed by the Uppsala method for dietary fibre analysis (Theander *et al.* 1995) and starch (including glucose, maltose and malto–olgosaccharides) according to Åman et *al.* (1995).

Trial 1

The composition of the diets used in Trial 1 (Razdan and Pettersson 1994) is displayed in Table 1. Production parameters were registered at day 2 1 and the digestibility study was conducted at day 23. One randomly selected bird from each of the four cages allocated per treatment was slaughtered by cervical dislocation. Thereafter, culling occurred every fourth hour for a further 20 h. Contents of the last third of the small intestine (denoted

ileum) were collected separately, pooled for each cage, frozen and freeze-dried. Digestibility rates were calculated relative to the Cr_2O_3 marker included at 4 g/kg diet.

Results from Trial 1 are displayed in Table 2. In general diets containing chitosan significantly reduced broiler chicken live weights and feed conversion was also generally inferior.

Table 1 Composition of the control broiler chicken diet.

Ingredient (g/kg air dry basis)	Control/Chitosan diet
Maize	405.0
Maize starch*	244.8/214.8
Soya bean meal	200.0
Fish meal	40.5
Meat and bone meal	40.5
Animal fat	20.0
Chitosan*	0.0/ 30.0
Limestone	17.0
Monocalcium phosphate	13.0
Vitamin and mineral premix	10.0
NaCl	3.0
Cholesterol	3.0
L–Lysine (HCl)	1.6
DL–Methionine	1.6

*Maize starch was substituted with chitosan in the chitosan containing diet.

Table 2 Production parameters and ileal carbohydrate digestibility rates (%) in broiler chickens fed deacetylated chitin (chitosan) differing in deacetylation and viscosity.

(g/b/wk)	Chitosan Control	Chitosan 590 mPa.s	620 mPa.s
Live weight	536[a]	451[b]	482[b]
Feed intake	677[a]	606[b]	629[b]
Feed conversion ratio	1.38[a]	1.50[b]	1.44[ab]
Ileal digestibility rates			
Starch	97	97	97
Arabinose residues	–17[a]	–44[b]	–42[b]
Xylose residues	–17[a]	–44[b]	–45[b]
Glucose residues	–8[a]	–30[b]	–30[b]
Uronic acids	10[a]	–1[b]	–7[b]
Total dietary fibres	–1[a]	–18[b]	–17[b]

[ab]Means within a row with different superscripts differ significantly ($P<0.05$).

Chitosan feeding did not influence ileal startch digestibility rates. As indicated by the high negative digestibility rates for arabinose, xylose and glucose residues as well as uronic acids, an apparent accumulation of these components occurred in the small intestine as a result of feeding the viscous chitosan polymer.

Trial 2

The composition of the diets used in Trial 2 (Pettersson *et al.* 1994) is displayed in Table 3. Production parameters were registered at day 2 1 and the digestibility study was conducted at day 23. Six randomly selected birds from each of the four cages allocated per treatment were slaughtered by cervical dislocation. Contents of the last third of the small intestine (denoted ileum) were collected separately, pooled for each cage, frozen and freeze–dried. Digestibility rates were calculated relative to the Cr_2O_3 marker included at 4.0 g/kg diet.

Table 3 Composition of the diets used in the production and ileal digestibility studies.

Ingredient (g/kg air dry basis)	Production study	Digestibility study
Rye bran (outer endosperm)	400.0	750.0
Maize	315.0	—
Soya bean meal	140.0	—
Fish meal	51.0	61.3
Maize starch	23.0	111.9
Animal fat	20.0	16.7
Limestone	17.0	17.0
Monocalcium phosphate	13.0	13.0
Vitamin and mineral premix	10.0	10.0
Cholesterol	2.5	2.5
NaCl	3.0	3.0
L–Lysine (HCl)	3.0	3.0
DL–Methionine	2.5	2.0

The results from Trial 2 are shown in Table 4. As a result of enzyme supplementation, significant improvements in all production parameters were registered. The digestibility rates of all neutral dietary fibre polysaccharide residues, as well as total dietary fibres, were significantly improved on enzyme supplementation. As a result, positive digestibilty values were obtained for all neutral dietary fibre residues indicating a degradation of these components. Ileal starch digestibilty was also significantly improved by enzyme addition.

Table 4 Production parameters and ileal carbohydrate digestibility rates (%) in broiler chickens fed a rye bran based diet without (–Enzyme) or with (+Enzyme) supplementation with an arabinoxylanase preparation.

(g/b/wk)	–Enzyme	+Enzyme
Live weight	389[a]	479[b]
Feed intake	646[a]	739[b]
Feed conversion ratio	1.83[a]	1.67[b]
Ileal digestibility rates		
Starch	85	96
Arabinose residues	–10[a]	6[b]
Xylose residues	–15[a]	1[b]
Glucose residues	–11[a]	10[b]
Uronic acids	–41[a]	–19[b]
Total dietary fibres	–7[a]	11[b]

[ab]Means within a row with different superscripts differ significantly ($P<0.05$).

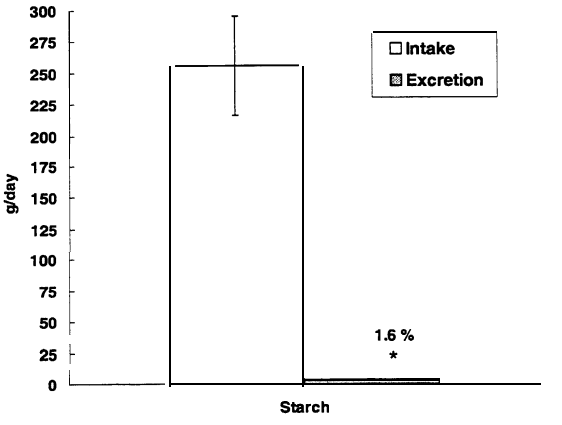

Figure 1 Daily (24 h) intake and excretion of enzyme available starch by ileostomy subjects (n=8) consuming a mixed diet containing rye bread. Data from days 3, 17 and 18 were averaged. Bars show SD and values give yield of ileal excretion as the percentage of daily intake. An asterisk indicates significant differences between intake and excretion.

Trial 3

Six men and two women who had been proctocol–ectomized for ulcerative colitis participated in the study (Pettersson et *al.* 1996). The subjects received a rye containing diet high in dietary fibre. The content (g/kg diet) in 1 portion of this high fibre diet was; protein 97.9, fat 88.8 and carbohydrates (including dietary fibre) 245.9. Subjects received the diet for a period of 3 weeks. Ileostomy effluents were collected during a 24 h collection period. This procedure was repeated at three different occasions (day 3, day 17 and day 18 of the experimental period). Comparisons between intake and excretions were made by Wilcoxon's signed rank matched-pairs test . Differences were considered significant at a probability level of $P<0.01$.

The average daily excretion of enzyme available starch was 4.1 g which constituted only 1.6 % of the amount of starch ingested (Figure 1).

The three major dietary fibre polysaccharide residues ingested by subjects were arabinose, xylose and glucose (Figure 2).

The ileal excretion of uronic acids was 188 % of the arnounts ingested.

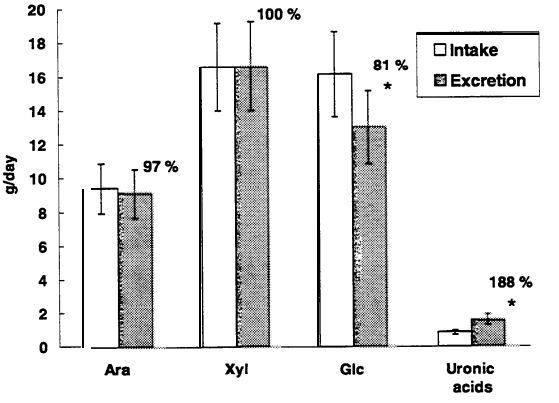

Figure 2 Daily (24 h) intake and excretion of the major neutral dietary fibre polysaccharide residues (Ara=arabinose, Xyl=xylose, Glc=glucose) and uronic acids by ileostomy subjects (n=8) consuming a mixed diet containing rye. Data from days 3, 17 and 18 were averaged. Bars show SD and values give yield of ileal excretion as the percentage of daily intake. An asterisk indicates significant differences between intake and excretion.

Discussion

In the present three trials the digestibility rates of starch were high, indicating an almost complete absorption of this component by the end of the small intestine. The results regarding starch digestion obtained in the animal experiments using the marker technique were also corroborated by the quantitative sampling technique used in the ileostomy study. These results demonstrate that the marker technique works well for estimating intestinal absorption. However, it produces negative digestibility values for dietary fibre polysaccharide residues which may seem confusing. These values, however, are merely a reflection of the fact that dietary fibre is not absorbed in the small intestine and consequently is enriched relative to the content found in the diet, when calculated per gram freeze dried digesta. Negative values may also be obtained depending on the transit time of the soluble and insoluble dietary fibre polysaccharides but are still not incorrect and actually indicates whether or not passage rates are altered due to the viscous properties of the dietary fibre fraction.

This becomes particularly notable when examining the results obtained in Trial 1, where high negative digestibility coefficients were obtained for the major

dietary fibre polysaccharides in birds fed the highly viscous chitosan preparation. Also, in Trial 2, negative digestibility values were obtained for dietary fibre polysaccharide residues in birds fed the rye bran diet without enzyme supplementation. On enzyme supplementation of this diet, positive digestibility values were obtained, due to the enzyme mediated degradation of the dietary fibre polysaccharides, which would cause degradation of these components into short polysaccharide chains with DP<10. Such fragments will not be precipitated in 80 % aqueous ethanol and are consequently not recovered in the dietary fibre analysis. Negative digestibility values for uronic acids were still obtained in both animal experiments due to the endogenous excretion of these components, which also is clearly demonstrated in Trial 3 and well known from human experiments (Danielsson and Sjövall, 1975; Åman et *al.* 1995).

Ileal digestibility trials using modem methods of carbohydrate analyses may considerably improve our knowledge on the mode of action of dietary fibres and also provide information about the efficacy of dietary fibre degrading enzyme preparations used in order to upgrade the nutritive value of diets for monogastrics. It is today, well acknowledged that viscosity measurements of digesta are not always a good predictor for animal performance at low digesta viscosity values (Cowan et *al.* 1996). Therefore, future development work on enzymes for improving the nutritive value of cereals or oil seeds and pulses will require the use of modem methods for carbohydrate analyses in order to better monitor the release and degradation of the carbohydrates that build up the cell wall matrix in different feed components. Viscosity measurements alone are not a sufficient tool for estimating the efficacy of a dietary fibre degrading enzymes since viscosity is easily reduced by simply breaking a few bonds in a soluble polysaccharide chain. In order to obtain maximum nutrient absorption an efficient solubilisation and degradation of the cell wall matrix in order to release enclosed nutrients is required. This demands a complex blend of different enzymatic activities. As a consequence more complex methods of analysis are required in order to describe the effects of these activities on the dietary carbohydrate fraction.

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