Animal Nutrition 1 (2015) 160–165

Contents lists available at ScienceDirect

Animal Nutrition

journal homepage: www.www.keaipublishing.com/en/journals/aninu

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Original research article

Pattern of non-starch polysaccharide digestion along the gut of the pig: Contribution to available energy

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ARTICLE INFO

Article history:
Received 20 July 2015
Accepted 6 August 2015
Available online 10 September 2015

Keywords:
Wheat
Non-starch polysaccharides
Xylanase
Pigs

ABSTRACT

We investigated the pattern of non-starch polysaccharide (NSP) digestion along the gut of pigs fed two different wheats, which were offered with or without xylanase supplementation. The two wheats used were pre-characterised before the experiment on the basis of low and normal feed intake of young pigs. Wheat type significantly influenced feed intake and growth rate in the first 7 days, however, by day 14 the only significant effect of wheat type was on growth rate. Xylanase supplementation increased the growth performance of pigs fed the poor quality wheat to a level similar to those fed the normal wheat. It also increased the daily gain of pigs fed the normal wheat. Wheat type had no significant effect on the digestibility of dry matter (DM), energy, free sugars or the different fractions of NSP in the duodenum, ileum or in the faeces. The duodenal gross energy digestibility values for the low and high performance diets were −27.4 and −47.5%, respectively, and xylanase supplementation significantly increased the digestibility of energy back to positive levels. Dry matter digestibility values followed a similar pattern. In the duodenum, xylanase increased ($P < 0.05$) the digestibility values of both soluble and insoluble NSP, whereas in the ileum, xylanase had a significant effect only on the digestibility of the soluble NSP fraction. Xylanase did not affect free sugar digestibility. The reduction in soluble NSP level coincided with a marked reduction in the amount of fucose, a prominent component of mucosal polysaccharides. This suggests that soluble NSP substantially increase endogenous losses. The absence of differences in the digestibility of the measured NSP between the two wheat samples suggests that the structures of the NSP, rather than just their amount and solubility, are important for the anti-nutritional properties of NSP in pig diets.

1. Introduction

Wheat is one of the most variable in composition among cereal grains (Choct et al., 1999a). These differences are exacerbated by the environmental conditions under which the grains are grown (Longstaff and MacNab, 1986). A review by van Barneveld (1997) using past data for more than 70 cultivars of wheat found differences of up to 3.7 MJ/kg dry matter (DM) in digestible energy (DE) content. The highest DE reported in Australia was at 17.0 MJ/kg DM (Kopinski, 1997), and the lowest was 13.8 MJ/kg DM (King, 1976). Batterham et al. (1980) found that the hemicellulose (mainly arabinoxylan) component of wheat correlated closely with the DE value in wheat. The relationship between DE and more specific components of wheat NSP has been variable (van Barneveld, 1997), although Zijlstra et al., 1988 found a strong correlation between xylose level and DE content in wheat.

The majority of research on wheat in pigs has evaluated the variation in energy content (Kopinski, 1997; van Barneveld, 1997) and devised methods to improve the digestibility of cereal grains (Wiseman, 1997). However, faecal DM digestibility and DE content of cereals are poorly related to pig growth performance compared to ileal DM digestibility measurements (van Barneveld et al., 2001; Cadogan et al., 2003). It appears that growth, feed intake and health of pigs are affected by wheat type but not by the energy and protein levels of wheat (Cadogan et al., 1999; Choct et al., 1999b;

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Peer review under responsibility of Chinese Association of Animal Science and Veterinary Medicine.

ELSEVIER Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.aninu.2015.08.011

Simmins et al., 2001; Caine et al., 1997). The majority of variation in pig growth performance produced by different wheats has been attributed to the content of non-starch carbohydrates (NSC), which includes NSP and free sugars, such as mono- and oligosaccharides up to 10 sugar units, present in feed ingredients (Cadogan, 1999). This observation is strongly supported by the significantly enhanced growth performance of pigs fed diets based on low quality wheats supplemented with xylanase (Choct et al., 1999b; Partridge et al., 1999; Simmins et al., 2001).

There have been many studies investigating the effect of NSP on human health and animal performance but their detailed modes of action in pig diets are largely speculative (Choct and Cadogan, 2001; Partridge, 2001). Numerous studies (Bach Knudsen and Hansen, 1991; Yin et al., 2000; van Barneveld et al., 2001; Bartelt et al., 2002; Pederson et al., 2012) have reported the digestion pattern of wheat NSP fractions at the ileal level. There is, however, limited information on the digestion of NSP from different wheat types and of the modifying effects of exogenous xylanase on wheat fibre in the small intestine of the pig. The hypothesis is that NSP fractions of pre-characterised high and normal feed intake wheats behave differently in the various sections of the gastrointestinal tract (GI tract) of the pig. It is expected that xylanase supplementation will eliminate the differences between the two wheats.

2. Materials and methods

2.1. Pig husbandry and bioassay

The animal protocol was approved by the Ethics Committee of Rivalea Australia Pty Ltd (formerly QAF Meat Industries), and followed principles established by the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes (National Health and Medical Research Council: Canberra, 1997). Sixty male pigs used in the experiments were from Large White × Landrace cross dams crossed with a synthetic terminal sire (Primegro Genetics, Corowa, NSW Australia). The pigs were weaned at 25 days of age and then put into individual cages with wire floors and sides and offered a commercial nursery diet for three days until the experiment commenced. The temperature was kept at a constant 28 °C. Water and feed were available ad libitum. Pigs were selected with a live weight range of 6.5 to 7.5 kg. After three days, pigs were re-weighed and randomly allocated to treatment groups of equal mean weight (12 pigs per treatment). Each pen had an area of 0.5 × 0.9 × 0.5 m and was equipped with a conventional dry feeder and a single drinking nipple. The drinking water was medicated with Apralan (Elanco Animal Health, Greenfield, IN, USA) to reduce potential of *Escherichia. coli* scours on a daily basis throughout each experiment.

Weight gain and feed intake of each individual pig were taken on a weekly basis (0 to 7, 7 to 14, and 14 to 21 days). From these measurements daily feed intake, feed conversion ratio (FCR) and rate of gain values were calculated on an individual pig basis.

2.2. Wheat pre-charactisation and experimental diets

Ten newly harvested wheats were sourced from the eastern and central Riverina districts of New South Wales, as well as the north eastern, central north and Wimmera regions of Victoria, Australia. From this ten, two wheats were selected, one low quality and one normal quality, based on feed intake of young pigs. Briefly, the low quality one was a Currawong cultivar (Wheat 1), and produced 23% (90 g/d) and 26% (83 g/d) lower feed intake and daily gain, respectively, compared with a Whistler cultivar (Wheat 2), which represented the average performance expected of the genotype of pigs used in the study. The total NSP contents of both Wheat 1 and Wheat 2 were similar at 9.49 and 9.75%, respectively, however wheat 1 contained a higher level of soluble NSP (1.67% versus 0.99%) but a lower level of insoluble NSP (11.39% versus 9.75%) compared with wheat 2. The protein and starch content of wheat 1 was 12.56 and 55.0%, respectively, with crude protein and starch in wheat 2 was measured at 11.81 and 58.9%.

Both wheats were hammer-milled through a 3.2 mm screen. A basal diet containing 70% wheat was formulated to have a DE of 14.5 MJ/kg and an available lysine content of 0.90 g/MJ DE for both wheats (Table 1). The dietary essential amino acid contents were formulated to 115% of requirements, which had been predetermined for the pig genotype within Rivalea Australia Pty Ltd. The 15% excess was based on the differences in the protein contents of the wheats in order to maintain an adequate level of protein in all diets. A commercially produced xylanase from *Thermomyces* spp. (Ronozyme WX; DSM Nutritional Products, Wagga Wagga, NSW, Australia), was added to the experimental diets at 0 or 300 mg/kg. An alkane digestibility marker, hexatriacontane ($C_{36}H_{74}$), was added to the diets at a level of 150 mg/kg.

2.3. Measurements

After 21 days, 8 randomly selected pigs were slaughtered, and digesta samples were obtained from the first 80 cm of the small intestine (duodenum and upper jejunum), from the terminal ileum and from the rectum. These were frozen immediately; freeze-dried after 4 days and stored for digesta (alkene) marker and nutrient analyses. Gross energy (GE) was analysed by complete combustion in a DDS CP500 isoperibol calorimeter (Digital Datasystems, Johannesburg). Free sugars, soluble and insoluble NSP were measured using the alditol acetate method of Englyst and Hudson, 1987. Dry matter (DM) was determined gravimetrically following drying at 105°C for 24 h. The alkane marker, hexatriacontane ($C_{36}H_{74}$), was determined as follows: from (100 to 500 mg) freeze-dried samples, an appropriate amount (50 to 200 mg) of internal standard ($C_{34}H_{70}$ in dodecane) was added. The samples were then subjected to 1.5 M ethanolic KOH in a heating-block at 90°C for 1 h with stirring. After cooling, the alkanes were extracted in n-hexane several times, filtered, purified and

Table 1
Ingredients and analyzed composition of the basal diet, as-fed basis.

Ingredient, g/kg	Amount	Analysis composition, g/kg	Amount
Wheat (11.0% CP)	700.0	DE, MJ/kg	14.5
Meatmeal (55% CP)	44.0	NE, MJ/kg	10.4
Fishmeal (67% CP)	100.0	Available lysine, g/(MJ · kg)	0.9
Bloodmeal	23.0	Crude protein	22.0
Skim milk powder	50.0	Fat	5.4
Whey powder	50.0	Ash	5.3
Water	10.0	Lysine	14.3
Tallow	12.0	Methionine	4.6
Salt	2.0	Methionine + Cysteine	7.9
Lysine HCl	1.8	Threonine	9.2
Threonine	1.0	Isoleucine	8.2
Tryptophan	0.3	Tryptophan	2.6
Endox[1]	0.2		
Premix[2]	2.7		
Zinc Oxide	3.0		

[1] Anti-oxidant.
[2] Premix provided the following levels of vitamins, trace minerals and medication per tonne of mixed feed; vitamin A 10 MIU, vitamin D_3 1.5 MIU, vitamin E 40 g, niacin 10 g, Ca-D-panthothenate 5 g, riboflavin 2.5 g, pyridoxine 2.5 g, cyanocobalamin 20 mg, biotin 50 mg, selenium 0.3 g, copper 20 g, iron 100 g, manganese 50 g, zinc 60 g, iodine 0.5 g, betaine 100 g, endox 100 g, anti-microbial (Lincospectin) 100 g.