Animal (2011), **5:4**, pp 558–564 © The Animal Consortium 2010
doi:10.1017/S1751731110002193

Growth performance, digestibility and faecal coliform bacteria in weaned piglets fed a cereal-based diet including either chicory (*Cichorium intybus* L) or ribwort (*Plantago lanceolata* L) forage

E. Ivarsson[1], B. E. Frankow-Lindberg[2], H. K. Andersson[1] and J. E. Lindberg[1†]

[1]Department of Animal Nutrition and Management, Swedish University of Agricultural Science, PO Box 7024, SE-750 07 Uppsala, Sweden; [2]Department of Crop Production Ecology, Swedish University of Agricultural Science, PO Box 7043, SE-750 07 Uppsala, Sweden

(Received 3 July 2009; Accepted 7 September 2010; First published online 3 November 2010)

Twenty-five weaned 35-day-old piglets were used in a 35-day growth experiment to evaluate the effect of inclusion of chicory and ribwort forage in a cereal-based diet on growth performance, feed intake, digestibility and shedding of faecal coliform bacteria. A total of seven experimental diets were formulated, a cereal-based basal diet (B), and six diets with inclusion of 40, 80 and 160 g/kg chicory (C40, C80 and C160) or ribwort (R40, R80 and R160). Piglets had ad libitum *access to feed and water throughout the experiment. Three and five weeks post-weaning faeces samples for determination of digestibility were collected once a day for five subsequent days. Additional faeces samples for determination of coliform counts were collected at days 1, 16 and 35 post-weaning. Piglets fed diet R160 had the lowest average daily feed intake (DFI) and daily weight gain (DWG), and differed ($P < 0.05$) from piglets fed diets B, R40 and R80. There were no differences in DFI and DWG between the chicory diets and diet B. Inclusion of chicory or ribwort had a minor negative impact on the coefficient of total tract apparent digestibility (CTTAD) of dry matter, organic matter and crude protein, whereas inclusion of both chicory and ribwort resulted in higher CTTAD of non-starch polysaccharides and neutral detergent fibre (NDF). The CTTAD of arabinose were higher for diets C160 and R160 than for diet B ($P < 0.05$), and the CTTAD of uronic acid was higher for diets C40, C80, C160, R80 and R160 than for diet B ($P < 0.05$). Age affected the CTTAD for all parameters ($P < 0.05$) except for NDF, with higher values at 5 than at 3 weeks post-weaning. The coliform counts decreased with increasing age ($P < 0.05$), but was not affected by treatment. The results indicate that inclusion of up to 160 g/kg of chicory do not negatively affect performance, whereas high inclusion of ribwort have a negative impact on feed consumption and consequently on growth rate. Both herbs have a higher digestibility of fibre compared to cereal fibre. Chicory and ribwort are both promising as feedstuffs to weaned piglets, but the low palatability of ribwort limits the inclusion level.*

Keywords: piglets, performance, digestibility, fibre, uronic acid

Implications

Despite high-fibre content, the unique nutritional properties of chicory forage will allow high inclusion levels in cereal-based pig diets without negative effects on performance. The negative effect on feed intake limits the inclusion level of ribwort in pig diets.

Introduction

A minimum level of fibre has to be included in a pig diet to support normal physiological functions in the digestive tract (Wenk, 2001). However, increasing inclusion of plant fibre in the diet may impair enzymatic digestion in the upper gastrointestinal (GI) tract, while microbial digestion in the lower GI tract increases. This may negatively affect the digestibility of dietary components and impair the energy value of the diet (Noblet and Le Goff, 2001). However, increased fibre level in the diet of weaned piglets lowers the pH in the hindgut (Högberg and Lindberg, 2006) and increases the content of organic acids in the stomach and the ileum (Högberg and Lindberg, 2004, 2006). These fibre induced changes in gut environment indicates a shift in dominating bacteria and may impair the conditions for pathogen bacteria and be more beneficial for maintaining gut health (Gibson and Roberfroid, 1995; Wenk, 2001). The impact of fibre level on gut environment and digestibility may differ with fibre properties (soluble *v.* insoluble) and with age

---

[†] E-mail: jan-eric.lindberg@huv.slu.se

(Högberg and Lindberg, 2006). Soluble fibre is well digested by both growing pigs and sows, whereas sows have a higher capacity to digest insoluble fibre (Jørgensen *et al.*, 2007).

Chicory (*Cichorium intybus* L.) and ribwort (*Plantago lanceolata* L.) are dicotelydenous herbs that have the potential to be complementary to more traditional forage crops, due to their favourable traits, that is, they are deep-rooted, drought resistant and have a high mineral content (Foster, 1988). They also have a high content of uronic acid (80 to 90 g/kg dry matter (DM)) of which approximately 80% is soluble. Uronic acid in dicotelydenous plants derives from galactosyluronic acid that is the building block in pectins (Voragen *et al.*, 2001). Uronic acid has a high digestibility in other forage crops fed to growing pigs (Leming and Lindberg, 2001). Moreover, pectin substances from sugar beet pulp have been shown to influence the gut microbial ecosystem, in particular by increasing the faecal *Lactobacillus* counts (Wang *et al.*, 2004), and is therefore a very interesting fibre component in piglet nutrition.

The aim of this experiment was to evaluate the effect of inclusion of chicory and ribwort forage in a cereal-based diet on growth performance, digestibility and faecal coliform bacteria in weaned piglets.

We hypothesized that increasing dietary inclusion of chicory and ribwort forage should have a negative impact on total tract digestibility and on growth performance due to a higher dietary fibre content in the diet.

Material and methods

Animals and housing

Twenty-five 35-day-old castrated male piglets (Swedish Landrace × Yorkshire), were used in a 35-day growth experiment. The piglets originated from five different litters and had a live weight of 11.7 kg (s.d. 0.8 kg). The piglets were purchased from a herd free from diseases according to the A-list of International Office of Epizootics (OIE, 2004). The piglets were housed individually in pens equipped with a rubber mat, urine drainage and no bedding. The light regime was a 12/12 h dark/artificial light cycle, room temperature was maintained at 20°C ± 1°C and the humidity varied between 40% and 70%. In addition, each pen had a heat lamp to increase the piglet comfort during the 1st week of the experiment. Piglets had *ad libitum* access to feed and water throughout the experiment, except for the first days when the feed allowance was restricted. They were weighed at days 0, 7, 14, 21, 28 and 35, and the feed intake was registered weekly.

The experiment was carried out at the Swedish University of Agricultural Sciences (SLU) and was approved by the ethical committee of the Uppsala region.

Diets and experimental design

A total of seven experimental diets were formulated (Table 1). They comprised a cereal-based basal diet (B) and three diets composed to contain 40, 80 and 160 g/kg air-dry forage made from vegetative shoots of chicory (C40, C80 and C160) and leaves of ribwort (R40, R80 and R160), respectively. The basal diet was composed of ground cereals (wheat, barley and oats), milled through a 5-mm screen, supplemented with protein, amino acids, mineral and vitamins to meet the nutritional requirements of piglets (Simonsson, 2006; Table 2). In diets with chicory and ribwort inclusion, the cereal mixture was substituted with the herbs on an air-dry basis. The herbs where harvested at the vegetative stage (September) with a stubble height of *c.* 5 cm and dried with forced air at 30°C for a week and milled through a 5-mm screen before mixing with the other feed ingredients. TiO_2 was included in the diets (2.5 g/kg) as an internal digesta marker.

Table 1 *Ingredient composition (g/kg) of the experimental diets*

		Chicory forage			Ribwort forage		
	Basal	40	80	160	40	80	160
Wheat	400	380	360	320	380	360	320
Barley	300	285	270	240	285	270	240
Oat	100	95	90	80	95	90	80
Chicory forage	–	40	80	160	–	–	–
Ribwort forage	–	–	–		40	80	160
Fish meal	30	30	30	30	30	30	30
Potato protein	50	50	50	50	50	50	50
Casein	40	40	40	40	40	40	40
Sugar	40	40	40	40	40	40	40
Vitamin–mineral premix[1]	11	11	11	11	11	11	11
Others[2]	29	29	29	29	29	29	29

[1] Content per kg premix: vitamins (mg): A 10 00 000 IE, D 1 00 000 IE, E 6000, K3 200, B1 200, B2 400, B6 300, B12 2, pantothenic acid 1500, niacin 2000, biotin 25. Minerals (mg): Fe 4000, Cu 1000, Mn 2000, Zn 7000, I 30, Se 35.

[2] Content per kg others: lysine 1.2, methionine 0.08, threonine 0.03, dibasic-calcium phosphate 20, Ca-carbonate, NaCl 2.5, $FeSO_4 + 4\ H_2O$ 0.24, titanium (IV) oxide 2.5.

The experiment was organized according to a randomized block design, with three replicates for the low- and medium-inclusion level of herbs, four replicates for the highest inclusion level of herbs and five replicates for diet B.

Sample collection and coliform counts

Faeces samples for determination of digestibility were collected once a day for five subsequent days from the carefully cleaned pen floor during the 3rd and the 5th week of the experiment, and were stored at −20°C. Feed samples were collected weekly. The feed and faeces samples were freeze-dried and milled through a 1-mm sieve before analysis. Additional faeces samples for determination of coliform bacteria numbers were collected from each piglet at days 1, 16 and 35. One gram of each faecal sample was diluted and mixed with 9 ml NaCl solution (9 g/l), then a serial dilution was made consisting of 0.5 ml of the previous dilution +4.5 ml NaCl solution. From each dilution, 100 μl was spread on blood agar plates. The plates were incubated in 37°C for 20 h before coliform counting.

Table 2 *Analysed chemical composition (g/kg DM) of the basal diet, chicory forage and ribwort forage*

	Basal diet	Chicory forage	Ribwort forage
Ash	67.0	255.6	133.6
CP	211.4	195.2	169.4
Crude fat	26.9	15.6	11.1
Starch	463.0	24.5	9.5
WSC	60.5	11.5	42.0
NDF	107.6	268.0	352.0
NSP			
Total	187.2	311.0	308.5
Insoluble	142.6	194.9	229.5
Glucose			
Total	89.4	133.7	134.9
Insoluble	56.9	118.3	134.9
Arabinose			
Total	25.0	13.4	17.8
Insoluble	22.4	5.6	10.4
Xylose			
Total	56.7	31.1	32.1
Insoluble	56.2	27.2	26.8
Uronic acid			
Total	7.4	97.0	88.3
Insoluble	4.0	21.2	19.9
Klason lignin	34.9	107.2	77.7
Dietary fibre	222.0	418.4	386.2

DM = dry matter; WSC = water soluble carbohydrates (free glucose + free fructose + sucrose + fructan); NSP = non-starch polysaccharides.

Chemical analyses

Samples were analysed for DM by drying at 103°C for 16 h and for ash after ignition at 600°C for 3 h, conventional methods adopted in Sweden (Jennische and Larsson, 1990). Crude protein ($N \times 6.25$) was determined by the Kjeldahl method (Nordic Committee on Feed Analysis, 2003), using a Kjeltec Auto 1030 analyser (Tecator, Höganäs, Sweden). Crude fat was determined according to Official Journal of the European Communities (1984), using a hydrolysing unit (Soxtec System 1047 Hydrolysing Unit, Tecator AB, Höganäs, Sweden) and an extraction unit (Soxtec System HT6, Tecator AB, Höganäs, Sweden). Starch and sugars were analysed by an enzymatic method (Larsson and Bengtsson, 1983). Neutral detergent fibre (NDF) was determined according to Weizhong and Udén (1998), with a 100% neutral detergent solution and the use of amylase and sulphite (for reduction of starch and protein). Total, soluble and insoluble non-starch polysaccharides (NSP) and their constituent sugars, Klason lignin and total dietary fibre were determined according to Bach Knudsen (1997). Titanium dioxide was analysed according to Short *et al.* (1996).

Calculations

Dietary fibre was calculated as total NSP+lignin.

The coefficients of total tract apparent digestibility (CTTAD) were calculated using the indicator technique (Sauer *et al.*, 2000) according to the equation:

$$\mathrm{CTTAD_T} = 100 - (\mathrm{Ti_T} \times \mathrm{N_F})/(\mathrm{N_T} \times \mathrm{Ti_F})$$

where, $\mathrm{CTTAD_T}$ is the coefficient of apparent digestibility of the nutrient in the treatment diet, $\mathrm{Ti_T}$ is the titanium dioxide concentration in the treatment diet (g/kg), $\mathrm{N_F}$ is the nutrient concentration in faeces (g/kg), $\mathrm{N_T}$ is the nutrient concentration in the treatment diet (g/kg) and $\mathrm{Ti_F}$ is the titanium dioxide concentration in faeces (g/kg).

The coliform counts were $\log_{10}$ transformed before statistical analysis.

Statistical analyses

The statistical analyses were performed with procedure Mixed in SAS (SAS Institute, Cary, NC, USA, version 9.1). The model included diet (B, C40, C80, C160, R40, R80, R160) and age (21 or 35 days) as fixed factors, and litter as random factor. For average daily weight gain (DWG), the initial weight was used as covariate in the model. Analysis was based on individual values. As faecal samples used for the digestibility and coliform counts were collected two and three times, respectively, age was analysed with repeated statement with homogeneous autoregressive of order one as covariate structure for digestibility and heterogeneous autoregressive of order one for coliform counts. Two-way interactions between treatment and age were tested, but without any significance. Degrees of freedom were estimated with the Satterthwaite method.

Results

Feed intake and growth performance

Herb inclusion affected ($P < 0.05$) the average daily feed intake (DFI) during days 0 to 21, 21 to 35 and during the total period (days 0 to 35; Table 3). DFI was lower for diet R160 than for diet B during these periods ($P < 0.05$). Within the different inclusion levels of ribwort, DFI was lower for diet R160 than for diets R40 and R80 during days 0 to 21 and during the total period ($P < 0.05$). Moreover, ribwort inclusion negatively affected DWG during days 0 to 21, 21 to 35 and the total period, whereas the effect on feed conversion ratio (FCR) only was observed during days 0 to 21 (Table 3). Compared to diet B, DWG was lower for diet R160 during days 0 to 21 and lower for R40, R80 and R160 during days 21 to 35 ($P < 0.05$). For the total period, DWG was lower for diets R40 and R160 than for diet B ($P < 0.05$). Within the different inclusion levels of ribwort, DWG was lower for diet R160 than for diets R40 and R80 during day 0 to 21 and the total period ($P < 0.05$), whereas no differences were observed during day 21 to 35 ($P > 0.05$). FCR was higher for diet R160 than for diets R40, R80 and diet B during day 0 to 21 ($P < 0.05$). However, no significant differences in DFI, DWG and FCR were observed within the chicory diets.

Digestibility

The CTTAD of DM, OM and CP were higher for diet B than for all diets with herb inclusion ($P < 0.05$; Table 4). Within the chicory diets, the CTTAD of DM and OM were lower for diets

Table 3 *Effects of diet on average daily weight gain (g/day) daily feed intake (g/day) and feed conversion ratio (kg DM feed/kg weight gain) during days 0 to 21, 21 to 35 and 0 to 35. Least square means and pooled s.e.*

Parameter	Basal	Chicory forage			Ribwort forage			s.e.	*P*-value diet
		40	80	160	40	80	160		
n	5	3	3	4	3	3	4		
Daily weight gain									
Days 0 to 21	553	506	528	498	489^{a}	529^{a}	$366^{\ddagger b}$	31.2	**
Days 21 to 35	894	897	849	826	$794^{\ddagger}$	$805^{\ddagger}$	$770^{\ddagger}$	33.5	*
Days 0 to 35	690	662	657	629	$610^{\ddagger a}$	640^{a}	$528^{\ddagger b}$	26.6	**
Daily feed intake									
Days 0 to 21	812	838	845	824	789^{a}	823^{a}	$644^{\ddagger b}$	65.6	*
Days 21 to 35	1618	1653	1688	1623	1563	1510	$1460^{\ddagger}$	51.8	*
Days 0 to 35	1135	1163	1181	1143	1101^{a}	1100^{a}	$970^{\ddagger b}$	56.1	*
Feed conversion ratio									
Days 0 to 21	1.51	1.62	1.59	1.61	1.55^{a}	1.59^{a}	$1.81^{\ddagger b}$	0.075	**
Days 21 to 35	1.81	1.83	1.99	2.0	1.99	1.89	1.89	0.086	ns
Days 0 to 35	1.67	1.74	1.79	1.80	1.78	1.74	1.85	0.065	ns

[‡] Symbol within a row, indicate difference ($P < 0.05$) compared with the basal diet.
[ab] Different letters within ribwort, in a row, indicate difference ($P < 0.05$).

Table 4 *Effects of diet on the CTTAD of DM, OM, CP, NDF, NSP, arabinose, xylose and uronic acid. Least square means and pooled s.e.*

Parameter	Basal	Chicory forage			Ribwort forage			s.e.	*P*-value diet
		40	80	160	40	80	160		
n	10	6	6	8	6	6	8		
DM	0.81	$0.79^{\ddagger a}$	$0.76^{\ddagger b}$	$0.76^{\ddagger b}$	$0.78^{\ddagger d}$	$0.78^{\ddagger d}$	$0.75^{\ddagger e}$	0.008	***
OM	0.84	$0.82^{\ddagger a}$	$0.80^{\ddagger b}$	$0.80^{\ddagger b}$	$0.81^{\ddagger d}$	$0.81^{\ddagger d}$	$0.78^{\ddagger e}$	0.007	***
CP	0.79	$0.75^{\ddagger}$	$0.72^{\ddagger}$	$0.75^{\ddagger}$	$0.75^{\ddagger}$	$0.75^{\ddagger}$	$0.72^{\ddagger}$	0.012	***
NDF	0.31	0.35^{b}	0.35^{b}	$0.49^{\ddagger a}$	0.32^{e}	$0.43^{\ddagger d}$	$0.46^{\ddagger d}$	0.038	**
NSP	0.68	0.69^{ab}	0.67^{b}	$0.72^{\ddagger a}$	0.64^{e}	0.68^{d}	0.70^{d}	0.016	**
Arabinose	0.62	0.62^{b}	0.62^{b}	$0.70^{\ddagger a}$	0.59^{f}	0.65^{e}	$0.69^{\ddagger d}$	0.017	***
Xylose	0.64	0.66^{ab}	0.62^{b}	0.68^{a}	$0.58^{\ddagger e}$	0.65^{d}	0.68^{d}	0.022	*
Uronic Acid	0.58	$0.66^{\ddagger c}$	$0.73^{\ddagger b}$	$0.78^{\ddagger a}$	0.60^{e}	$0.72^{\ddagger d}$	$0.75^{\ddagger d}$	0.017	***

CTTAD = coefficient of total tract apparent digestibility; DM = dry matter; OM = organic matter; NSP = non-starch polysaccharides.
[‡] Symbol within a row, indicate difference ($P < 0.05$) compared with the basal diet.
[abc] Different letters within chicory, in a row, indicate difference ($P < 0.05$).
[def] Different letters within ribwort, in a row, indicate difference ($P < 0.05$).

C80 and C160 than for diet C40 ($P < 0.05$). Within the ribwort diets, the CTTAD of DM and OM were lower for diet R160 than for diets R40 and R80 ($P < 0.05$).

In general, the fibre digestibility was higher for the herbs than for the cereals resulting in higher fibre digestibility with increasing herb inclusion (Table 4). The CTTAD of NDF was higher for diets C160, R80 and R160 than for diet B ($P < 0.05$). The CTTAD of NSP was higher for diet C160 and lower for diet R40 than for diet B ($P < 0.05$). The CTTAD of arabinose was higher for diets C160 and R160 than for the diet B ($P < 0.05$). The CTTAD of xylose was lower for diet R40 than diet B, and the CTTAD of uronic acid was higher for diets C40, C80, C160, R80 and R160 than for diet B ($P < 0.05$). Within the chicory diets, the CTTAD of fibre was higher for diet C160 than for diets C40 and C80 ($P < 0.05$). Between diets C40 and C80 no differences were observed except for the CTTAD of uronic acid which increased with increasing level of chicory ($P < 0.05$). Within the ribwort diets, the CTTAD of fibre was lower for diet R40 than for diets R80 and R160 with exception for the CTTAD of arabinose, where diets R40 and R80 were lower than diet R160 ($P < 0.05$).

The CTTAD was higher during week 5 than during week 3 post-weaning ($P < 0.05$) for all parameters, except for NDF ($P > 0.05$; Figure 1). However, a numerical difference for the CTTAD of NDF was also observed.

Coliform counts

The coliform counts decreased with increasing age ($P < 0.05$) but was not affected by diet, there were no interaction ($P > 0.05$) between diet and age (Table 5).

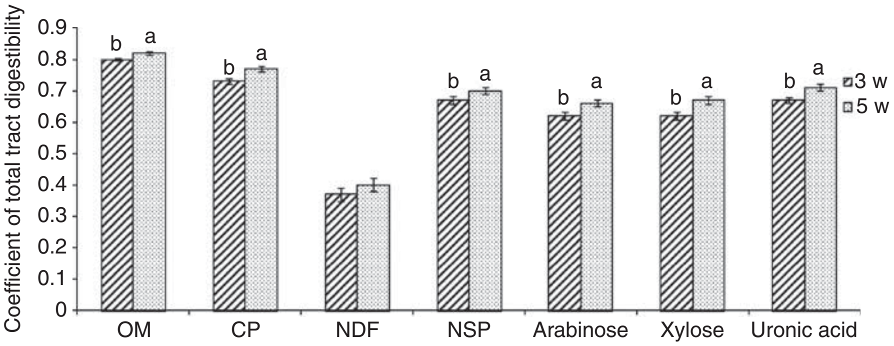

Figure 1 Effect of age (3 and 5 weeks post-weaning) on the CTTAD of dietary components. The results are presented as least square means ± s.e. Bars with different letters differ significantly ($P < 0.05$). OM = organic matter; NSP = non-starch polysaccharides.

Table 5 *Effects of diet, age (days 1, 16 and 36 post-weaning) and diet*age interaction on coliform counts (*$log^{10} cfu^{-1}$*). Least square means and pooled s.e.*

		Chicory forage			Ribwort forage						*P*-value		
	Basal	40	80	160	40	80	160	s.e	Age	s.e.	Diet	Time	Diet*Age
n	5	3	3	4	3	3	4		25		ns	***	ns
Day 1	7.45	7.51	7.57	7.96	8.02	7.82	8.17	0.306	7.79^{a}	0.116			
Day 16	7.61	6.45	6.74	5.30	5.10	7.72	6.85	1.078	6.54^{b}	0.409			
Day 35	5.68	5.28	4.56	5.44	4.79	5.87	4.78	0.380	5.22^{c}	0.144			
Days 1–35	6.91	6.41	6.28	6.23	5.97	7.14	6.60	0.380					

^{abc}Different letters in a column, indicate difference ($P < 0.001$).

Discussion

This is the first study on the impact on growth performance, digestibility and coliform counts of feeding chicory and ribwort forage to piglets. Chicory and ribwort forage are new as feedstuffs to piglets, but have previously been fed to deer, calves, lambs and young rabbits with good growth performance results (Fraser *et al*., 1988; Rumball *et al*., 1997; Castellini *et al*., 2007).

Piglets fed chicory diets showed a high DWG, DFI and FCR at all inclusion levels and did not differ significantly from the piglets fed the control diet (diet B). However, not significant, numerical differences with lower DWG and higher FCR with increased chicory inclusion were observed in the current study. The non-significant results may be due to few animals per treatment and therefore further studies are needed to confirm the results of this study. Vestergaard *et al*. (1996), reported decreased DFI and DWG when grass meal was included in the diet, whereas Longland *et al*. (1994) reported maintained feed intake, body weight gain and FCR in weaning piglets fed a cereal-based diet with inclusion of fibre in the form of sugar-beet pulp. The similar response in DWG and FCR in this study and in the study by Longland *et al*. (1994), as compared with those reported by Vestergaard *et al*. (1996), may be explained by differences in the chemical properties between fibre sources (Bach Knudsen, 1997; Voragen *et al*., 2001).

Pluske *et al*. (2003) also reported maintained body weight gain when high-amylose maize starch and lupin isolate were included in rice-based diets and fed to weaning piglets. However, increased content of dietary fibre in the diet resulted in increased GI organ weight and decreased empty body weight gain. This may also have been the case in this study, although weights of GI organs were not recorded.

A decrease in DWG compared to diet B was observed for ribwort diets. This was due to a lower DFI on the ribwort diets than on the diet B and the chicory diets. There appeared to be a progressive decline in DFI with increasing ribwort inclusion. In the period 0 to 21 days, the FCR was higher for piglets fed the highest inclusion of ribwort (diet R160). This was due to feed refusal and feed spoilage on this diet, indicating that ribwort has a low palatability for piglets.

In general, the extent of digestion of OM, CP and fibre components in this study was comparable to data on barley-based diets with lucerne meal inclusion (Leming and Lindberg, 2001). However, the decrease in the CTTAD of OM and CP when chicory and ribwort were included in the cereal-based basal diet was smaller than that reported with the inclusion of other fibre-rich feedstuffs (Lindberg and Andersson, 1998; Noblet and Le Goff, 2001).

In contrast to the CTTAD of OM and CP, the CTTAD of NDF and NSP were higher in the diets with high inclusion of both herbs. Inclusion of chicory or ribwort in the diet increased the uronic acid content and thereby also the soluble NSP fraction. Diet C160 contained three times more uronic acid than diet B. Interestingly, the CTTAD of uronic acid was improved with increased inclusion of chicory and ribwort, implicating a higher digestibility of uronic acid from the herbs than from the cereals. Similar results were obtained for sugar-beet pulp included in cereal-based diets fed to weaning piglets (Longland *et al.*, 1994), and for lucerne leaf meal (Leming and Lindberg, 2001) included in barley-based diets fed to growing pigs. Longland *et al.* (1994) showed large difference in digestibility of different NSP monomers between sugar-beet pulp and the cereal-based diet. Arabinose and uronic acids were the monomers that differed most in digestibility between the two diets. The digestibility of arabinose was almost two times higher and uronic acid more than one third higher in sugar-beet pulp compared to the cereal-based diet. The reason for differences in digestibility of NSP monomers between fibres of different origin may be related to the differences in the fibre structure and chemistry (Andersson and Åman, 2001). In cereals cell walls, glucouronoarabinoxylans, a heterogenous structure that includes the monomers arabinose, xylose and uronic acid (Fardet *et al.*, 1997), is one of the major polysaccharides (Andersson and Åman, 2001). In contrast, in the cell walls of sugar beet pulp and other dicotelydenous plants pectin is a major component were arabinose and xylose can be side chains in the galactosyluronic acid chain (Voragen *et al.*, 1995, 2001). Fardet *et al.* (1997) showed that barley bran compared to sugar-beet pulp only was half-degraded during fermentation with human faecal bacteria and suggested that the fermentability of barley bran were limited by highly branched glucoarabinoxylans. Longland *et al.* (1994) suggested that sugar-beet pulp either stimulated the proliferation of gut microbes or rendered the existing population more efficient when compared with cereal fibres. Leming and Lindberg (2001) showed that the hindgut digestibility of uronic acid from lucerne leaf meal was 75%. Canibe and Bach Knudsen (1997) found that more than 65% of the total tract digestibility of uronic acids in peas was digested by the hindgut microbiota. This suggests that the higher digestibility of NSP observed with inclusion of chicory and ribwort is a result of increased hindgut fermentation due to more easily degradable polysaccharides in the herbs than the cereals.

The improved digestibility of OM and fibre components, at 5 compared to 3 weeks post-weaning, indicates maturation of the hindgut and increased hindgut fermentation with increasing age. It has earlier been reported that adult sows fed fibre-rich diets have a higher digestibility of dietary components and energy than growing pigs (Noblet and Le Goff, 2001). Longland *et al.* (1994) found an improved digestibility of NSP in 56-day-old compared to 32-day-old piglets when they were fed diets with inclusion of sugar-beet pulp, but not when they were fed cereal-based diets. The full capacity to degrade soluble NSP from sugar-beet pulp are developed within 2 weeks, whereas it may take up to 5 weeks to develop the full capacity to digest insoluble fibres (Longland *et al.*, 1993). This demonstrates that the origin of the fibre has a major influence on the time needed to establish effective hindgut fermentation in the pig. The increased digestibility of chicory and ribwort from 3 to 5 weeks post-weaning support our suggestion that the soluble NSP in chicory and ribwort are comparable with those found in sugar-beet pulp fibre.

The coliform numbers decreased with increased age, supporting the indication of higher hindgut fermentation, and thereby a changed gut environment. Wellock *et al.* (2008) showed decreased coliform numbers and increased lactobacillus : coliform ratio between day 6 and 14 post-weaning with addition of both soluble and insoluble NSP. Although diet did not have an effect of coliform counts in this study, the high CTTAD of fibre from the herbs indicates that the microflora can utilize fibres from herbs better than cereal fibres.

Conclusion

Chicory and ribwort forage are both promising as fibre-rich feedstuffs to weaned piglets, but the low palatability of ribwort will limit the inclusion level in the diet. Both herbs have a high-fibre digestibility and only a small negative effect on the digestibility of OM and crude protein. Thus, it should be possible to maintain a high energy and nutritive value of the diet when chicory is included as fibre source.

References

Andersson R and Åman P 2001. Cereal arabinoxylan: occurrence, structure and properties. In Advanced dietary fibre technology (ed. BV McCleary and L Prosky), pp. 301–314. Blackwell Science Ltd, Oxford, UK.

Bach Knudsen KE 1997. Carbohydrate and lignin contents of plant materials used in animal feeding. Animal Feed Science and Technology 67, 319–338.

Canibe N and Bach Knudsen KE 1997. Digestibility of dried and toasted peas in pigs. 1. Ileal and total tract digestibilities of carbohydrates. Animal Feed Science and Technology 64, 293–310.

Castellini C, Cardinali R, Rebollar PG, Dal Bosco A, Jimeno V and Cossu ME 2007. Feeding fresh chicory (*Cichorium intybus*) to young rabbits: performance, development of gastro-intestinal tract and immune functions of appendix and Peyer's patch. Animal Feed Science and Technology 134, 56–65.

Fardet A, Guillon C, Hoebler C and Barry JL 1997. In vitro fermentation of beet fibre and barley bran, of their insoluble residues after digestion and of ileal effluents. Journal of the Science of Food and Agriculture 75, 315–325.

Foster L 1988. Herbs in pastures. Development and research in Britain, 1850-1984. Biological Agriculture and Horticulture 5, 97–133.

Fraser TJ, Cosgrove GP, Thomas WJ, Stevens DR and Hickey MJ 1988. Performance of grassland Puna chicory. Proceedings of the New Zealand Grassland Association 49, 193–196.

Gibson GR and Roberfroid MB 1995. Dietary modulation of the human colon microbiota: introducing the concept of prebiotics. The Journal of Nutrition 125, 1401–1412.

Högberg A and Lindberg JE 2004. Influence of cereal non-starch polysaccharides and enzyme supplementation on digestion site and gut environment in weaned piglets. Animal Feed Science and Technology 116, 113–128.

Högberg A and Lindberg JE 2006. The effect of level and type of cereal non-starch polysaccharides on the performance, nutrient utilization and gut environment of pigs around weaning. Animal Feed Science and Technology 127, 200–219.

Jennische P and Larsson K 1990. Traditionella svenska analysmetoder för foder och växtmaterial, Rapport 60. Statens Lantbrukskemiska Laboratorium, Uppsala, Sweden.

Jørgensen H, Serena A, Hedemann MS and Bach Knudsen KE 2007. The fermentative capacity of growing pigs and adult sows fed diets with contrasting type and level of dietary fibre. Livestock Science 109, 111–114.

Larsson K and Bengtsson S 1983. Determination of water soluble carbohydrates in plant material, Method 22. Statens Lantbrukskemiska Laboratorium, Uppsala, Sweden.

Leming R and Lindberg JE 2001. Digestion of carbohydrates in fibre-rich diets for pigs. Agraarteadus XII, 210–218.

Lindberg JE and Andersson C 1998. The nutritive value of barley-based diets with forage meal inclusion for growing pigs based on total tract digestibility and nitrogen utilization. Livestock Production Science 56, 43–52.

Longland AC, Low AG, Quelch DB and Bray SP 1993. Adaptation to the digestion of non-starch polysaccharide in growing pigs on cereal or semi-purified basal diets. British Journal of Nutrition 70, 557–566.

Longland AC, Carruthers J and Low AG 1994. The ability of piglets 4 to 8 weeks old to digest and perform on diets containing two contrasting sources of non-starch polysaccharide. Animal Production 58, 405–410.

Noblet J and Le Goff G 2001. Effect of dietary fibre on the energy value of feeds for pigs. Animal Feed Science and Technology 90, 35–52.

Nordic Committee on Feed Analysis 2003. Determination in feeds and faeces according to Kjeldahl, 4th edition, Method no. 6 – Nitrogen. NMKL, Oslo, Norway.

OIE (Office International des Epizooties) 2004. Old classification of diseases notifiable to the OIE. Retrieved 15 April 2009, from http://www.oie.int/eng/maladies/en_OldClassification.htm

Official Journal of the European Communities 1984. Determination of crude oils and fat. Method B. Official Journal of the European Community L 15, 28–38.

Pluske JR, Black B, Pethick DW, Mullan BP and Hampson DJ 2003. Effects of different sources and levels of dietary fibre in diets on performance, digesta characteristics and antibiotic treatment of pigs after weaning. Animal Feed Science and Technology 107, 129–142.

Rumball W, Keogh RG, Lane GE, Miller JE and Claydon RB 1997. Grassland Lancelot plantain (*Plantago lanceolata* L.). New Zealand Journal of Agricultural Research 40, 373–377.

Sauer WC, Fan MZ, Mosenthin R and Drochner W 2000. Methods for measuring ileal amino acid digestibility in pigs. In Farm animal metabolism and nutrition (ed. JPF D'Mello), pp. 279–306. CABI Publishing, Wallingford, UK.

Short FJ, Gorton P, Wiseman J and Boorman KN 1996. Determination of titanium dioxide added as an inert marker in chicken digestibility studies. Animal Feed Science and Technology 59, 215–221.

Simonsson A 2006. Fodermedel och näringsrekommendationer för gris, Report 226. Swedish University of Agricultural Science, Department of Animal Nutrition and Management, Uppsala, Sweden.

Vestergaard EM, Danielsen V, Eklund Larsen A and Bejerholm C 1996. Dried grass meal for finishing pigs and pregnant sows, report 50. National Institute of Animal Science, Research Centre Foulum, Foulum, Denmark.

Voragen AGJ, Pilnik W, Thibault JF, Axelos MAV and Renard CMGC 1995. Pectins. In Food polysaccharides and their applications (ed. AM Stephen), pp. 287–339. Marcel Dekker Inc., New York, NY, USA.

Voragen F, Beldman G and Schols H 2001. Chemistry and enzymology of pectins. In Advanced dietary fibre technology (ed. BV McCleary and L Prosky), pp. 379–398. Blackwell Science Ltd, Oxford, UK.

Wang JF, Zhu YH, Li DF and Jensen BB 2004. Effect of type and level of dietary fibre and starch on ileal and faecal microbial activity and short-chain fatty acid concentrations in growing pigs. Animal Science 78, 109–117.

Weizhong C and Udén P 1998. An alternative oven method combined with different detergent strengths in the analysis of neutral detergent fibre. Animal Feed Science and Technology 74, 281–288.

Wellock IJ, Fortomaris PD, Houdijk JGM, Wiseman J and Kyriazakis I 2008. The consequences of non-starch polysaccharide solubility and inclusion level on the health and performance of weaned pigs challenged with enterotoxigenic *Esherichia coli*. British Journal of Nutrition 99, 520–530.

Wenk C 2001. The role of dietary fiber in the digestive physiology of the pig. Animal Feed Science and Technology 90, 21–33.