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Flow of endogenous and exogenous nitrogen in different segments of the small intestine in pigs fed diets with soyabean concentrate, soyabean meal or rapeseed cake

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ABSTRACT

Six barrows of an average initial BW 27.5±1.2 kg were used. Each pig was fitted with two cannulas in different segments of the small intestine: pig 1 in the duodenum (C1) and upper jejunum (C2), pig 2 in C2 and the lower jejunum (C3), pig 3 in C2 and C3, pig 4 in C1 and the terminal ileum (C4), pig 5 in C3 and C4, pig 6 in C1 and C4. Pigs were also fitted with one catheter in the *vena jugularis* for blood sampling and with a second one in the *arteria carotis* for continuous infusion of ^{15}N-leucine (4.2 mg/kg$^{0.75}$ BW/d). Pigs were used in a crossover design experiment with three treatments and three periods of digesta collection (36 h) and blood sampling (36 h). Maize starch-based diets that contained: soyabean concentrate (SC), a mixture of toasted and untoasted soyabean meal (mSBM) of a high trypsin inhibitor activity, or rapeseed cake (RC) of a high NDF

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content were used in the experiment. The flow of endogenous and exogenous N along the small intestine and the net reabsorption rate of endogenous N were estimated.

In the C1 digesta of pigs fed on the SC, mSBM and RC diets, total N was 138, 127 and 126% of the ingested N, respectively. Sixteen, 15 and 10% of the ingested N was absorbed up to C1, and 11.1, 11.6 and 9.4 g of endogenous N (Ed-N) per kg DM intake was secreted, respectively. For corresponding diets in the C2 digesta, total N was 126, 117 and 111% of the ingested N. Thirty four, 11 and 31% of the exogenous N (Ex-N) inflow and -32, 1 and -39% of the Ed-N inflow was absorbed. In the C3 digesta, total N was 44, 47 and 43% of the ingested N, while 81, 71 and 71% of the Ex-N inflow and 54, 38 and 49% of the Ed-N inflow was absorbed, respectively. Accordingly, in the C4 digesta total N was 24, 33 and 33% of the ingested N, and 45, 43 and 4% of the Ex-N inflow was absorbed. True N digestibility at the terminal ileum was 94, 88 and 82% for the SC, mSBM and RC diets. The reabsorption rate of endogenous N before the terminal ileum was estimated as 75, 51 and 69%, respectively.

It was concluded that regardless of the dietary protein source, the middle segment of the small intestine is the site of the most intense absorption of endogenous and exogenous N. Reabsorption rather than secretion of endogenous nitrogen along the pig's small intestine seems to be influenced by dietary factors.

KEY WORDS: pigs, endogenous nitrogen, secretion, absorption, flow

INTRODUCTION

Secretion and absorption of nitrogenous compounds occur simultaneously along the intestinal tract in the pig. These two processes are influenced by a number of factors such as age and body weight of animals, protease inhibitors and dietary fibres. Dietary antinutritional factors (ANF) may increase endogenous N losses at the terminal ileum and decrease digestibility of dietary protein (Nyachoti et al., 1997). The energy and protein requirements for maintenance may be increased as a result of extra synthesis of endogenous protein to replenish the losses (De Lange et al., 1995) and, therefore, less dietary N can be used for retention (Grala et al., 1998). In that respect, the extent of recycling of endogenous protein [secretion, reabsorption and (re)synthesis] may have a significant impact on the post-absorptive efficiency of amino acid utilization for protein deposition (Nyachoti et al., 1997).

Huisman et al. (1993) calculated that about 30% of urinary N may originate from N losses, which occur during recycling of endogenous protein. The calculation is based on the 75% reabsorbtion of endogenous N before the terminal ileum (Souffrant, 1991). In terms of effective pig production it is important to know whether different losses of endogenous N affected by different protein sources are associated with different or similar secretion of endogenous protein and its reabsorption rate up to the terminal ileum.

The objective of this study was to estimate the flow of endogenous and exogenous N along the small intestine of pigs fed semi-purified diets with soyabean con-

centrate, a mixture of toasted and untoasted soyabean meal, or rapeseed cake. Another aim of this study was to estimate the net reabsorption rate of endogenous N in the small intestine when using different protein sources. The trial was run on cannulated pigs using the ^{15}N-isotope dilution technique.

MATERIAL AND METHODS

Protein sources

Three protein sources were used in the study: 1. a commercial soyabean concentrate (SC), 2. a mixture of toasted soyabean meal and untoasted soyabean meal (mSBM; ratio of 75:25, respectively), and 3. toasted rapeseed cake (RC). It was assumed that each protein source affects the flow of endogenous N along the small intestine in pigs in a different way. The SC was considered to cause low flow, while mSMB and RC a high flow. The RC was prepared by CETIOM-GERDOC (Pessac, France) from a double-low glucosinolate variety of rape oilseeds (*Brassica napus* L.). A detailed description of the technological processing of the soyabean and rapeseed products has already been presented elsewhere (Grala et al., 1997b). Chemical characteristics of the feedstuffs is given in Table 1.

Animals and housing

The experiment was carried out using six Polish Landrace barrows. Pigs were 12 to 13-wk-old with BW (± SE) of 27.5 kg (± 1.2 kg) upon arrival. They were individually housed in metabolism cages at an ambient room temperature of 22 to 24°C and a relative air humidity of 55%. Pigs were fed a commercial diet for the adaptation period. The experimental procedures were approved by the ethics committee of The Kielanowski Institute of Animal Physiology and Nutrition.

Diets and feeding

The SC, mSBM and RC were the only protein sources in the maize starch-based diets. Diets were balanced for the apparent ileal digestible (ID) crude protein (CP; N x 6.25) and essential amino acids (AA). The contents of ID essential AA (Lys, Thr, Met+Cys, and Trp) were at least 85% of pigs' requirements (CVB, 1994). Apparent ileal digestibility of CP and AA of the diets containing the same ingredients were determined in a previous ^{15}N / ileal digestibility experiment (Grala et al., 1997b). In the present study, Cr_2O_3 was used as a solid-phase marker (1.5 g/kg feed) and Co-EDTA as a liquid-phase marker (5 g/kg feed). The diets were pelleted

TABLE 1

Chemical composition of feeds, g/kg DM

	Diet		
	SC	mSBM[1]	RC
Dry matter	953.0	909.0	947.0
Crude protein	709.3	555.0	356.9
Ether extract	8.4	13.6	122.5
Ash	72.4	73.6	71.8
Crude fibre	29.4	39.9	153.1
NDF	–	75.7	241.8
TIA, mg/g[2]	2.5	14.5	–
Glucosinolates, μm/g[3]	–	–	12.6
Amino acids			
arginine	47.6	42.7	21.1
histidine	19.8	15.6	9.2
isoleucine	33.2	26.9	14.9
leucine	57.9	44.5	25.8
lysine	46.5	37.9	18.6
methionine	10.3	7.7	6.4
cystine	11.1	8.8	8.1
phenylalanine	37.1	33.3	12.1
threonine	27.3	24.8	17.3
tryptophan	9.2	7.2	4.6
valine	35.1	30.9	21.1
alanine	31.2	29.0	16.8
aspartic acid	84.8	79.8	27.6
glutamic acid	127.4	108.7	58.1
glycine	31.5	26.2	19.1
proline	45.3	69.4	21.8
serine	35.7	31.9	18.0
tyrosine	25.7	19.8	11.8

[1] SC is soyabean concentrate, mSBM is mixture of toasted soyabean meal and untoasted soyabean meal (ratio of 75:25, respectively), and RC is toasted rapeseed cake

[2] trypsin inhibitor activity (TIA) expressed as milligrams of trypsin inhibited per gram of the product's DM

[3] fat-free DM

in low-temperature conditions (< 60°C). The ingredient content and calculated chemical composition of the diets are given in Tables 2 and 3, respectively.

During the experimental periods pigs were given equal meals at 8.00 and 20.00 h. A daily amount of feed offered to each pig was at a level 2.7 times its maintenance requirement for metabolizable energy (ME) (2.7 x 420 kJ ME/kg$^{0.75}$; ARC, 1981). Water was available *ad libitum* from drinking nipples.

TABLE 2

Composition of the experimental diets, %

	Diet		
	SC	mSBM[1]	RC
Soya concentrate	18.17	–	–
mSBM[1]	–	31.50	–
Rapeseed cake	–	–	46.78
Maize starch	43.605	39.362	27.274
Dextrose	15.00	15.00	15.00
Soya oil	4.10	2.45	4.05
Cellulose	11.00	4.40	–
$CaCO_3$	1.16	1.20	0.75
$Ca(H_2PO_4)2H_2O$	1.80	1.70	1.35
NaCl	0.30	0.30	0.30
$KHCO_3$	0.82	0.10	0.45
$NaHCO_3$	0.25	0.25	0.25
MgO	0.06	–	–
Cr_2O_3	0.15	0.15	0.15
Co-EDTA	2.50	2.50	2.50
L-lysine HCl	–	–	0.146
DL-methionine	0.071	0.088	–
L-threonine	0.014	–	–
Premix[2]	1.00	1.00	1.00

[1] mixture of toasted (75%) and untoasted (25%) soyabean meal

[2] the premix supplied per kilogram of feed: 9,000 IU of vitamin A; 1,800 IU of vitamin D_3; 40 mg of vitamin E; 5 mg of riboflavin; 30 mg niacin; 12 mg of d-pantothenic acid; 1,000 mg of choline, 40 mg of vitamin B_{12}; 2 mg of thiamine; 3 mg of pyridoxine; 0.1 mg of biotin; 1 mg of folic acid; 3 mg of vitamin K; 50 mg of ascorbic acid; 72.8 mg of Zn ($ZnSO_4 \times H_2O$); 44 mg of Mn (MnO_2); 80 mg of Fe ($FeSO_4 \times 7H_2O$); .525 mg of Co ($CoSO_4 \times 5H_2O$); 0.38 mg of K (KI); 0.254 mg of Cu ($CuSO_4 \times 5H_2O$); 0.06 mg of Se ($Na_2SeO_3 \times 5H_2O$); 40 mg tylosin.

TABLE 3

The analyzed[1] and calculated[2] chemical composition of the experimental diets, % as-fed basis

	Diet		
	SC	mSBM	RC
Dry matter[1]	87.14	86.93	87.60
Crude protein (N x 6.25)[1]	11.28	15.05	14.65
Ether extract[1]	3.35	1.79	8.11
Crude fibre[1]	8.23	3.63	5.86
Ash[1]	4.64	4.96	5.67
NDF[1]	11.50	6.09	11.76
TIA (mg/g)[2]	0.40	3.38	ND
Cr[1]	0.142	0.142	0.142
Co[1]	0.242	0.242	0.242
ID CP[2]	10.4	10.4	10.4
ME, MJ/kg[2]	14.4	14.4	14.4

Experimental procedures

The scheme of the experiment is presented in Table 4. After 16 days of the adaptation period, each pig was fitted with two cannulas. The cannulas were placed in the small intestine as follows:

cannula 1: in the duodenum (C1); T-shape, silicon cannula (ø 10 mm); placed about 35 cm distal to the pylorus.

cannula 2: upper jejunum (C2); T-shape, silicon cannula (ø 10 mm); placed posterior to C1 at a distance of about 300 cm.

cannula 3: lower jejunum (C3); T-shape, silicon cannula (ø 20 mm); placed anterior to the end of the ileum at a distance of about 250-300 cm.

cannula 4: at the terminal ileum (C4); PVTC-cannula (van Leeuwen et al., 1991).

Each pig was provided with two cannulas as following:

pig 1: C2 + C3
pig 2: C1 + C2
pig 3: C2 + C3
pig 4: C1 + C4
pig 5: C3 + C4
pig 6: C1 + C4

After 13 days of a recovery, pigs were catheterized with one catheter in the *vena jugularis* for blood sampling and the second one in the *arteria carotis* for infusion of the ^{15}N-leucine (99% ^{15}N-enrichment; Euriso-Top, Belgium). The commercial diet was replaced by the experimental diets and a 34-day continuous ^{15}N-leucine infusion started. The daily rate of the ^{15}N-leucine infusion was about 4.2 mg per kg BW per day. ^{15}N-leucine dissolved in a sterile non-pyrogenic, physiological saline solution (NaCl, 9 g/L) was infused at a rate of about 45 mL/d using perfusion pumps (Fr. B. Braun Melsungen AG, Germany).

Pigs were used in a crossover design experiment comprising three dietary treatments and three periods. Such a design allowed obtaining three observations for each cannula on each treatment. Diets with SC, RC and mSBM were fed as follows:

	Period 1	**Period 2**	**Period 3**
pig 1 (C2 + C3):	SC	RC	mSBM
pig 2 (C1 + C2):	SC	RC	mSBM
pig 3 (C2 + C3):	mSBM	SC	RC
pig 4 (C1 + C4):	mSBM	SC	RC
pig 5 (C3 + C4):	RC	mSBM	SC
pig 6 (C1 + C4):	RC	mSBM	SC

Digesta collection lasted 72 h. An 8-day adaptation period to the experimental diets preceded each digesta collections. The first period (P1) was started after 9

TABLE 4

Scheme of the experimental procedures

Items	Preliminary period				Experimental periods							
					Labelling period (fore-period of P1)		Period 1 P1	Fore-period of P2	Period 2 P2	Fore-period of P3	Period 3 P3	The end
Day of experiment: (Day of exp. period)	1→16	17→19	18→31	32→34	35 (0)[1]	36→43 (1→8)	44→46 (9→11)	47→54 (12→19)	55→57 (20→22)	58→65 (23→30)	66→68 (31→33)	69 (34)
	Adaptation	Cannulation	Recovery	Catheterization (taking of "0" blood sample)	Start of ^{15}N-leucine infusion	Adaptation to experimental diets	a) 3 x 12 h collection[2] b) 3 x 12 h collection[3] c) 3 x blood sampling[4]	Changing of exp. diets	Similarly to P1	Changing of exp. diets	Similarly to P1	

[1] Days of the experimental period

[2] a) collection of digesta from distal cannula

[3] b) collection of digesta from first cannula

[4] c) blood sampling 6 h after feeding

days of labelling the pigs with the ^{15}N-leucine. Digesta were collected from the distal cannula for the first 36 h (3 x 12 h). Afterwards the distal cannula was closed and digesta were collected from the proximal one for the next 36 h (3 x 12h). The procedure for the digesta collection was as follows:

A. Duodenal digesta (C1):
   The duodenal cannula was opened 0.5, 1.0, 1.5, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 h after feeding time. Digesta (90±10 g) collected for about 5-10 min at each time point were weighed and stored at -20°C until freeze-drying. Within a period, freeze-dried digesta from the 3 x 12 h collections were pooled per pig and time sampling (14 samples).
B. Jejunal digesta (C-2 and C-3):
   Spot samples of 80-100 g of digesta were taken every 1 h (3 x 12 h), immediately frozen and stored at -20°C until analyses.
C. Ileal digesta (C-4):
   A continuous collection was performed for 3 x 12 h. Plastic bags with digesta were emptied and weighed every 1 h. Samples were stored at -20°C until pooling per 3 x 12 h collection per pig.

Pooled samples of duodenal and jejunal digesta, and a representative sample of ileal digesta were freeze-dried. Pooled duodenal and jejunal digesta from each sampling time per pig over 36 h (14 samples) were pooled again to obtain a representative sample from 12 h collection for each pig.

Blood sampling (2 x 4 ml) begun during the catheterization when a blank sample was taken to determine the background of the ^{15}N-enrichment in the total N of the trichloroacetic acid (TCA)-blood plasma. Then, blood samples were taken 6 h after feeding (midpoint between feedings) during each 12 h digesta collection period. Blood was centrifuged for 10 min at 2600 rpm and then kept frozen until analysis of ^{15}N-enrichment.

Chemical analyses

Nitrogen, DM and ether extract (EE) in the diets and in freeze-dried ileal digesta were analyzed according to standard methods (AOAC, 1984). Neutral detergent fibre (NDF) was determined as described by van Soest (1973). Chromium in the diets and ileal digesta was determined according to Kimura and Miller (1957), and cobalt, using an atom spectrophotometry method of Philips Scientific (1988). The soyabean products were analyzed for activity of trypsin inhibitors (TIA) according to van Oort et al. (1989). Glucosinolates of RC were determined according to EEC method No. 1864/90 (1990). The ^{15}N-enrichment of ileal digesta, feed and of the TCA-soluble fraction of blood plasma was determined according to the procedure of Schulze et al. (1995).

Calculations and data analyses

The ratio of ^{15}N-enrichment excess in digesta to that in the TCA-soluble blood plasma, referred to as the dilution factor, was calculated for each site of digesta collection according to the following equation:

$$DF = (^{15}N_{dig} - ^{15}N_{d(0)}) / (^{15}N_{pl} - ^{15}N_{pl(0)}) \times 100 \quad [1]$$

where DF is dilution factor (%), $^{15}N_{dig}$ is ^{15}N-enrichment of digesta (at. %), $^{15}N_{d(0)}$ is the background ^{15}N-enrichment in the diet (at. %), $^{15}N_{pl}$ is ^{15}N-enrichment in the TCA-soluble blood plasma (at. %), $^{15}N_{pl(0)}$ is the background ^{15}N-enrichment in the TCA-soluble blood plasma (at. %).

In digesta for the consecutive cannulas, the amount of total N [g/100 g N intake (NI)] was calculated using Cr and Co as indigestible markers according to the following equation:

$$N_{tfl} = (N_{dig} / N_d) \times (M_d / M_{dig}) \times 100 \quad [2]$$

where N_{tfl} is the amount or flow of N in particular parts of the intestine, N_{dig} is the N content in digesta (%), N_d is the N content of the diet (%), M_d and M_{dig} are the contents (%) of indigestible markers in diet and digesta, respectively. The N flows were separately calculated for each marker.

The endogenous N (g/100 g NI) was estimated from the dilution factor (Equation 1) and the total N (Equation 2):

$$N_{efl} = DF \times N_{tfl} / 100 \quad [3]$$

where N_{efl} is the amount of endogenous N in digesta from different cannulas (g/100 g NI). The amount of exogenous (dietary) N in digesta was calculated as the difference between the N_{tfl} and N_{efl}.

For the estimation of the N flow (g/kg dry matter intake-DMI) in consecutive segments of the small intestine, the amounts of N per 100 g NI were related to 1000 g of DMI.

The net absorption of endogenous N, and absorption of exogenous N in each intestinal segment (g/kg DMI) were calculated according to the following scheme: a. NI minus N in C1 digesta, b. N in C1 digesta minus N in C2 digesta, c. N in C2 digesta minus N in C3 digesta, d. N in C3 digesta minus N in C4 digesta. The net absorption of total N in the whole upper intestinal tract was also calculated [(total N in C1 – total N in C4 digesta) / total N in C1 x 100]. Additionally, the net absorption of endogenous N (reabsorption rate) in the small intestine was calculated [(N in C1 – N in C4) / N in C1 x 100] for each treatment.

Apparent ileal N digestibility was calculated according to the formula: NI – N in C4 / NI x 100.

Part of the scheduled observations could not be included into the data set because of dysfunction of cannulas and/or feed refusals. As a consequence, the number of observations (n) obtained for each cannula and treatment were for the SC diet: C1 = 3, C2 = 2, C3 = 2, C4 = 3; for the mSBM diet: C1 = 2, C2 = 1, C3 = 1, C4 = 3; for the RC diet: C1 = 2, C2 = 1, C3 = 1, C4 = 3.

RESULTS

The flow of both markers (ratio Cr to Co) appeared to be in a constant ratio throughout the different intestinal segments (Figure 1). It was assumed, therefore, that the flow of both solid and liquid phase was constant throughout the upper intestinal tract. The results presented in this section were calculated on the average data for both markers within each treatment.

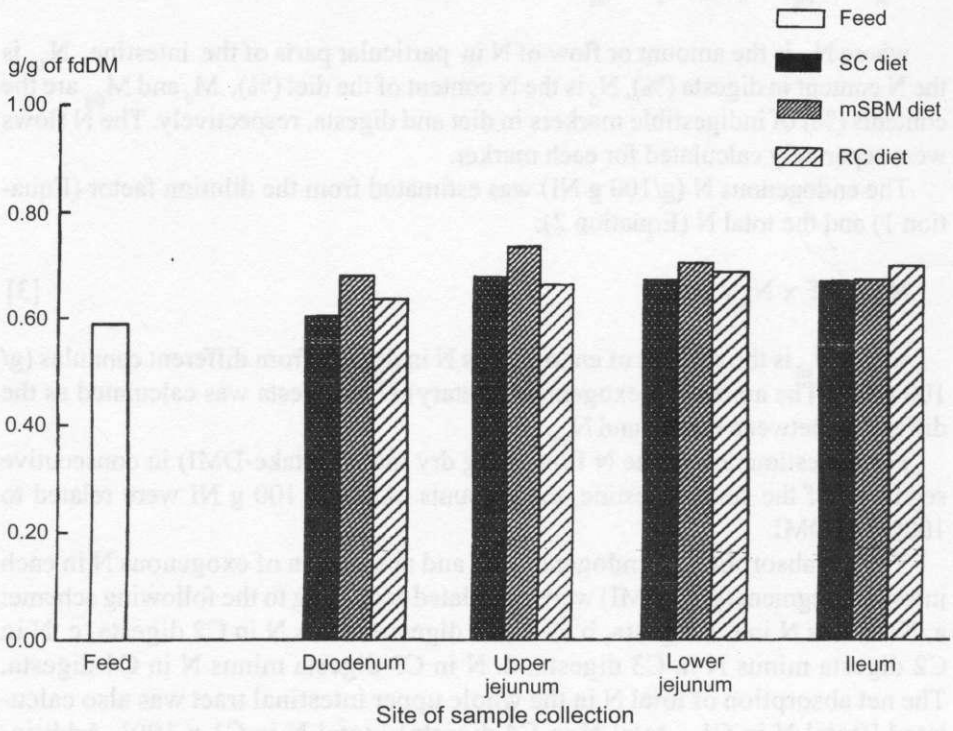

Figure 1. Chromium to cobalt ratios in different segments of the small intestine in pigs fed diets with soyabean concentrate (SC), a mixture of toasted and untoasted soyabean meal (mSBM) or rapeseed cake (RC)

^{15}N-enrichment of blood plasma and digesta

The background ^{15}N-enrichment of the N in the TCA-soluble blood plasma and the diets was 0.3651 and 0.3647, respectively. The mean ^{15}N-enrichment excesses of the N in blood plasma ranged from 0.0379 (±0.0093) at % for C4 to 0.0389 (±0.082) at % for C3 (Table 5). The highest ^{15}N-enrichment excess of the N in digesta was found for the SC and RC diets in C3 while for the mSBM diet, the highest ^{15}N-enrichment excess was in N of digesta from C4.

The highest proportion of endogenous N to total N was estimated in digesta from C3 of pigs fed the SC and RC diet while those fed the mSBM diet had the highest proportion of endogenous N to total N in C4. The lowest dilution factor for each diet was found in duodenal digesta (C1).

TABLE 5

^{15}N-enrichment excess (at. %)[1,2] in the trichloroacetic acid-soluble blood plasma and in digesta collected from different segments of the small intestine in pigs fed diets with soyabean concentrate (SC), a mixture of toasted and untoasted soyabean meal (mSBM) or rapeseed cake (RC)

	Diet		
Item	SC	mSBM	RC
Duodenum	[n=3]	[n=2]	[n=2]
Blood plasma[3]		0.0389 ± 0.0082	
Digesta	0.0152 ± 0.0013	0.0129 ± 0.0018	0.0109 ± 0.0026
Dilution factor[4], %	39.0 ± 0.4	33.1 ± 3.1	27.9 ± 1.8
Upper jejunum	[n=2]	[n=1]	[n=1]
Blood plasma		0.0381 ± 0.0043	
Digesta	0.0215 ± 0.0006	0.0135	0.0168
Dilution factor, %	56.3 ± 1.4	35.4	43.9
Lower jejunum	[n=2]	[n=1]	[n=1]
Blood plasma		0.0383 ± 0.0085	
Digesta	0.0289 ± 0.0043	0.0208	0.0221
Dilution factor, %	75.5 ± 0.1	54.3	57.7
Terminal ileum	[n=3]	[n=3]	[n=3]
Blood plasma		0.0379 ± 0.0093	
Digesta	0.0281 ± 0.0025	0.0237± 0.0009	0.0173 ± 0.0029
Dilution factor, %	74.1 ± 5.8	62.6 ± 2.8	45.6 ± 3.3

[1] values represent means (±SD) when number observations is n > 2

[2] the background ^{15}N-enrichment of the N in the TCA-soluble blood plasma and feed were 0.3651 and 0.3647, respectively

[3] mean value for three diets (n = 7 for C1; n = 4 for C2; n = 5 for C3 and n = 9 for C4)

[4] dilution factor = ^{15}N-enrichment excess in digesta / ^{15}N-enrichment excess in blood plasma x 100

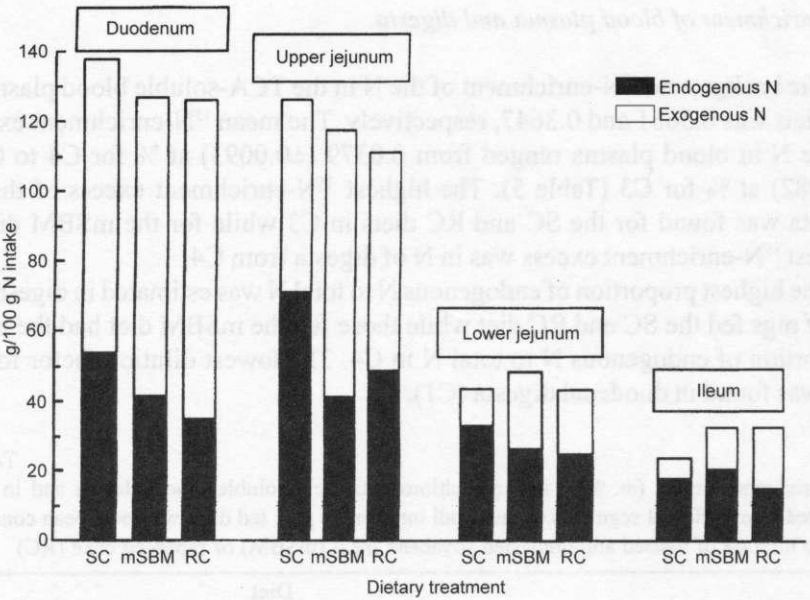

Figure 2. Amounts of total N, endogenous N and exogenous N (g/100 g N intake) in different segments of the small intestine in pigs fed diets with soyabean concentrate (SC), a mixture of toasted and untoasted soyabean meal (mSBM) or rapeseed cake (RC)

Nitrogen content in digesta

The content of total N in duodenal digesta (C1) was 138, 127 and 126 g/100 g NI, for the SC, mSBM and RC diet, respectively (Figure 2). The endogenous N content for the SC and RC diet was higher in digesta from the upper jejunum (C2) than in digesta from C1, but similar to that for the mSBM diet. At the same time, the total N content decreased as compared with the C1 digesta, because the exogenous N content of the C2 digesta was greater by 26, 17 and 11 g/100 g NI, respectively, than the ingested N amounts.

In the more distal segments of the small intestine the amount of total N declined progressively with the greatest difference between C3 and C2. This difference resulted mainly from a decrease in the exogenous N contents. The greatest successive decrease in the contents of endogenous and exogenous N was determined in the digesta of pigs fed the SC diet, while the lowest decrease was found in pigs fed the mSBM diet. Pigs fed the latter diet had a greater content of endogenous N of digesta at the terminal ileum (C4) than those fed the SC and RC diets (21, 18 and 15 g/100 g NI). It was shown that pigs fed the SC diet had the lowest exogenous N content of the C4 digesta, in comparison with pigs fed the mSBM and RC diets (6, 12 and 18 g/100 g NI, respectively).

Nitrogen flow in different segments of the small intestine

Nitrogen flow (g/kg DMI) and absorption rates of N (%) in different intestinal segments are presented in Table 6. In general, the amount of the endogenous N found in duodenal digesta (C1) was similar for all diets (9.4-11.6 g/kg DMI). Ten to 16% of the ingested dietary N (20.7-27.7 g/kg DMI) was already absorbed up to

TABLE 6

Flow of endogenous and exogenous N and its net absorption (g/kg DMI)[1] in different segments of the small intestine in pigs fed diets with soyabean concentrate (SC), a mixture of toasted and untoasted soyabean meal (mSBM) or rapeseed cake (RC)

Item	Diet								
	SC			mSBM			RC		
	endogenous N	exogenous N	total N	endogenous N	exogenous N	total N	endogenous N	exogenous N	total N
N intake (NI)	–	20.7	–	–	27.7	–	–	26.8	–
Duodenum		[n=3]			[n=2]			[n=2]	
N secretion	11.1	–	–	11.6	–	–	9.4	–	–
N inflow	11.1	20.7	31.8	11.6	27.7	39.3	9.4	26.8	36.2
N outflow	11.1	17.4	28.5	11.6	23.5	35.1	9.4	24.2	33.6
Net absorption[2]	0	3.3	3.3	0	4.2	4.2	0	2.6	2.6
Absorption NI→C1[3], %	–	16	10	–	15	11	–	10	7
Upper jejunum		[n=2]			[n=1]			[n=1]	
N inflow	11.1	17.4	28.5	11.6	23.5	35.1	9.4	24.2	33.6
N outflow	14.7	11.4	26.1	11.5	21.0	32.5	13.1	16.7	29.8
Net absorption	-3.6	6.0	2.4	0.1	2.5	2.6	-3.7	7.5	3.8
Absorption C1→C2 [3], %	-32	34	8	1	11	7	-39	31	11
Lower jejunum		[n=2]			[n=1]			[n=1]	
N inflow	14.7	11.4	26.1	11.5	21.0	32.5	13.1	16.7	29.8
N outflow	6.8	2.2	9.0	7.1	6.0	13.1	6.7	4.9	11.6
Net absorption	7.9	9.2	17.1	4.4	15.0	19.4	6.4	11.8	18.2
Absorption C2→C3[3], %	54	81	66	38	71	60	49	71	61
Terminal ileum		[n=3]			[n=3]			[n=3]	
N inflow	6.8	2.2	9.0	7.1	6.0	13.1	6.7	4.9	11.6
N outflow	3.7	1.2	4.9	5.7	3.4	9.1	4.0	4.7	8.7
Net absorption	3.1	1.0	4.1	1.4	2.6	4.0	2.7	0.2	2.9
Absorption C3→C4 [3], %	46	45	46	20	43	31	40	4	25
Absorption C1/2→C4[4], %	75	–	83	51	–	74	69	–	74
Digestibility NI→C4[5], %	–	94	76	–	88	67	–	82	67

[1] values represent means when number observations are n ≥ 2

[2] calculated as N inflow – N outflow

[3] for each intestinal segment calculated as net absorption / N inflow x 100

[4] absorption of endogenous N calculated as $(C1/2_{N/\ outflow} - C4_{N/\ outflow}) / C1/2_{N/\ outflow} \times 100$; absorption of total N calculated as $(C1_{N\ /outflow} - C4_{N/\ outflow}) / C1_{N/\ outflow} \times 100$

[5] digestibility of exogenous N (true) and of total N (apparent) was calculated as $(NI - C4_{N/\ outflow}) / NI \times 100$

the duodenal cannula. The endogenous N estimated in the upper jejunum digesta (C2) of pigs fed the SC and RC diets was 3.6-3.7 g/kg DMI higher than in duodenal digesta. Pigs fed the mSBM diet had similar endogenous N flows between the duodenum and upper jejunum. The absorption of exogenous N was 31-34% in the upper jejunum of pigs fed on SC and RS diets, while it was only 11% for pigs on mSBM diet. The absorption of both endogenous and exogenous N in the lower jejunum (C3) was higher for pigs fed the SC diet than for those fed the mSBM and RC diets. In the last segment of the small intestine (lower jejunum → terminal ileum) absorption of endogenous N was similar for the SC and RC diets (40-46% of the inflow) and lower (20% of the inflow) for the mSBM diet. It was shown that the absorption of exogenous N was 43-46% of the inflow for the SC and mSBM diets while only 4% of the inflow for the RC diet.

Net absorption of total N in the small intestine (duodenum → terminal ileum), was 83, 74 and 74% for the SC, mSBM and RC diet, respectively. Apparent ileal N digestibilities were 76, 67 and 67%, respectively. Total absorption of exogenous N, which is equal to the true ileal N digestibility, was 94, 88 and 82% for corresponding diets. The net reabsorption of endogenous N in the small intestine was 75% for the SC diet, 69% for the RC diet (in both diets estimated for the upper jejunum → ileum), and 51% for the mSBM diet (estimated for the duodenum → ileum).

DISCUSSION

Duodenum

The total N exceeded the N intake by 26-27% (6.8-7.4 g N/kg DMI) in the duodenum of pigs fed the mSBM and RC diets and 38% (7.8 g N/kg DMI) in those fed SC diet. Żebrowska et al. (1982, 1992) and Krawielitzki et al. (1996) reported that the amount of total N in the duodenum of pigs fed diets with various protein sources exceeded the intake by 12 to 20% (3.6-6.7 g N/kg DMI). The higher amounts of total N in duodenum compared with N intake were caused by secretion of endogenous N from such sources as saliva, gastric juice, bile and pancreatic juice (Low and Żebrowska, 1989). In absolute values, assuming no reabsorption of endogenous N in the proximal gastro-intestinal tract (GIT), these sources may contribute to a total of about 6 to 13 g of N/d up to the middle duodenum (Souffrant, 1991). In earlier studies with re-entrant cannulated pigs the flow of endogenous N in duodenal digesta, estimated as the difference between the total N passing duodenum and N intake, was about 7 g/d in pigs fed the casein-based diet (Żebrowska and Buraczewska, 1972) to 14 g/d in pigs fed soyabean meal-based diet (Buraczewska et al., 1975).

In the present study, the use of diets with different protein sources did not influence markedly the flow of endogenous N in the duodenal digesta (range of 9.4 to 11.6 g N/kg DMI). It seems, as far as pancreatic protein secretion is concerned, the different dietary N contents did not affect the amount of secreted endogenous N in pigs. These findings are in agreement with the data of Li et al. (1997).

Ten to 16% of the ingested N was already absorbed up to the middle duodenum. Krawielitzki et al. (1996) using the ^{15}N-isotope dilution technique for the labeling of endogenous N, reported that 8.8 g N/kg DMI of endogenous N was secreted and 14% of ingested N was absorbed in the proximal part of GIT in 30-kg pigs fed wheat and meat-bone meal based diet. Also other studies suggest that part of exogenous N may already be absorbed in the stomach and the anterior duodenum (Żebrowska et al., 1983; Low and Żebrowska, 1989).

Upper jejunum

In the consecutive segments of the small intestine, the flow of both endogenous and exogenous N showed considerable variation among treatments. The flow of endogenous N in the upper jejunum tended to be higher than in the duodenum for the SC and RC diets, while it was as high as in the duodenum for the mSBM. Although the results for the mSBM and RC diets are based on one observation only, they support findings that the amount of endogenous N secreted in the intestinal juices of the upper segment of the small intestine exceeds, or at least equals, the N amount secreted up to the duodenum (Buraczewska, 1979; Simon and Żebrowska 1988; Souffrant, 1991). In this segment (duodenum → upper jejunum) intensive secretion of endogenous N and protein digestion occurs (Low and Żebrowska, 1989) while absorption is limited at this site (Buraczewska, 1981).

The tendency to lower absorption of exogenous N in pigs fed the mSBM diet, compared with the other two treatments, may be an effect of a lower protein digestion affected by a high TI activity.

Lower jejunum

The results of the N flow from the upper jejunum to the lower jejunum (middle part) are in agreement with findings of Buraczewska et al. (1975) and Buraczewska (1981) that this segment of the small intestine plays a dominant role in absorption of nitrogenous compounds. Among the tested diets, the highest absorption of exogenous N (about 80%) was estimated for the SC diet that contained highly soluble dietary protein and low TIA. Also, the absorption of endogenous N was the highest for this diet. Nevertheless, the 70-percentage absorption of exogenous N estimated for the high TIA diet (mSBM), may suggest that there was sufficient enzyme activity for protein digestion in this part of the small intestine. According to Partridge et

al. (1982), synthesis and secretion of proteolytic enzymes exceeds the amounts needed to digest dietary protein. Yen et al. (1977) and Żebrowska et al. (1985) showed that the use of raw soyabean, or soyabean TI, does not affect the activity of enzymes in pancreatic juice. Schulze et al. (1993) reported a 30-50-percent (not significant) decrease in secretion of trypsin and chymotrypsin in pigs fed a diet with a high inclusion of purified soyabean TI. The absorption of endogenous N was the lowest in pigs fed the mSBM diet. Pigs fed the RC diet had similar endogenous N absorption to those fed the SC diet.

Terminal jejunum and ileum

In general, relative enrichments of N with ^{15}N and the estimated amounts of both exogenous and endogenous N for the ileal digesta were within the range of values previously reported for the same feedstuffs (Grala et al., 1997a,b, unpublished data; Grala et al., 1998).

In pigs fed the SC and mSBM diets the percentage of absorption of exogenous N from the last part of the small intestine was similar, while pigs fed the RC diet had very low absorption in this segment of GIT. Previous results showed that the low digestibility of rapeseed protein is caused by very low digestibility of protein (only 26%) in the hull fraction (Grala et al. 1997a, unpublished data; Grala et al., 1998). Moreover, most of the hull N is of non-protein origin and is strongly bound to the fibrous fraction. This N is hardly digested in the small intestine because digestive enzymes have restricted access to both the cell wall components and the enclosed cell contents. Additionally, rapeseed carbohydrates (hemicellulose, cellulose, pectin) and lignin may adsorb AA released during protein hydrolysis (Bell, 1984). As a result, more AA of both endogenous and exogenous origin pass into the large intestine.

In pigs fed the mSBM diet only 20% of endogenous N was absorbed in the last segment of the small intestine. Such low absorption may be associated with TI that can form stable complexes with the pancreatic enzymes. In this way they are withdrawn from absorption (Liener and Kakade, 1980).

Total digestion and absorption of endogenous and exogenous nitrogen in the small intestine

The true and apparent ileal digestibilities of exogenous N of the diets, with the exception of the SC diet, were within the range of previously reported values for the same feedstuffs (Grala et al., 1997a,b, unpublished data; Grala et al., 1998).

Net absorption of total N at the terminal ileum was 83, 74 and 74% of intake for the SC, mSBM and RC diets, respectively. The net reabsorption of endogenous N was estimated as 75, 51 and 69% for the corresponding diets. The value estimated

for the SC diet is very close to the results (70-79%) reported by other authors for highly digestible protein sources with low levels of ANF (Souffrant et al., 1986, 1993; Żebrowska et al., 1992; Krawielitzki et al., 1996). Since the other two values from the present study are below the range given above, this may indicate a specific effect of protein sources on the reabsorption rate of endogenous N in the small intestine.

The results of the present study suggest that soyabean concentrate, a mixture of toasted and untoasted soyabean meal, and rapeseed cake cause a different reabsorption of endogenous N up to the end of the small intestine.

CONCLUSIONS

Regardless of the dietary protein source fed to pigs, the middle segment of the small intestine is the most intense site of endogenous and exogenous N absorption in the pig. The flow of both endogenous and exogenous nitrogen along the small intestine depended on the protein source. It seems that reabsorption rather than secretion of endogenous nitrogen along the small intestine of the pig is influenced by different dietary factors.

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STRESZCZENIE

Przepływ endogennego i egzogennego azotu w różnych odcinkach jelita cienkiego u świń, karmionych paszami zawierającymi koncentrat sojowy, śrutę sojową lub wytłok rzepakowy

W doświadczeniu użyto 6 wieprzków o początkowej masie ciała 27,5±1,2 kg. Każde zwierzę zaopatrzono w 2 kaniule umieszczone w różnych częściach jelita cienkiego. Założono łącznie 12 kaniul, z czego 3 w dwunastnicy (C1), 3 w początkowej części jelita czczego (C2), 3 w końcowej części jelita czczego (C3) oraz 3 przy końcu jelita biodrowego (C4). Rozmieszczenie par kaniul pozwalało na zbadanie przepływu oraz wchłaniania N endogennego (Ed-N) i egzogennego (Ex-N) w poszczególnych odcinkach jelita cienkiego. Zwierzęta miały założone katetery do żyły szyjnej zewnętrznej celem pobierania próbek krwi i do tętnicy szyjnej wspólnej użytej do ciągłej infuzji ^{15}N-leucyny (4.2 mg/kg$^{0.75}$/dobę). Doświadczenie przeprowadzono w układzie przemiennym w 3 okresach po 12 dni; w ostatnich 72 godz. każdego okresu pobierano treść pokarmową i próbki krwi. Diety doświadczalne zawierały: koncentrat sojowy (SC), mieszankę tostowanej i nietostowanej poekstrakcyjnej śruty sojowej (mSBM) z dużą zawartością inhibitora trypsyny, wytłok rzepakowy (RC) z dużą zawartością NDF oraz skrobię kukurydzianą i dodatki witaminowo-mineralne.

W treści pokarmowej dwunastnicy świń (C1) karmionych dietami SC, mSBM i RC, N ogólny stanowił odpowiednio 138, 127 i 126% N pobranego; w odcinku przed kaniulą C1 zostało wchłonięte 16, 15, i 10% N pobranego, natomiast wydzielanie wynosiło odpowiednio 11,1, 11,6 i 9,4g Ed-N, w przeliczeniu na kg pobranej suchej masy paszy. Dla wyżej wymienionych diet, w treści pokarmowej z kaniuli C2, N ogólny wynosił odpowiednio 126, 117 i 111% N pobranego, uległo wchłonięciu 34, 11 i 31% Ex-N przepływającego przez kaniulę C1 oraz nastąpiło dalsze zwiększenie puli Ed-N przy żywieniu dietami SC i RC. W treści pokarmowej końcowej części jelita czczego (C3), N ogólny stanowił odpowiednio 44, 47 i 43% N pobranego. W porównaniu z przepływem N w C2, w dalszej części jelita czczego uległo wchłonięciu 81, 71 i 71% Ex-N oraz 54, 38 i 49% Ed-N, odpowiednio przy żywieniu dietami SC, mSBM i RC. Przy końcu jelita cienkiego (C4), przepływ N ogólnego stanowił odpowiednio 24, 33 i 33% N pobranego, a strawność rzeczywista wynosiła 94, 88 i 82%. Stopień wchłaniania zwrotnego Ed-N w jelicie cienkim oszacowano na 75, 51 i 69%, przy żywieniu odpowiednio SC, mSBM i RC.

Stwierdzono, że niezależnie od źródła białka w diecie, środkowa część jelita cienkiego jest miejscem największego wchłaniania Ed-N i Ex-N. Wydaje się, że w jelicie cienkim u świni czynniki żywieniowe (inhibitor trypsyny, włókno) mogą wpływać bardziej na wchłanianie zwrotne Ed-N niż na jego wydzielanie.