Effects of different dietary threonine levels on growth and slaughter performance in finishing pigs

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ABSTRACT: The objective of this study was to determine the threonine (Thr) requirement of a modern crossbred growing pig from Austria in the finisher stage (67 to 113 kg body weight). For on average 50 days, 30 castrated male and 30 female pigs were fed isonitrogenous diets (135 g/kg crude protein, 8.0 g/kg lysine) supplemented with increasing levels of crystalline Thr. Total dietary Thr contents (g/kg) were 4.9 (basal diet), 5.0, 5.4, 5.8, 6.1, 6.5, corresponding to a Thr:Lys ratio of about 0.60, 0.64, 0.68, 0.73, 0.76, 0.81. Dietary Thr concentration of 5.4 g/kg improved daily gains by about 15 percentage points ($P < 0.05$) and the feed conversion ratio by about 7 percentage points, compared to pigs fed the basal diet (4.9 g/kg Thr). Increasing dietary Thr above 5.4 g/kg had no further effects on performance. The blood plasma urea concentration was minimized at a dietary Thr concentration of 6.1 g/kg. For all treatments there was a low effect of dietary Thr supply on carcass quality. Goblet cell density in the small intestine and colon did not differ between different levels of dietary Thr. Based on the results of growth performance, an optimum total dietary Thr:Lys ratio in the finisher stage of pigs ranges from 0.66 to 0.68.

Keywords: threonine; pigs; urea; goblet cell; requirement

The optimal dietary supply of amino acids to growing pigs has been intensively studied for many years. The ideal ratios of threonine (Thr), tryptophan (Trp) and sulphur amino acids (SAA) relative to lysine (Lys) are reported (Lys = 100) to be about 142, 29 and 150% for maintenance, and about 69, 18 and 53% for protein accretion (Fuller and Wang, 1987). Because of different requirements for maintenance and production, for some amino acids the ratio relative to Lys is assumed to increase with increasing body weight. Mainly Thr has important functions in the gut and hence the Thr requirement increases with higher live weights of growing pigs (Stoll et al., 1998). Therefore, the ideal amino acid ratios for Thr rise from 65% of lysine for 5–20 kg live weight to 70% of Lys for 50–100 kg live weight (Van Lunen, 2001). This implies different amino acid requirements for different body weights. Current requirement estimates for the optimum Lys:Thr ratio in finishing pigs range from 1 to 0.60 (GfE, 1987) to 1:0.68 (NRC, 1998). In a previous study (Plitzner et al., 2006) with modern crossbred finishing pigs (68–113 kg) the total dietary Thr:Lys ratio was estimated to be 0.65 or higher. In this study, however, the highest growth performance was observed at the highest Thr supplies, but unfortunately neither the breakpoint nor the plateau could be identified by means of regression.

In this context the aim of the present study was to determine the Thr requirement of finishing pigs

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on the basis of a wider range of dietary Thr supply (4.9 to 6.5 g/kg). Furthermore, a morphological analysis of the gut tissue was conducted since Thr supply is considered to contribute significantly to the protein metabolism of the gut tissue (Stoll et al., 1998). Given that intestinal mucins, which are rich especially in Thr (Lien et al., 1997), are synthesized and secreted from goblet cells (Ball et al., 1999), the goblet cell density should be evaluated in the present study as a potential response criterion to a varying dietary Thr supply.

MATERIAL AND METHODS

Animals and housing

The study involved a total of 60 finishing Austrian crossbred (OEHYB) pigs. The animals arrived at the experimental station (Austrian Pig Testing Facility, Streitdorf) with an average body weight of 30 kg and were distributed equally among 12 pens of 5 animals each (2 pens of 5 pigs per experimental group) considering sex (5 castrated male and 5 female pigs per group), litter, and body weight. The pigs were housed in a fully air-conditioned piggery at a room temperature of 20–22°C. Each pen was equipped with an automatic dry-feeding system and a nipple drinking system.

Diets and feeding

During the first 10 days of adaptation period, animals received a common medicated diet (H 427 MED., Hofer KG, Austria) for prophylaxis. Subsequently, all animals were fed a grower diet mainly based on maize, extracted soybean meal and barley (Table 1) providing all nutrients according to current recommendations (GfE, 1987) until the

Table 1. Composition of grower and finisher diet

Component	Grower diet	Finisher diet
Maize (%)	33.8	30.3
Soybean meal, extracted (%)	19.5	10.3
Barley (%)	20.0	14.0
Oil[1] (%)	2.0	0.5
Wheat bran (%)	5.0	4.0
Wheat (%)	16.0	37.5
Mineral and vitamin supplement (%)	3.35[2]	3.13[3]
L-lysine (%)	0.28	0.28
DL-methionine (%)	0.05	0.04
L-threonine (%)	0.08	–
L-tryptophan (%)	0.01	0.02
Calculated nutrients		
ME (MJ/kg)	13.3	13.4
Crude protein (g/kg)	17.8	135
Ether extracts (g/kg)	4.6	31
Crude fibre (g/kg)	3.5	31
Lys (total) (g/kg)	10.5	8.2
Met (total) (g/kg)	6.6	5.5
Thr (total) (g/kg)	7.0	4.5
Trp (total) (g/kg)	2.2	1.8

[1]composition: 8% soybean oil, 14% palm-oil fatty acid, 78% as a mixture of soybean oil, sun flower oil and rapeseed oil
[2]providing the following per kg of diet: 8.9 g Ca, 6.3 g P, 1.65 g Na, 1.55 g Mg, 9.59 mg Cu, 129 mg Fe, 3.63 mg J, 38 mg Mn, 0.42 mg Se, 80 mg Zn, 12 000 IU vitamin A, 2 000 IU vitamin D_3, 336 mg vitamin E, 1.2 mg vitamin K_3, 4.0 mg vitamin B_1, 4.1 mg vitamin B_2, 4.3 mg vitamin B_6, 18 µg vitamin B_{12}, 51 mg nicotinic acid, 21 mg pantothenic acid, 1 529 µg folic acid, 870 mg choline chloride, 229 µg biotin
[3]providing the following per kg of diet: 8.1 g Ca, 6.0 g P, 1.55 g Na, 1.84 g Mg, 8.0 mg Cu, 37 mg Mn, 0.41 mg Se, 77 mg Zn, 12 000 IU vitamin A, 2 000 IU vitamin D_3, 88 mg vitamin E

Table 2. Analysed chemical composition of finisher diets

Nutrients (g/kg feed)	Treatment					
	1	2	3	4	5	6
Dry matter	899	889	894	888	889	899
Crude protein	141	138	136	137	137	137
Ether extracts	31	30	30	31	31	32
Crude fibre	43	34	31	29	29	33
Ash	74	53	48	49	48	50
Starch	483	502	513	508	511	513
Sugar	39	37	37	34	33	33
ME[1] (MJ/kg)	13.3	13.6	13.8	13.7	13.7	13.8
Amino acids (total g/kg feed)						
Lys	8.2	7.8	7.9	8.0	8.0	8.0
Thr	4.9	5.0	5.4	5.8	6.1	6.5
Met	2.5	2.5	2.4	2.5	2.4	2.5
Cys	2.5	2.4	2.4	2.4	2.5	2.4
Met+Cys	5.0	4.9	4.8	4.9	4.9	4.9
Try	2.02	1.84	1.86	1.83	1.86	1.85
Lys:Thr	0.60	0.64	0.68	0.73	0.76	0.81

[1]calculated according to GfE (1987)

start of the experiment. Pelleted feed and water were provided *ad libitum*.

The feeding experiment started when animals of each pen reached on average 67 (± 6.4) kg body weight. The feed was switched to six pelleted experimental finisher diets which were based on the same components as the grower diet. Animals of the first treatment group received a basal diet containing 135 g/kg crude protein and 4.9 g/kg Thr (Table 2). The basal diet was deficient in Thr compared to current recommendations (NRC, 1998). For animals fed the remaining diets, the basal diet was supplemented with graded levels of L-Thr with analysed Thr concentrations of 5.0, 5.4, 5.8, 6.1 and 6.5 g/kg, respectively. For all diets, L-Lys × HCl was added to give an adequate Lys supply of 0.61 g Lys/MJ ME (Rademacher et al., 2001).DL-Met and L-Trp were supplemented at a ratio of Lys:Met + Cys:Trp of 1:0.67:0.22 according to the concept of the ideal protein (Rademacher et al., 2001). Calculated energy and CP content were 13.4 MJ ME/kg and 135 g/kg, respectively.

The six dietary treatments were equally distributed among the 12 pens. Feed intake of each animal was registered and recorded daily by a transponder system. Individual body weight was recorded weekly. During the growing phase, one pig was lost (6.5 g Thr/kg diet) due to pneumonia and two pigs (5.8 g Thr/kg diet) were excluded due to insufficient growth.

Sampling and chemical analyses

The animals were slaughtered under standardized conditions in a slaughter-house of the Pig Testing Facility when the individual body weight of animals reached 113 kg. Slaughters took place once a week after feed withdrawal for 12 h. Blood samples were taken during slaughter. Blood plasma was separated immediately by centrifugation. Carcass characteristics and meat quality parameters were assessed according to the guidelines of the Austrian Pig Testing Facility at the day of slaughter and at the following day.

Organ samples were taken immediately after slaughter. The small intestine (duodenum and jejunum, excl. ileum) was dissected and divided into eight segments of the same length. From each segment, samples were taken for determination of goblet cell density. Additionally, three samples from the colon (flexura centralis) were taken. All samples were fixed in 4% buffered paraformaldehyde and embedded in paraffin wax.

All diets were analysed for dry matter (DM), crude protein (CP), crude fibre (CF), ether extracts

(EE), ash, starch and sugar (Table 2) according to standard methods (Naumann and Bassler, 1997). Concentration of metabolisable energy (ME) was calculated according to GfE (1987). The amino acid composition of finisher diets was analysed according to Naumann and Bassler (1997). The blood plasma urea concentration was measured using a commercial test kit (R-Biopharm, Darmstadt, Germany).

To determine the goblet cell density samples from the intestine of each of the five representative animals from Thr levels 4.9, 5.0, 5.8 and 6.1 g Thr/kg diet were selected. These Thr levels were chosen to cover the range slightly below and above the suggested Thr requirement, but not to cover the range of Thr oversupply. Morphological samples were analysed quantitatively for the goblet cell density using stereology. For this purpose, the paraffin embedded tissue from each segment (11/animal) was cut at a thickness of 3 µm. Sections were mounted on glass slides and stained for mucopolysaccharides using a Periodic Acid Schiff (PAS) staining protocol. Slides were deparaffinized (Limonen > 96%, SAV LP, Feldkirchen-Westerham, Germany), hydrated in graded alcohol and water and oxidized in a 0.75% periodic acid solution for 8 min. Then they were rinsed and placed into Schiff reagent (0.5 g pararosanilin, 0.5 g potassium disulphide, 15 ml 1N HCl in 100 ml water) for 20 min, rinsed again and passed through water containing 0.6 g sodium disulphide and 5 ml 1 N HCl per 100 ml (3 × 3 min). After counterstaining with Gill's haematoxylin, slides were rinsed, dehydrated and mounted with a cover slip. The density of mucus-producing goblet cells in the mucosa was determined with a light microscope using a system for semiquantitative image analysis.

Statistical analysis

The GLM procedure of SAS (SAS, 2002) was used to determine treatment effects by analysis of variance (ANOVA) using a randomized complete block design. The treatments were included in a two-factor arrangement to test the effect of dietary concentration of Thr, sex and interaction of Thr × sex. The initial body weights were used as covariates for the analysis of growth performance. Means of each treatment were compared by Student-Newman-Keul's test for each variable. The tables present the mean values of the different Thr levels and the pooled standard error of the mean (SEM) derived from the analysis of variance. Significant differences between means ($P < 0.05$) are indicated by superscripts.

A broken line and a quadratic regression procedure with means for treatments were used to determine the Thr requirement of pigs. The models were fitted to the experimental data using SAS (2002). The coefficient of determination (R^2) was used to assess the goodness of fit for the model.

RESULTS

As shown in Table 3, growth performance was influenced by dietary Thr concentration. Increasing dietary Thr from 4.9 or 5.0 to 5.4 g/kg improved daily gains by about 15 and 11 percentage points ($P < 0.05$), respectively. Further increase of Thr supply from 5.4 up to 6.5 g/kg did not enhance daily gains. As a result of variations in initial body weight among treatment groups and differences in daily gains, time to reach the desired end weight (days on experiment) tended to be shorter (1 to

Table 3. Growth performance and blood plasma urea concentration

Dietary threonine (g/kg feed)	4.9	5.0	5.4	5.8	6.1	6.5	SEM
Treatment	1	2	3	4	5	6	
Number of pigs (*n*)	10	10	10	8	10	9	–
Days on experiment (day)	49.2	50.0	46.5	52.6	47.2	51.6	8.2
Initial weight (kg)	68.0	66.2	66.5	65.4	68.0	65.3	6.4
Final weight (kg)	111.4	112.3	113.4	113.8	113.0	114.9	2.8
Daily growth rate (g)	890^{b}	923^{b}	1 025^{a}	936^{b}	964^{ab}	974^{ab}	94
Daily feed intake (g/day)	2 557^{ab}	2 596^{ab}	2 740^{a}	2 506^{b}	2 633^{ab}	2 635^{ab}	215
Feed conversion (feed/gain) (g/g)	2.88	2.79	2.68	2.69	2.73	2.70	0.16
Blood plasma urea (mmol/l)	4.16	4.11	4.09	3.88	3.49	4.41	1.17

^{a,b,c}means of the same parameter without common superscripts differ at $P < 0.05$

Table 4. Carcass measurements

Dietary threonine (g/kg feed)	4.9	5.0	5.4	5.8	6.1	6.5	SEM
Treatment	1	2	3	4	5	6	
Dressing percentage[1] (%)	81.2[ab]	80.2[b]	81.7[a]	81.5[ab]	81.5[ab]	81.2[ab]	1.00
Lean (%)	59	57	57	57	57	57	2.31
Backfat depth 13/14th rib (mm)	22.7	24.1	25.1	24.4	24.0	23.8	2.51
Meat thickness (mm)	76.7	76.3	75.8	76.4	77.4	75.8	4.08
Longissimus muscle area (cm²)	60.0	57.7	60.4	58.9	61.0	56.8	4.97
Longissimus fat area (cm²)	15.1	16.8	17.3	17.3	17.7	17.3	2.69
Loin ph, 60 min	6.10	6.01	5.98	6.02	5.98	6.14	0.19
Ham ph, 60 min	6.31	6.05	6.20	6.12	6.17	6.29	0.35
Loin conductivity, 60 min[3] (mS/cm)	4.58	3.86	4.57	4.26	4.74	4.19	1.09
Ham conductivity, 60 min[3] (mS/cm)	4.10	4.95	4.25	4.51	4.57	4.69	1.63
Loin conductivity, 24 h[4] (mS/cm)	5.15	4.85	5.65	6.02	6.54	4.99	1.68
Ham conductivity, 24 h[4] (mS/cm)	8.53	8.36	8.52	9.56	8.96	7.97	2.76
Loin lightness (U)[5]	59.6	57.1	55.0	55.4	56.4	57.3	4.99
Drip loss[6] (%)	7.6	7.3	8.8	8.4	8.3	6.9	2.90
Intramuscular fat (%)	0.98[b]	1.18[ab]	1.36[a]	1.19[ab]	1.14[ab]	1.46[a]	0.28

[a,b,c]means of the same parameter without common superscripts are statistically different
[1]weight of warm carcass expressed as a percentage of slaughter weight
[2]optimum: ph >6.0
[3]optimum: loin and ham conductivity < 5.0 mS/cm
[4]optimum: loin and ham conductivity < 8.0 mS/cm
[5]Göttinger Farbhelligkeitsmesser < 45 U = PSE > 80 U = DFD (U = units)
[6]optimum: drip loss 3 to 5%

6 days) in treatment 3 (5.4 g Thr/kg) compared to the remaining groups. Comparable to daily gains, there was no clear dose-response relationship between Thr supply and daily feed intake. Daily feed intake of 2 740 g/day in treatment 3 (5.4 g Thr/kg) was higher ($P < 0.05$) than in treatment 4 (2 506 g/day), whereas the remaining groups showed intermediate daily feed intake. Compared to pigs fed diets containing 4.9 or 5.0 g Thr/kg feed, the feed to gain ratio of treatment 3 (5.4 g Thr/kg) was numerically improved by about 7 and 4 percentage points. Pigs of other treatment groups had intermediate feed to gain ratios.

Treatment differences in plasma urea concentrations were obvious but not significant. The lowest plasma urea concentration of 3.5 mmol/l was observed at 6.1 g Thr/kg and the highest plasma urea concentration of 4.4 mmol/l at 6.5 g Thr/kg.

Carcass characteristics are shown in Table 4. For all treatment groups a high dressing percentage (on average 81%) was observed. Pigs fed the diet containing 5.4 g Thr/kg showed higher ($P < 0.05$) dressing percentage (81.7%) than pigs fed the diet containing 5.0 g Thr/kg (80.2%). Moreover, good carcass quality was observed as characterized by the lean meat percentage of 57% on average and longissimus muscle and fat area of 59.1 and 16.9 cm^2, respectively. Nevertheless, there was no influence of dietary treatment. Regardless of dietary Thr concentration, loin and ham pH value, loin and ham conductivity, loin lightness and drip losses were within the normal range for pigs. The intramuscu-

Table 5. Goblet cell density (% of gut surface) in the small intestine and colon (n = 5 per treatment)

Dietary threonine (g/kg feed)	4.9	5.0	5.8	6.1	SEM
Treatment	1	2	4	5	
Goblet cells in small intestine (%)	12.4	13.0	11.3	13.6	2.0
Goblet cells in colon (%)	29.7	30.8	30.6	30.8	5.8

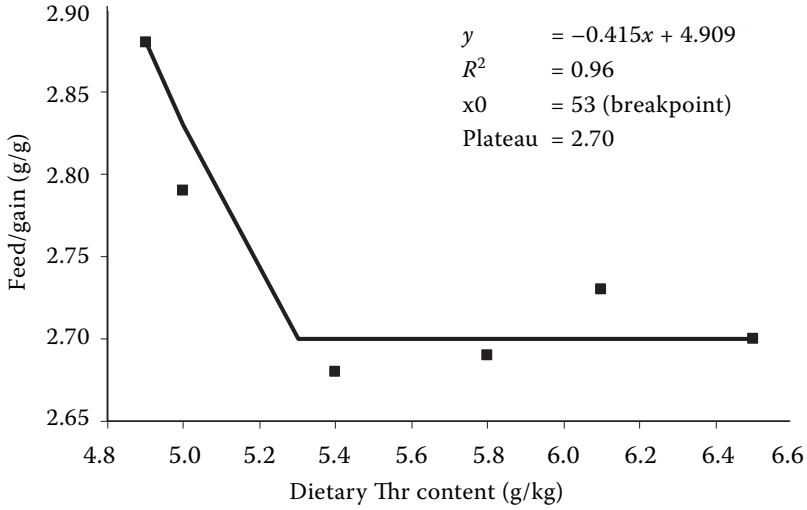

Figure 1. Effect of dietary Thr content on the feed to gain ratio of finishing pigs

lar fat concentration in animals of treatments 3 and 6 was higher ($P < 0.05$) compared to animals of treatment 1.

Goblet cell density in the small intestine and colon did not differ between different levels of dietary threonine supply (Table 5). On average, 13% (small intestine) and 30% (colon) of the intestinal epithelium was covered with goblet cells. There was no significant correlation between individual goblet cell density and zootechnical performance data (for the small intestine and colon:

$r_{\text{daily weight gain}}$ = 0.17 and 0.11;

$r_{\text{daily feed intake}}$ = –0.31 and –0.32;

$r_{\text{feed/gain}}$ = 0.30 and 0.25)

For determination of Thr requirement, feed to gain ratio was the most appropriate parameter. To optimize the feed to gain ratio, regression analysis (Figure 1) indicated an optimum dietary Thr level of 5.3 g/kg diet ($R^2 = 0.96$).

For none of the response criteria an interaction between Thr level and sex was observed. Moreover, the results were similar for female and castrated male pigs. Although it is known that Thr requirements for female and male castrated pigs differ, no separate requirement estimation according to sex was performed for this purpose.

DISCUSSION

Growth performance

One objective of the present study was to determine the Thr requirement of modern crossbred pigs in the finishing stage (67 to 113 kg body weight) using a dose-response approach. Daily growth rate increased ($P < 0.05$) with increasing dietary Thr concentration up to a level of 5.4 g Thr/kg diet, indicating Thr concentrations of 4.9 and 5.0 g/kg (treatment 1 and 2) to be clearly deficient for finishing pigs. Thr supply of 5.8 g/kg, however, did not improve growth over Thr supply of about 5.0 g/kg and decreased growth compared to treatment 3. Because of variations in growth and feed intake at dietary Thr concentrations above 5.4 g/kg, these data did not fit very well to nonlinear or linear regression equations (in the case of daily gains the regression procedure did only approximate estimable values). However, the use of a broken-line model led to requirement estimations of 5.4 (R^2 = 0.64) and 5.3 (R^2 = 0.14) g Thr/kg diet to optimize gain and feed intake. Even if based on regression analysis with a relatively high level of uncertainty, this estimation can serve as a supporting evidence for requirement estimation from data on feed conversion ratio which showed a more pronounced plateau at higher dietary Thr concentrations (Figure 1). Regression analysis using the broken-line model (Robbins et al., 1979) revealed an optimum dietary Thr concentration of 5.3 g/kg for optimizing feed to gain ratio, corresponding to a Thr:Lys ratio of 0.66 (R^2 = 0.96).

An optimum Thr:Lys ratio of about 0.66 to 0.68 in finishing pig diets is in reasonable agreement with current recommendations (NRC, 1998) and previous studies conducted with pigs in the live weight range given in the present study. Plitzner et al. (2006) reported maximum growth rates of pigs from 68 to 110 kg live weight at a Thr:Lys ratio of 0.65. Derivation of Thr requirement using

the feed to gain ratio as a response criterion gave an optimum Thr:Lys ratio of about 0.68. Similarly, the Thr:Lys ratio to optimize feed to gain ratio was estimated to be about 0.65 to 0.68 by Schutte et al. (1997) and 0.67 (using the quadratic method) by Saldana et al. (1994). For optimum growth in boars (65–105 kg live weight), a comparable Thr:Lys ratio of 0.66 (5.7 g Thr/kg diet) was estimated, whereas for gilts a considerably lower optimum Thr:Lys ratio of 0.60 (5.2 g Thr/kg) was derived from data on feed conversion ratio (Lenis et al., 1990). In contrast to literature data (Lenis and van Diepen, 1990; Saldana et al., 1994; Plitzner et al., 2006), requirements estimated from feed to gain ratio in the present study were slightly lower than those estimated from growth data.

Pedersen et al. (2003) used three different parameters to determine the optimal dietary Thr:Lys ratio for finishing pigs (60 to 110 kg body weight): the concentration of blood plasma urea, performance data and data from a nitrogen-balance study. Based on numerical differences in a performance experiment and nitrogen-balance study the optimum Thr:Lys ratio was calculated to be about 0.62 to 0.64. Similarly, Cohen and Tanksley (1977) reported the Thr:Lys ratio in growing pigs (60 to 90 kg body weight) not to be higher than about 0.62. According to the concept that the optimum Thr:Lys ratio is assumed to decrease with increasing body weight, this low estimate of Thr:Lys ratio may result from the low body weight of pigs compared to our study. Nevertheless, Boisen (1997) also concluded from the review of literature that the optimum Thr:Lys ratio for finishing pigs was 0.64 and therefore considerably lower than derived from data of the present study. The Thr:Lys ratio of about 0.66 to 0.68 as derived from growth data in the present study is within the upper range of the literature data (NRC, 1998). Recalculation of data using standardized praecaecal digestibility coefficients for Lys and Thr (GfE, 2006) results in the optimum ratio of praecaecal digestible Thr:Lys of about 0.62 to 0.64. These values agree also with the literature (GfE, 2006).

Urea concentration in the blood plasma

The blood plasma urea concentration can be used as an indicator of protein status in various animal species (Kohn et al., 2005). Once the dietary amino acid pattern differs from the ideal protein, urea synthesis by the animal is increased because some of the amino acids cannot be used for protein synthesis and are therefore utilized for oxidation. Therefore, the blood plasma urea concentration is expected to be minimized at an adequate amino acid supply and may therefore serve as a useful tool to estimate the optimum Thr supply (Coma et al., 1995). In the present study, the blood plasma urea concentration was minimized at a dietary Thr concentration of 6.1 g/kg (Table 3). Assuming a quadratic response, nonlinear regression analysis gives a Thr requirement of 5.7 g/kg ($y = 0.7397x^2 - 8.4625x + 27.9895$; $R^2 = 0.44$) from blood plasma urea concentrations, but, as indicated by the low R-square of 0.44, this estimate seems rather inappropriate. It is known that the plasma urea concentration depends on the time between feeding and blood collection. Given that in the present study blood was taken after several hours of feed withdrawal, this may be an explanation for the discrepancy of requirement estimations based on performance or plasma urea data. Pedersen et al. (2003) observed that the optimum Thr:Lys ratio derived from blood plasma urea concentration was higher than the requirement derived from growth data, but Taylor et al. (1982) and Plitzner et al. (2006) reported the opposite. However, in all those studies the Thr requirement calculated from blood plasma urea differs considerably from the Thr requirement estimated from data on growth performance. In the present study, the blood plasma urea concentration was not minimized in animals with the highest growth. It may be concluded that the blood plasma urea concentration responds sensitively to variations in dietary Thr concentration, but the validity of using the blood plasma urea concentration for derivation of Thr requirement for optimal growth remains unclear.

Carcass characteristics

Dressing percentage was reduced ($P < 0.05$) in treatment 2 compared to treatment 3. Since treatment 3 did not differ from the other treatments, Thr supply does not appear to affect dressing percentage directly. The intramuscular fat concentration was tendentiously or significantly reduced at the lowest Thr level (treatment 1). At higher levels of Thr supply, however, there was a poor relation between Thr supply and intramuscular fat content. Marginal differences in carcass charac-

teristics between the treatments are within the normal range and hardly explainable by variations in Thr supply.

As discussed earlier (Plitzner et al., 2006) the influence of Thr supply on carcass characteristics is much lower than the influence on growth performance. This is in clear contrast to other amino acids, for example Lys (Yen et al., 1986; Cline et al., 2000), which negatively affects carcass characteristics when supplied below requirement. These observations support the theory that the Thr requirement for growing pigs is substantially higher for maintenance (e.g. gut mucin production or immunoglobulin synthesis) than for protein accretion (Fuller and Wang, 1987; Han and Lee, 2000). Accordingly, considering data from Fuller et al. (1989) and NRC (1998) the maintenance requirement for Thr contributes to about 13.3% of total requirement, whereas for other amino acids such as Lys this proportion is much lower (6.2%).

Goblet cell density

Faure et al. (2005) observed in rats that the restriction of dietary Thr significantly impaired intestinal mucin synthesis. This seems to reflect intestinal mucins being particularly enriched with Thr. Lien et al. (1997) observed in pigs that Thr accounted for about 15 to 16% of the total amino acid composition of the mucin protein. Stoll et al. (1998) reported that in toto, 64% of the protein consumed by piglets appeared as free amino acids in the portal blood, except for Met and Thr showing a significantly lower recovery (48 and 38% of intake, respectively). This low portal appearance of Thr presumably reflects the high concentration of Thr in the intestinal mucus mentioned above. Schaart et al. (2005) also reported the portal-drained viscera in piglets having a high obligatory requirement for Thr. They concluded that the high rate of intestinal Thr utilization was mainly due to the incorporation of Thr into mucosal proteins and these data are in accordance with the investigations of Van der Schoor et al. (2002). As a result, in physiological situations associated with increased Thr utilization, Thr availability may limit mucin synthesis and consequently reduce the gut barrier function (Faure et al., 2005). Given that intestinal mucins are synthesized and secreted from goblet cells, the goblet cell density in the small intestine and colon may indirectly reflect the dietary Thr supply and mucin synthesis (Ball et al., 1999). However, as shown in Table 5, there was no influence of dietary Thr supply on goblet cell density in the present study, neither in the small intestine nor in the colon. In the present study, however, we did not quantify intestinal mucus production or secretion and hence the present data do not allow any conclusion on an influence of dietary Thr supply on the mucosal protein fractional synthesis rates as reported by Faure et al. (2005). Nevertheless, the density of goblet cells in the intestine of pigs does not seem to be affected by the dietary Thr concentration within the range investigated in the present study.

This experiment showed that a low-protein diet (135 g/kg CP) based on cereals (barley, maize and wheat) and extracted soybean meal without adequate addition of crystalline Thr has negative effects on growth in finishing pigs but has only minor impacts on slaughter performance. Further studies are required to determine the impact of different Thr supply on the gut morphology.

REFERENCES

Ball R.O., Law G., Bertolo R.F.P., Pencharz P.B. (1999): Adequate oral threonine is critical for mucin production and mucosal growth by neonatal piglet gut. In: Lobely G.E., White A., MacRae J.C. (eds.): Proc. 8th International Symposium on Protein Metabolism and Nutrition. Wageningen Pers., Wageningen, Netherlands. 31 pp.

Boisen S. (1997): Ideal protein - and its suitability to characterize protein quality in pig feeds. A review. Acta Agr. Scand. Sect. A, 47, 31–38.

Cline T.R., Cromwell, G.L., Crenshaw T.D., Ewan R.C., Hamilton C.R., Lewis A.J., Mahan D.C., Southern L.L. (2000): Further assessment of dietary lysine requirement of finishing gilts. J. Anim. Sci., 78, 987–992.

Cohen R.S., Tanksley T.D.J. (1977): Threonine requirement of growing and finishing swine fed sorghum-soybean meal diets. J. Anim. Sci., 45, 1079–1083.

Coma J., Carrion D., Zimmermann D.R. (1995): Use of plasma urea nitrogen as a rapid response criterion to determine the lysine requirement of pigs. J. Anim. Sci., 73, 472–481.

Faure M., Moennoz D., Montigon F., Mettraux C., Breuillé D., Ballèvre O. (2005): Dietary threonine restriction specifically reduces intestinal mucin synthesis in rats. J. Nutr., 135, 486–491.

Fuller M.F., McWilliam R., Wang T.C., Giles L.R. (1989): The optimum dietary amino acid pattern for growing

pigs. 2. Requirement for maintenance and for tissue protein accretion. Brit. J. Nutr., 62, 255–267.

Fuller M.F., Wang T.C. (1987): Amino acid requirements of the growing pig. In: Barnett J.L. (ed.): Manipulating Pig Production. Australian Pig Science Assoc., Werribee, Australia.

GfE (1987): Energie- und Nährstoffbedarf landwirtschaftlicher Nutztiere. Nr. 4 Schweine. DLG-Verlag, Frankfurt/Main, Germany.

GfE (2006): Empfehlungen zur Energie- und Nähr stoffversorgung von Schweinen. Nr. 10 Schweine. DLG-Verlag, Frankfurt/Main, Germany.

Han I.K., Lee J.H. (2000): The role of synthetic amino acids in monogastric animal production. Asian-Australas. J. Anim. Sci., 13, 543–560.

Kohn R.A., Dinneen M.M., Russek-Cohen E. (2005): Using blood urea nitrogen to predict nitrogen excretion and efficiency of nitrogen utilization in cattle, sheep, goats, horses, pigs, and rats. J. Anim. Sci., 83, 879–889.

Lenis N.P., Van Diepen (1990): Amino acid requirement of pigs. 3. requirement for apparent digestible threonine of pigs in different stages of growth. Neth. J. Agric. Sci., 38, 609–622.

Lenis N.P., Van Diepen J.Th.M., Goedhart P.W. (1990): Amino acid requirement of pigs. 1. requirements for methionine + cystine, threonine and tryptophan of fast-growing boars and gilts, fed ad libitum. Neth. J. Agric. Sci., 38, 577–595.

Lien K.A., Sauer W.C., Fenton M. (1997): Mucin output in ileal digesta of pigs fed a protein-free diet. Z. Ernährungswiss., 36, 182–190.

Naumann C., Bassler R. (1997): Die chemische Untersuchung von Futtermitteln. In: Methodenbuch, Band III, 3. Ausgabe, 4. Ergänzungslieferung, VDLUFA-Verlag Darmstadt, Germany.

NRC (1998): Nutrient Requirements of Swine, 8th revised ed. Nat. Acad. Press, Washington.

Pedersen C., Lindberg J.E., Boisen S. (2003): Determination of the optimal dietary threonine:lysine ratio for finishing pigs using three different methods. Livest. Prod. Sci., 82, 233–243.

Plitzner C., Ettle T., Windisch W. (2006): Experimental study on the requirement of threonine in finishing pigs. Bodenkultur, 57, 161–168.

Rademacher M., Sauer W.C., Jansmann A.J.M. (2001): Standardized Ileal Digestible Amino Acids for Pigs. Degussa AG, Hanau-Wolfgang, Germany.

Robbins K.R., Norton H.W., Baker D.H. (1979): Estimation of nutrient requirements from growth data. J. Nutr., 109, 1710–1714.

Saldana C.I., Knabe D.A., Qwen K.Q., Burgoon K.G., Gregg E.J. (1994): Digestible threonine requirements of starter and finisher pigs. J. Anim. Sci., 72, 144–150.

SAS (2002): Statistical Analysis System Inc. SAS/STAT User's Guide, Version 9. SAS Institute Inc., Cary, NC.

Schaart M.W., Schierbeek H., Van der Schoor S.R.D., Stoll B., Burrin D.G., Reeds P.J., Van Goudoever J.B. (2005): Threonine utilization is high in the intestine of piglets. J. Nutr., 135, 765–770.

Schutte J.B., Jong J., Smink W., Koch F. (1997): Threonine requirement of growing pigs (50 to 95 kg) in relation to diet composition. Anim. Sci., 64, 155–161.

Stoll B., Henry J., Reeds P.J., Yu H., Jahoor F., Burrin D. G. (1998): Catabolism dominates the first-pass intestinal metabolism of dietary essential amino acids in milk protein-fed piglets. J. Nutr., 128, 606–614.

Taylor A.J., Cole D.J.A., Lewis D. (1982): Amino acids requirement for growing pigs, 3. Threonine. Anim. Prod., 34, 1–8.

Van Lunen T.A., Cole D.J.A. (2001): Energy-amino acid interactions in modern pig genotypes. In: Garnsworthy P.C. (ed.): Recent Developments in Pig Nutrition 3. Nottingham University Press., Nottingham, UK.

Van der Schoor S.R.D., Reeds P.J., Stoll B., Henry J.F., Rosenberger J.R., Burrin D.G., Van Goudoever J.B. (2002): The high metabolic cost of a functional gut. Gastroenterology, 123, 1931–1940.

Yen H.T., Cole D.J.A., Lewis D. (1986): Amino acid requirement of growing pigs. 7 The response of pigs from 25 to 55 kg live weight to dietary ideal protein. Anim. Prod., 43, 141–154.

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