Effects of Low Crude Protein Diets Supplemented with Synthetic Amino Acids on Performance, Nutrient Utilization and Carcass Characteristics in Finishing Pigs Reared Using a Phase Feeding Regimen**

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ABSTRACT : This experiment was conducted to investigate the effect of feeding a low CP diet supplemented with synthetic amino acids on performance, nutrient utilization and carcass characteristics of finishing pigs fed under a three-phase feeding regimen. Ninety-six finishing pigs (Landrace×Large White×Duroc), 55.75 kg±0.65 of initial body weight, were blocked by weight and sex and allotted to four dietary treatments in a randomized block design. There were six pens per treatment and four pigs per pen. Pigs were fed a 16%-14%-12% CP (for phase I-II-III, respectively), sequence of diets. Dietary treatments were 1) Control, 2) Con+L (a sequence of diets reduced in CP by 1 percentage unit with lysine (L) supplementation, 3) Con+LMT (a sequence of diets reduced in CP by 2 percentage unit with LYS, methionine (MET) and threonine (THE) supplementation) and 4) Con+LMTT (a sequence of diets reduced in CP by 3 percentage unit with LYS, MET, THR and tryptophan (TRP) supplementation). The finishing period (55 to 105 kg) was divided into three phases (55 to 72 kg, 72 to 90 kg and 90 to 105 kg). Pigs fed either the control or Con+L diet grew faster ($p<0.05$) than pigs fed the Con-LMT or Con+LMTT diet. There was no difference in ADFI among dietary treatments. Phosphorus (P) digestibility was lowest in the control group and highest in the Con+LMTT group ($p<0.05$). Within each phase, no significant differences in dry matter (DM) and CP digestibilities were found. Although some amino acid digestibilities were affected by dietary treatments, digestibilities of essential amino acids (EAA), non-essential amino acids (NEAA) and total amino acid were not significantly influenced by dietary treatments. For the entire experiment periods, Con+L, Con+LMT and Con+LMTT treatments resulted in 13.4, 18.8 and 21.6% lower total N excretion compared with the control. Con+LMT and Con+LMTT treatments showed significantly lower BUN concentration compared with the control and Con+L treatment ($p<0.05$), but there was no significant difference in BUN concentration between pigs fed the control and Con+L treatment or between pigs fed Con+LMT and Con+LMTT treatments ($p>0.05$). Carcass length, backfat thickness and carcass grade were not significantly affected by dietary treatments ($p>0.05$). In conclusion, reducing dietary CP level by 1 percentage unit and supplementing only LYS at each phase could be a very beneficial feeding strategy for finishing pigs fed under a three phase feeding regimen in terms of both environmental and economical aspects. *(Asian-Aust. J. Anim. Sci. 2001. Vol. 14, No. 5 : 655-667)*

Key Words : Phase Feeding, Synthetic Amino Acids, Low Protein Diets, Growth Performance, Nutrient Excretion, Carcass Characteristics

INTRODUCTION

With increasing concerns regarding the negative impact of livestock production systems on the environment, the swine industry must attend to be environmentally sound to ensure its long-term sustainable growth. In the past, dietary adjustments were aimed at maximizing production performance without regard to nutrient oversupply, namely protein and amino acids. However, recent environmental constraints have forced swine nutritionists to evaluate the protein feeding not only in terms of nitrogen retained in animal products but also in terms of nitrogen excreted. This necessitates a close adjustment of protein and/or amino acid supply to the pigs requirements so as to obtain the lowest level of nitrogen output.

There have been various nutritional approaches used to reduce environmental pollution from swine production by many researchers. Recently, it has been recognized that phase feeding could be used to reduce nitrogen and phosphorous excretion by feeding these nutrients accoding to the age and physiological state of the pigs (Jongbloed and Lenis, 1992; Paik et al., 1996; Honeyman, 1996).

One of the most effective ways to reduce nitrogen excretion could be the use of synthetic amino acids (SAA) in low protein diets. It is well known that the crude protein concentration of diets for

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growing-finishing pigs can be reduced by one or two percentage units with the addition of crystalline lysine without sacrificing performance (Easter and Baker, 1980). Recently, Carter et al. (1996) reported that a reduction of dietary protein by four percentage units with the addition of lysine (LYS), methionine (MET), threonine (THR) and tryptophan (TRP) resulted in a significant reduction in nitrogen excretion from growing-finishing pigs. However, a reduction of crude protein (CP) by four percentage units may decrease daily gain and increase backfat in finishing pigs (Schoenherr, 1992; Tuitoek et al., 1997). Also, the effects of feeding reduced levels of CP with synthetic amino acids on performance, nutrient excretion and carcass quality of pigs reared under a phase feeding system have not been well evaluated.

In our previous study (Lee et al., 2000a), the application of a three phase feeding regimen instead of a one phase feeding regimen for the finishing period (50 to 110 kg) reduced nitrogen excretion by 12% without sacrificing performance. In another study (Lee et al., 2000b), we have concluded that the optimal dietary crude protein sequences were 16-14-12% CP when a three phase feeding regimen was applied during the finishing period (50 to 110 kg BW). It is expected that a slightly larger reduction in nitrogen excretion could be achieved by both a three phase feeding regimen and the use of low protein diets with supplementation of limiting amino acids.

Therefore, this experiment was conducted to investigate the effects of feeding a low protein diet supplemented with synthetic amino acids on performance, nutrient excretion and carcass characteristics of finishing pigs fed suing a three phase feeding regimen and to determine the safety margin for dietary protein level to minimize nitrogen excretion without sacrificing performance of pigs.

MATERIALS AND METHODS

A total of 96 finishing pigs (Landrace×Large White×Duroc), weighing 55.75±0.65 kg, were blocked by weight and sex and allotted to four dietary treatments in a randomized block design. There were six pens per treatment and four pigs per pen. The feeding trial was conducted for 62 d. Pigs were fed a 16%-14%-12% CP (for phase I-II-III, respectively), sequence of diets as the control. Dietary treatments were 1) Control, 2) Con+L (a sequence of diets reduced in CP by 1 percentage unit with lysine (LYS) supplementation, 3) Con+LMT (a sequence of diets reduced in CP by 2 percentage unit with LYS, methionine (MET) and threonine (THR) supplementation) and 4) Con+LMTT (a sequence of diets reduced in CP by 3 percentage unit with LYS, MET, THR and tryptophan (TRP) supplementation). The finishing period (55 to 105 kg) was divided into three phases (55 to 72 kg, 72 to 90 kg and 90 to 105 kg). The formulas and chemical composition of experimental diets are presented in tables 1, 2 and 3. To allow an ideal balance of major limiting amino acids (Chung and Baker, 1992), the control diets were supplemented with a small quantity of synthetic amino acids. All other nutrients met or exceeded NRC (1998) requirements. Pigs were housed in concrete floored pens, equipped with a self feeder and a nipple waterer, and allowed *ad libitum* access to feed and water throughout the experimental period. Temperature was not controlled in this study. Since this experiment was initiated in May and finished in July, the range of temperatures in the building varied according to the environmental temperature ranging from 25 to 33℃. Body weight and feed intake were recorded at the point of feed changing and at the end of the experiment.

For the determination of nutrient digestibility, 3 groups of 12 pigs (three pigs per treatment) averaging 58.5±0.47, 75.8±0.69 and 100.7±0.89 kg body weight, respectively, were housed in individual metabolic cages. Diets corresponding to each phase were offered to the pigs. Following seven days of adaptation, pigs were subjected to a 5-d collection period. The total amount of feed consumed and excreta produced were recorded daily during the metabolic trial. Collected excreta from each pig were pooled, sealed in plastic bags, and stored at -20℃ until they were dried in an forced air drying oven at 55℃ for 72 h and ground to 1 mm in a Wiley Mill for chemical analysis.

Urine was collected daily and filtered through 8 μm glass wool into 5 L collection vessels containing 0.5 N HCl (from 50 to 75 mL/d) to maintain pH below 3. Glass wool was changed daily. The total amount of urine was weighed and subsamples were taken for chemical analysis. The nitrogen content of diets, feces and urine samples were determined by the Kjeldahl procedure (AOAC, 1990).

Feeders were removed from pens for 1 h before blood samples were collected from the jugular vein. Blood samples were obtained the last day of the adjustment period and were obtained once a week for the entire experimental period. In order to avoid individual differences, a total of 24 pigs (six replications per treatment) having similar body weight were selected for blood sample collection before the experiment began and blood was collected from the same pigs each week during the whole experimental period. After blood sample collection, all samples were quickly transferred to a centrifuge tube and then centrifuged for 15 min at 3,000 rpm. in a cold room (5℃). The serum was carefully removed to plastic vials and stored at -20℃ for blood urea analysis.

Table 1. Formulas and calculated values of the experimental diets fed during phase I (55 to 72 kg)

	Control (CP 16%)	Con+L (CP 15%)	Con+LMT (CP 14%)	Con+LMTT (CP 13%)
Ingredient :				
Corn	70.82	71.86	75.39	77.96
Soybean meal (44% CP)	22.59	19.52	16.47	13.44
Wheat bran	2.99	4.57	3.96	3.62
Tallow	1.00	1.34	1.10	1.10
Limestone	0.44	0.43	0.38	0.32
Tri-calcium phosphate	1.32	1.35	1.43	1.54
Salt	0.20	0.20	0.20	0.20
L-lysine-HCl (80%)	0.14	0.23	0.33	0.44
DL-methionine (88%)	0.05	0.05	0.12	0.15
Threonine	0.05	0.05	0.22	0.33
Tryptophan	-	-	-	0.50
Vit.-min. premix[1]	0.28	0.28	0.28	0.28
Antibiotics[2]	0.06	0.06	0.06	0.06
Choline cloride	0.06	0.06	0.06	0.06
Total	100.00	100.00	100.00	100.00
Calculated value :				
ME (kcal/kg)	3,303.01	3,301.11	3,299.67	3,303.09
Crude protein (%)	16.00	15.00	14.00	13.00
Lysine (%)	0.92	0.92	0.92	0.92
Methionine+cystine (%)	0.59	0.56	0.59	0.59
Threonine (%)	0.63	0.59	0.63	0.63
Tryptophan (%)	0.22	0.20	0.18	0.22
Calcium (%)	0.70	0.70	0.70	0.70
Total phosphorus (%)	0.60	0.60	0.60	0.60

[1] Provided the following per kilogram of diet : vitamin A 5,500 IU, vitamin D_3 550 IU, vitamin E 27 IU, menadione sodium bisulfate 2.5 mg, pantothenic acid 27 mg, niacin 33 mg, riboflavin 5.5 mg, vitamin B_{12} 0.04 mg, thiamin 5 mg, pyridoxine 3 mg, biotin 0.24 mg, folic acid 1.5 mg, selenium 0.15 mg, manganese 0.03 g, zinc 0.1 g, iron 0.1 g, iodine 0.5 mg, magnesium 0.1 g.

[2] Provided 600 mg of Avilamycin per kg of diet.

Total blood urea nitrogen (BUN) concentration was analyzed by blood analyzer (Ciba-corning model, Express Plus, Ciba Corning Diagnostics Co., USA).

All pigs were slaughtered when they reached an average body weight of 105 kg. The tenth rib fat thickness (cm), carcass percentage (%) and carcass grade were measured.

Analysis of the experimental diets and excreta was done according to the methods of the AOAC (1990). The amino acid content of the experimental feed and excreta was determined following acid hydrolysis with 6 N HCl at 110℃ for 24 h, using an amino acid analyzer (Biochrom 20, Pharmacia Biotech, England). Sulfur-containing amino acids were analyzed after cold performic acid oxidation (Moore, 1963) overnight with subsequent hydrolysis.

Statistical analysis was carried out by comparing means according to Duncan's Multiple Range Test (Duncan, 1955), using the General Linear Model (GLM) procedure of SAS (1985). Data were analyzed as a randomized complete block design. Pigs were blocked by initial weight with pen as the experimental unit. Initial BUN (adjustment period) was used as a covariate to correct BUN data (treatment period) for individual animal differences.

RESULTS AND DISCUSSION

Growth performance

During phase I (55 to 72 kg), there were no significant differences in average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR) among dietary treatments (table 4). However, during phase II (72 to 90 kg), the reduction in CP from 14 to 12 or 11% with supplemental LYS, MET and THR or LYS, MET, THR and TRP reduced ADG, ADFI and feed efficiency ($p<0.05$). Pigs fed Con or Con+L diet grew similarly ($p>0.05$). During phase III (90 to 105 kg), no significant difference was found in any of the criteria measured among dietary treatments. For the overall period (55 to 105 kg), pigs reared on control diets (Con) grew faster ($p<0.05$) and

Table 2. Formulas and calculated values of the experimental diets fed during phase II (72 to 90 kg)

	Control (CP 14%)	Con+L (CP 13%)	Con+LMT (CP 12%)	Con+LMTT (CP 11%)
Ingredient :				
Corn	75.61	78.02	80.70	82.45
Soybean meal (44% CP)	17.19	14.25	11.11	8.01
Wheat bran	3.54	3.94	4.00	4.50
Tallow	1.00	1.00	1.00	1.10
Limestone	0.37	0.33	0.29	0.25
Tri-calcium phosphate	1.44	1.51	1.43	1.65
Salt	0.20	0.20	0.20	0.20
L-lysine-HCl (80%)	0.14	0.26	0.33	0.46
DL-methionine (88%)	0.03	0.03	0.10	0.13
Threonine	0.06	0.06	0.25	0.35
Tryptophan	-	-	-	0.50
Vit.-min. premix[1]	0.28	0.28	0.28	0.28
Antibiotics[2]	0.06	0.06	0.06	0.06
Choline cloride	0.06	0.06	0.06	0.06
Total	100.00	100.00	100.00	100.00
Calculated value :				
ME (kcal/kg)	3,303	3,301	3,300	3,299
Crude protein (%)	14.00	13.00	12.00	11.00
Lysine (%)	0.80	0.80	0.80	0.80
Methionine+cystine (%)	0.52	0.49	0.52	0.53
Threonine (%)	0.56	0.51	0.56	0.56
Tryptophan	0.19	0.17	0.15	0.19
Ca (%)	0.70	0.70	0.70	0.70
Total P (%)	0.60	0.60	0.60	0.60

[1] Provided the following per kilogram of diet : vitamin A 5,500 IU, vitamin D_3 550 IU, vitamin E 27 IU, menadione sodium bisulfate 2.5 mg, pantothenic acid 27 mg, niacin 33 mg, riboflavin 5.5 mg, vitamin B_{12} 0.04 mg, thiamin 5 mg, pyridoxine 3 mg, biotin 0.24 mg, folic acid 1.5 mg, selenium 0.15 mg, manganese 0.03 g, zinc 0.1 g, iron 0.1 g, iodine 0.5 mg, magnesium 0.1 g.

[2] Provided 600 mg of Avilamycin per kg of diet.

had a tendency to utilize feed more efficiently than those fed the Con+LMT or Con+LMTT diet. However, pigs reared on the Con+L diet grew at a similar rate (p>0.05) to those reared on the Con diet. The ADFI during all phases was not significantly different among dietary treatments.

In the present study, pigs fed 1 percentage unit lower diets with only LYS supplementation performed similar to pigs fed the control diet during the entire experimental period. This result indicates that the supplementation of LYS to diets can spare at least 1 percentage unit of protein within each phase of the finishing period, without reducing growth. This is supported by the results of Gatel and Grosjean (1992), who also reported the protein sparing effect of lysine supplementation. Similar observations were made by Latimier and Dourmad (1993) and Valaja et al. (1993).

However, there have been different results regarding the performance of pigs fed even lower CP diets. The present study showed that feeding a diet reduced in protein by 2 or 3 percentage units with SAA supplementation resulted in decreased ADG and impaired feed efficiency compared with feeding high CP diets during the overall period. This result is supported by the results of Corley and Easter (1980) and Easter et al. (1980), who suggested that feeding a corn-soybean meal diet containing less than 12% CP will limit the response to essential amino acids (EAA). Similar observations were recently made by Schoenherr (1992), Kerr and Easter (1995) and Tuitoek et al. (1997). In contrast, Canh et al. (1998) observed no negative effects on the performance of growing pigs when they reduced dietary CP by 4 percentage unit and supplemented LYS, MET+cystine (CYS), THR and TRP.

In the present study, the poorer growth and feed efficiency for pigs reared using the Con+LMT and Con+LMTT diets compared with pigs reared in the control group might be due to the shortage of some nonessential amino acids required for optimal growth in part of the finishing period. Chung and Baker

Table 3. Formulas and calculated values of the experimental diets fed during phase III (90 to 105 kg)

	Control (CP 12%)	Con+L[3] (CP 11%)	Con+LMT (CP 10%)	Con+LMTT (CP 9%)
Ingredient :				
Corn	80.08	83.03	85.44	87.94
Soybean meal (44% CP)	11.82	9.03	5.85	2.86
Wheat bran	4.43	4.25	4.51	4.33
Tallow	1.00	0.90	1.00	0.90
Limestone	0.30	0.25	0.23	0.17
Tri-calcuim phosphate	1.56	1.64	1.70	1.79
Salt	0.20	0.20	0.20	0.20
L-lysine-HCl (80%)	0.30	0.26	0.36	0.46
DL-methionine (88%)	-	-	0.07	0.11
Threonine	0.04	0.04	0.24	0.34
Tryptophan	-	-	-	0.50
Vit.-min. premix[1]	0.28	0.28	0.28	0.28
Antibiotics[2]	0.06	0.06	0.06	0.06
Choline cloride	0.06	0.06	0.06	0.06
Total	100.00	100.00	100.00	100.00
Calculated value :				
ME (kcal/kg)	3,299	3,300	3,301	3,299
Crude protein (%)	12.00	11.02	10.01	9.03
Lysine (%)	0.67	0.67	0.67	0.67
Methionine+cystine (%)	0.45	0.42	0.45	0.45
Threonine (%)	0.47	0.42	0.47	0.47
Tryptophan	0.16	0.14	0.13	0.16
Ca (%)	0.70	0.70	0.70	0.70
Total P (%)	0.60	0.60	0.60	0.60

[1] Provided the following per kilogram of diet : vitamin A 5,500 IU, vitamin D_3 550 IU, vitamin E 27 IU, menadione sodium bisulfate 2.5 mg, pantothenic acid 27 mg, niacin 33 mg, riboflavin 5.5 mg, vitamin B_{12} 0.04 mg, thiamin 5 mg, pyridoxine 3 mg, biotin 0.24 mg, folic acid 1.5 mg, selenium 0.15 mg, manganese 0.03 g, zinc 0.1 g, iron 0.1 g, iodine 0.5 mg, magnesium 0.1 g.

[2] Provided 600 mg of Avilamycin per kg of diet.

[3] Abbreviations : L=lysine, LMT=lysine, methionine and threonine, LMTT=lysine, methionine, threonine and tryptophan.

(1992) suggested that a combination of glutamate, glycine and proline as a source of non-essential amino acid (NEAA) may result in an improved efficiency of N utilization in comparison to glutamate alone. Futhermore, Ball et al. (1986) and Kirchgessner et al. (1995) demonstrated that, in some situations, amino acids that are believed to be nonessential, especially proline, may be required for optimum pig performance. These results indicate that certain NEAA might not be sufficiently synthesized by pigs to realize maximum growth and N retention and pig diets should contain adequate amounts of NEAA for maximum growth. Lenis et al. (1999) suggested that a ratio of N from EAA:N from NEAA should be approximately 50:50 for optimal N retention and utilization when pigs are fed restrictedly. In addition, the reduction of feed intake may be attributed to a higher environmental temperature during the current feeding trial which may have limited the intake of NEAA. However, it is unclear which NEAA contributed to the reduction in performance of pigs fed the Con+LMT or Con+LMTT diets. Further research is needed to investigate the optimum dietary amino acid pattern in pigs diet and potential interactions of NEAA with EAA.

Nutrients utilization

Within each phase, no significant differences in dry matter (DM) and CP digestibilities were found (table 5). As a result, DM, CP and phosphorus (P) digestibilites averaged over the entire period were also not affected by dietary treatments ($p>0.05$). However, during phase III and the overall period, P digestibility was the lowest in the control group and the highest in the Con+LMTT group ($p<0.05$). P digestibility had a tendency to be increased as dietary CP levels decreased. This may be attributed to the relative increase of P supply present as the inorganic P form as dietary CP level decreased in the present study.

Kerr and Easter (1995) reported that there was no significant difference in N digestibility between pigs

Table 4. Effects of dietary treatments on the growth performance of finishing pigs

Item	Control [1]	Con+L[2]	Con+LMT	Con+LMTT	SE[3]
Phase I period (55 to 72 kg)					
Initial weight (kg)	55.79	55.73	55.76	55.76	0.65
Final weight (kg)	73.12	72.90	72.39	72.57	0.75
Average daily gain (kg)	0.91	0.90	0.88	0.89	0.01
Average daily feed intake (kg)	2.59	2.61	2.54	2.57	0.04
Feed conversion ratio	2.84	2.89	2.91	2.87	0.04
Phase II period (72 to 90 kg)					
Initial weight (kg)	73.12	72.90	72.39	72.57	0.75
Final weight (kg)	92.35	91.04	89.28	89.00	1.01
Average daily gain (kg)	0.87^{a}	0.82^{a}	0.77^{b}	0.75^{b}	0.01
Average daily feed intake (kg)	2.68^{a}	2.56^{ab}	2.49^{b}	2.44^{b}	0.03
Feed conversion ratio	3.07^{c}	3.11^{bc}	3.26^{ab}	3.30^{a}	0.04
Phase III period (90 to 105 kg)					
Initial weight (kg)	92.35	91.04	89.28	89.00	1.01
Final weight (kg)	107.08	106.04	104.03	103.64	1.07
Average daily gain (kg)	0.70	0.71	0.70	0.70	0.01
Average daily feed intake (kg)	2.57	2.54	2.53	2.58	0.03
Feed conversion ratio	3.66	3.58	3.65	3.72	0.07
Overall period (54 to 104 kg)					
Initial weight (kg)	55.79	55.73	55.76	55.76	0.65
Final weight (kg)	107.08	106.04	104.03	103.64	1.07
Average daily gain (kg)	0.83^{a}	0.81^{ab}	0.78^{bc}	0.77^{c}	0.01
Average daily feed intake (kg)	2.61	2.56	2.51	2.52	0.03
Feed conversion ratio	3.15	3.16	3.22	3.26	0.02

[1] Control : Feeding CP 16-14-12% diets for phase I, II and III, respectively.

Con+L : Feeding CP 1% lower than control diets with identical level of lysine.

Con+LMT : Feeding CP 2% lower than control diets with identical levels of lysine, methionine and threonine.

Con+LMTT: Feeding CP 3% lower than control diet with identical levels of lysine, methionine, threonine and tryptophan.

[2] Abbreviations : L=lysine, LMT=lysine, methionine and threonine, LMTT=lysine, methionine, threonine and tryptophan.

[3] Pooled standard error.

[a,b] Means in the same row with different superscripts differ ($p<0.05$).

fed a 16% CP and those fed a 12% CP diet with supplemented with both EAA and NEAA. This partially supports the present study which indicated that no significant difference in CP digestibility was observed between pigs fed the high CP diet and those fed lower CP diets with supplemented with the major limiting AA. However, some studies indicated an increase in N digestibility as CP levels increased (Just, 1982a, b; Noblet et al., 1987). This is likely due to a reduction in the negative effect of endogenous N at high N intakes (Just, 1982b) or may be due to a higher digestibility of feedstuffs used to obtain higher CP levels (Just, 1982b; Sato et al., 1987). In contrast, Leibholz et al. (1986) and Izquierdo et al. (1988) reported that feeding a low CP diet with supplemental AA could improve N digestibility compared with feeding high CP diet without supplemental AA due to the greater digestibility of crystalline AA in comparison with protein-bound AA.

The response of amino acid digestibilities to dietary treatments are summarized in tables 6, 7 and 8. Within each phase, although some amino acid digestibilities were affected by dietary treatments, average values of essential amino acids (EAA), non-essential amino acids (NEAA) and total amino acids digestibilities were not significantly influenced by dietary treatments. During phase I, supplementation of LYS, MET and THR to low CP diets increased LYS, MET and THR digestibilities ($p<0.05$). During phase II and III, LYS, MET and THR digestibilities tended to increase as the amount of supplementation of corresponding amino acids to diets increased. This increased digestibility may be due to the greater digestibility of crystalline AA in comparison with protein-bound amino acids (Leibholz et al., 1986; Sato et al., 1987; Izquierdo et al., 1988).

Table 9 shows the effects of dietary treatments on nutrient excretion and N retention. Within each phase,

Table 5. Effects of dietary treatments on the nutrient digestibility of finishing pigs

Item	Control[1]	Con+L[2]	Con+LMT	Con+LMTT	SE[3]
Phase I (55 to 72 kg)					
Dry matter (%)	88.26	88.12	88.32	88.36	0.24
Crude protein (%)	84.86	83.85	83.16	83.80	0.46
Phosphorus (%)	41.73	44.01	45.60	47.86	1.26
Phase II (72 to 90 kg)					
Dry matter (%)	85.93	86.93	86.40	86.90	0.24
Crude protein (%)	83.98	84.40	82.83	84.13	0.37
Phosphorus (%)	47.96	49.04	51.59	51.69	0.82
Phase III (90 to 105 kg)					
Dry matter (%)	83.82	84.45	83.93	83.49	0.38
Crude protein (%)	81.46	81.38	79.69	79.99	0.68
Phosphorus (%)	48.77^{b}	50.20^{ab}	51.32^{ab}	53.35^{a}	0.73
Overall (55 to 105 kg)					
Dry matter (%)	86.00	86.50	86.22	86.25	0.19
Crude protein (%)	83.43	83.21	82.64	81.89	0.43
Phosphorus (%)	46.15^{b}	47.75^{ab}	49.50^{ab}	50.97^{a}	0.77

[a,b] Means in the same row with different superscripts differ ($p<0.05$).

[1] See table 4 for abbreviation.

[2] Abbreviations: L=lysine, LMT=lysine, methionine and threonine, LMTT=lysine, methionine, threonine and tryptophan.

[3] Pooled standard error.

Table 6. Effects of dietary treatments on the amino acid digestibilities of finishing pigs for phase I

Item	Control[1]	Con+L[2]	Con+LMT	Con+LMTT	SE[3]
Threonine	77.72^{c}	79.06^{bc}	80.13^{ab}	84.92^{a}	0.86
Valine	73.43	74.52	78.44	71.26	1.50
Cystine	84.28^{a}	79.85^{b}	76.11^{c}	83.87^{a}	1.07
Methionine	75.86^{b}	77.17^{ab}	80.25^{a}	80.23^{a}	0.70
Isoleucine	80.92	79.62	87.02	80.95	1.63
Leucine	85.18	79.00	82.49	78.45	1.88
Phenylalanine	81.76^{c}	83.75^{b}	85.52^{a}	78.64^{d}	0.79
Lysine	81.13^{b}	82.78^{ab}	84.79^{a}	85.14^{a}	0.61
Histidine	90.96^{a}	88.84^{a}	80.36^{b}	85.68^{ab}	1.71
Arginine	88.16	87.53	82.27	85.41	1.45
Averaged essential amino acids	**81.94**	**81.21**	**81.94**	**81.46**	**0.51**
Averaged non essential amino acids	**81.27**	**80.38**	**81.10**	**78.65**	**0.45**
Total amino acids	**81.66**	**80.87**	**81.48**	**80.30**	**0.38**

[a,b] Means in the same row with different superscripts differ ($p<0.05$).

[1] See table 4 for abbreviation.

[2] Abbreviations: L=lysine, LMT=lysine, methionine and threonine, LMTT=lysine, methionine, threonine and tryptophan.

[3] Pooled standard error.

no significant differences in DM and fecal P excretion were found. However, N excretion was largely affected by dietary treatments. During phase I, there was no significant difference in fecal N excretion among dietary treatments, but a gradual reduction of dietary CP levels with supplemental AA resulted in a dramatic reduction ($p<0.05$) in urinary N excretion. As a result, the Con+L, Con+LMT and Con+LMTT treatments resulted in 5.9, 15.9 and 20.8% lower total N excretion, respectively, compared with the control. Overall, N excretion during phase II and III followed a similar pattern to that of the phase I. Fecal N and P excretion averaged overall periods were not affected by dietary treatments ($p>0.05$). However, urinary N excretion was significantly reduced by reducing dietary CP levels with supplemental LYS or LYS, MET and THR or LYS, MET, THR and TRP compared to high dietary CP diets ($p<0.05$). Over all periods, the

Table 7. Effcts of dietary treatments on the amino acid digestibilities of finishing pigs for phase I

Item	Control[1]	Con+L[2]	Con+LMT	Con+LMTT	SE[3]
Threonine	75.78^{b}	78.02^{ab}	79.16^{ab}	79.96^{a}	0.67
Valine	81.42	79.14	78.96	78.43	0.94
Cystine	84.82	81.33	83.65	83.62	1.14
Methionine	80.46	81.11	82.20	83.78	0.83
Isoleucine	83.25	82.09	81.59	80.74	0.73
Leucine	81.04	78.30	81.59	79.49	0.91
Phenylalanine	84.81	81.05	83.77	80.01	0.90
Lysine	80.60	84.10	85.41	86.23	1.04
Histidine	81.15^{a}	78.41^{ab}	74.36^{b}	74.63^{b}	1.13
Arginine	79.98	80.53	74.24	73.10	1.54
Averaged essential amino acids	**81.33**	**80.41**	**80.49**	**80.00**	**0.34**
Averaged non essenfial amino acids	**83.58**	**81.17**	**80.42**	**81.15**	**0.59**
Total amino acids	**82.26**	**80.72**	**80.46**	**80.47**	**0.41**

[a,b] Means in the same row with different superscripts differ ($p<0.05$).

[1] See table 4 for abbreviation.

[2] Abbreviations: L=lysine, LMT=lysine, methionine and threonine, LMTT=lysine, methionine, threonine and tryptophan.

[3] Pooled standard error.

Table 8. Effects of dietary treatments on the amino acid digestibilities of finishing pigs for phase III

Item	Control[1]	Con+L[2]	Con+LMT	Con+LMTT	SE[3]
Threonine	78.60	79.92	80.56	80.69	0.92
Valine	77.67	79.89	81.84	79.53	1.21
Cystine	86.82	83.48	85.68	82.95	0.96
Methionine	80.07	81.24	82.26	83.89	1.28
Isoleucine	81.96	77.78	77.66	79.96	1.29
Leucine	81.02	81.94	85.25	84.30	0.89
Phenylalanine	79.86^{b}	81.65^{ab}	85.61^{a}	79.21^{b}	0.94
Lysine	81.70	82.28	83.34	84.11	0.98
Histidine	76.78	74.74	82.72	75.67	1.90
Arginine	82.15^{a}	75.62^{ab}	87.26^{a}	65.30^{b}	2.97
Averaged essential amino acids	**80.67**	**79.86**	**83.22**	**79.56**	**0.66**
Averaged essential amilno acids	**79.06**	**79.14**	**81.15**	**79.36**	**0.81**
Total amino acids	**80.00**	**79.56**	**82.37**	**79.49**	**0.70**

[a,b] Means in the same row with different superscripts differ ($p<0.05$).

[1] See table 4 for abbreviation.

[2] Abbreviations: L=lysine, LMT=lysine, methionine and threonine, LMTT=lysine, methionine, threonine and tryptophan.

[3] Pooled standard error.

Con+L, Con+LMT and Con+LMTT treatments resulted in significantly reduced average total N excretion in comparison with the control.

Nitrogen retention was significantly higher in the control than the Con+LMT and Con+LMTT groups during phase I ($p<0.05$), but efficiency of N retention had a tendency to be improved by feeding lower CP diets with supplemental AA compared with feeding high CP diets. During phase II, N retention followed a similar pattern to that of phase I, but efficiency of N retention was similar between the control and other dietary treatments. During phase III, N retention and efficiency of N retention were not significantly affected by dietary treatments. Over all periods, no significant differences in N retention and efficiency of N retention were found among dietary treatments.

For the entire experimental period, the Con+L, Con+LMT and Con+LMTT treatments resulted in 13.4, 18.8 and 21.6% lower total N excretion compared with the control (high CP diets). This is in good agreement with many previous studies (Low, 1980; Kephart and Sherritt, 1990; Yu et al., 1991; Gatel and Grosjean, 1992; Latimier and Dourmad, 1993; Kerr and Easter, 1995). With growing environmental concerns in animal production, reduction of N excretion through feed formulation may become

Table 9. Effects of dietary treatments on the nutrient excretion and nitrogen retention of finishing pigs

Items	Control[1]	Con+L[2]	Con+LMT	Con+LMTT	SE[3]
Phase I (55 to 72 kg)					
Excretion (g/d)					
Dry matter	205.75	207.35	203.57	203.14	4.31
Urinary N	13.16^{a}	12.07^{ab}	10.23^{bc}	9.67^{c}	0.50
Fecal N	6.96	6.87	6.68	6.27	0.19
Total N	20.13^{a}	18.94^{ab}	16.91^{bc}	15.94^{c}	0.59
N intake (g/d)	46.02	42.54	39.69	38.70	-
N retention*					
Daily N, g	25.89^{a}	23.59^{ab}	22.77^{b}	22.75^{b}	0.51
N% of N intake	56.26	55.46	57.38	58.79	0.85
Phase II (72 to 90 kg)					
Excretion (g/d)					
Dry matter	271.32	250.95	260.73	251.46	4.83
Urinary N	20.52	17.82	17.50	17.15	0.58
Fecal N	8.10^{a}	7.30^{ab}	7.49^{ab}	6.75^{b}	0.94
Total N	28.63^{a}	25.12^{b}	24.99^{b}	23.90^{b}	0.20
N intake (g/d)	50.62	46.80	43.66	42.57	-
N retention					
Daily N, g	21.98^{a}	21.67^{ab}	18.66^{b}	18.66^{b}	0.10
N% of N intake	43.44	46.31	42.75	43.83	0.99
Phase III (90 to 105 kg)					
Excretion (g/d)					
DM	339.49	342.11	346.88	351.34	7.86
Urinary N	27.89^{a}	21.14^{b}	18.62^{b}	18.78^{b}	1.29
Fecal N	10.20	9.98	9.97	9.44	0.34
Total N	38.09^{a}	31.12^{b}	28.59^{b}	28.22^{b}	1.35
N intake (g/d)	55.19	53.59	49.27	47.19	-
N retention					
Daily N, g	17.10	22.46	20.67	18.97	0.91
N% of N intake	30.84	41.92	41.83	40.31	1.82
Overall (55 to 105 kg)					
Excretion (g/d)					
DM	272.19	266.80	270.39	268.65	3.43
Urinary N	20.52^{a}	17.01^{b}	15.45^{c}	15.20^{c}	0.65
Fecal N	8.42	8.05	8.04	7.48	0.28
Total N	28.95^{a}	25.06^{b}	23.50^{bc}	22.69^{c}	0.76
N intake (g/d)	50.61	47.64	44.20	42.82	-
N retention					
Daily N, g	21.66	22.57	20.70	20.12	0.44
N% of N intake	43.51	47.90	47.32	47.64	0.81

* N retention was assessed by the balance method (daily intake minus out put in feces and urine)

[1] See table 4 for abbreviation.

[2] Abbreviations: L=lysine, LMT=lysine, methionine and threonine, LMTT=lysine, methionine, threonine and tryptophan.

[3] Pooled standard error.

[a,b] Means in the same row with different superscripts differ ($p<0.05$).

necessary in the livestock industry. Based on current and many previous studies, it seems that for each one percentage unit reduction in dietary CP combined with AA supplementation can reduce total N losses (fecal plus urinary) approximately 7%. Supplementation of limiting AA to low-CP diets has also been shown to reduce the ammonia emissions into the air (Latimier and Dourmad, 1993; Pfeiffer, 1993). Recently, Obrock et al. (1997) investigated the effects of dietary protein concentration on ammonia production in swine facilities. They found that reducing dietary crude protein by 4% and formulating the diet to meet the requirements for the first four limiting amino acids decreased aerial ammonia concentration by 29%.

Reduced ammonia production should be beneficial for both pigs and humans. Since, most of modern pigs are raised in a closed building, there should be more studies on the relationship between feeding regimen and ammonia production.

Even though N retention during the entire period was not significantly affected by dietary treatments in the current experiment, efficiency of N retention had a tendency to be improved with supplementation of AA to lower CP diets compared with pigs fed high CP diets. Similar results have been reported by others (Low, 1980; Roth and Kirchgessner, 1993; Valaja et al., 1993; Kerr and Easter, 1995) suggesting that the utilization of dietary AA has been greatly improved with the supplementation of AA to low CP diets.

Blood urea nitrogen concentration

The response of blood urea nitrogen concentration (BUN) to dietary treatments during the entire experimental period is shown in figure 1. Blood urea nitrogen (BUN) concentration ranged from 6.37 to 13.56 mg/dL in this experiment. Over time, BUN concentration tended to decrease irrespective of dietary treatments, which may be attributed to the gradual reduction of dietary CP level by at a 2 percentage units according to the application of the three phase feeding regimen for finishing period in the present study. This followed a similar pattern to the response of BUN concentration to different feeding regimens from our previous study (Lee et al., 2000a). Within each phase, pigs fed lower dietary CP diets with supplementation of AA resulted in a reduction of BUN concentration compared with those fed high CP diets ($p<0.05$). Over all periods, supplementation of AA to low CP diets dramatically reduced average BUN concentration ($p<0.05$). The Con+LMT and Con+LMTT groups showed significantly lower average BUN concentration compared with the control and Con+L groups ($p<0.05$), but there was no significant difference in average BUN concentration between the control and Con+L group or between the Con+LMT and Con+LMTT groups ($p>0.05$).

In the current study, the BUN concentration was significantly affected by dietary CP levels ($p<0.05$) and had a tendency to be reduced as dietary CP levels decreased. This result is in good agreement with previous research (Lopez et al., 1994; Kerr and Easter, 1995; Ward and Southern, 1995; Miller et al. 1996) that indicated reduced BUN concentrations in pigs fed low-CP diets supplemented with AA diets compared with pigs fed diets in which amino acids were provided entirely from intact protein. The response of BUN concentration to dietary treatments in the current study indicate that the quantity of excess dietary amino acids is lower in pigs fed low-CP diets with supplemental AA. Also, pigs fed these low CP diets supplemented with AA could utilize dietary protein more efficiently than pigs fed high CP diets. This is supported by the response of efficiency of N retention to dietary treatments in the present study.

Carcass characteristics

The effect of dietary treatments on carcass characteristics is summarized in Table 10. Carcass percentage was significantly higher in pigs fed the control diet (high CP diets) than those fed Con+LMT or Con+LMTT, respectively ($p<0.05$). However, no difference in carcass percentage was found between pigs fed control diets and those fed Con+L. Carcass length, backfat thickness and carcass grade were not

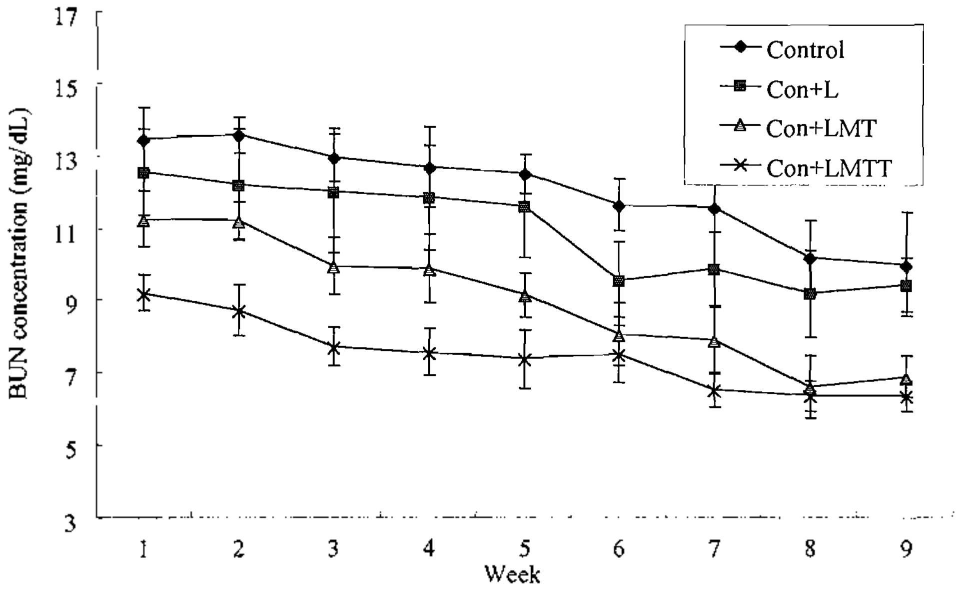

Figure 1. The responses of blood urea nitrogen (BUN) to dietary treatments in finishing pigs

Table 10. Effects of dietary treatments on the carcass characteristics* of finishing pigs

Item	Control[1]	Con+L[2]	Con+LMT	Con+LMTT	SE[3]
Slaughter weight (kg)	107.08	106.04	104.03	103.64	1.07
Carcass weight (kg)	83.75	81.56	78.24	78.69	0.43
Carcass percentage (%)	78.21^{a}	76.91^{ab}	75.21^{b}	75.93^{b}	0.41
Carcass length (cm)	100.37	100.22	100.55	100.00	0.23
10th rib backfat thickness (cm)	3.15	3.22	3.26	3.36	0.05
Carcass grade[4]	1.82	2.13	2.20	2.82	0.10

[1] See table 4 for abbreviation.

[2] Abbreviations: L=lysine, LMT=lysine, methionine and threonine, LMTT=lysine, methionine, threonine and tryptophan.

[3] Pooled standard error.

[4] Based on a scale with 1=grade A (excellent), 2=grade B (good), 3=grade C (average), 4=grade D (under average).

* Carcass parameter were covariated based on slaughter weight.

[a,b] Means in the same row with different superscripts differ ($p<0.05$).

significantly affected by dietary treatments ($p>0.05$).

In the present study, it was observed that pigs fed high CP diets had a tendency to have more favorable effects on overall carcass characteristics than other dietary treatments. Although there was no significant deference in backfat thickness among dietary treatments, reduction of dietary CP levels with supplemental AA caused numerical increases in average backfat thickness and poorer carcass grade compared with pigs fed control diets. Slight increase in backfat thickness of pigs fed lower CP diets with supplemental SAA coincided with the response in feed efficiency and growth rate in the present study. In numerous studies, it has been concluded that feeding low CP diets with supplemental AA produced carcasses with slighty less muscle and an increase in backfat thickness (Fuller et al., 1984 from 22 to 55 kg; Boisen et al., 1991 from 20 to 95 kg; Spiekers et al., 1991 from 30 to 100 kg; Schoenherr, 1992 from 57 to 103 kg). One explanation for the increase in carcass fat is that carcass quality is sensitive to the N content of the diet and will not respond to AA supplementation independently of CP level (Kerr et al., 1995). Another is that diets low in CP may have a higher NE value, allowing the extra NE associated with the low CP diets with supplemental AA to be deposited as fat. This is supported by the data of others (Easter and Baker, 1980; Taylor et al., 1981; Fuller et al., 1984, 1986; Noblet et al., 1987; Lenis and van Diepen, 1990), which suggested that NE increases by approximately 0.6% for each 1 percentage unit reduction in CP.

Pigs fed control diets had a higher carcass percentage than those fed Con+LMT or Con+LMTT, respectively in the present study ($p<0.05$). It could be hypothesized that animals with more lean body mass have a greater metabolic rate and require greater blood volume, resulting in larger heart, liver and kidney (McMeekan, 1940). Kerr et al. (1995) reported that pigs fed high CP diets had a greater heart, liver and kidney size than those fed low CP diets with supplemental AA. This is supported by other studies (Vipperman et al., 1963; Ostrowski, 1969; Stahly et al., 1979). Although the organs response to dietary treatments was not determined in the present study, it is speculated that organ weights of pigs fed high CP diets may be higher than those of pigs fed low CP diets with supplemental AA. The present experiment did not show any difference in carcass length due to dietary treatments, as has been previously reported (Easter and Baker, 1980).

Feed cost

Table 11 summarized the results of feed cost evaluation in the current study. As shown in the table, feed cost per kg weight gain was significantly lower in the control and Con+L groups than the Con+LMT and Con+LMTT groups ($p<0.05$). There was no difference in feed cost per kg weight gain between the control and Con+L groups. Feeding Con+LMT or Con+LMTT to finishing pigs under a three phase feeding regimen resulted in increases in feed cost per kg weight gain by 5.5 and 7.8% compared with feeding the control diet. This is partially attributed to the relatively higher cost of synthetic MET, THR and TRP in the current industry situation. However, the current study showed that supplemental LYS added to 1% lower CP diets could reduce feed costs and be more economical diet manipulation compared with higher CP diets.

Collectively, reducing the dietary CP level by 2 or 3 percentage units and supplementing with limiting amino acids (LYS, MET, THR and TRP) significantly reduced total nitrogen excretion (18.8 to 21.6%). However, these dietary treatments resulted in the reduction of growth and feed efficiency and caused higher feed cost in finishing pigs production. Reducing dietary CP level by 1 percentage units and supplementing LYS at each phase could be recommended for finishing pigs fed using a three phase feeding

Table 11. Effects of dietary treatments on the feed cost per gain in finishing pigs

Items	Control[1]	Con+L[2]	Con+LMT	Con+LMTT	SE[3]
Total weight gain (kg)	51.3^{a}	50.3^{ab}	48.3^{bc}	47.9^{c}	0.5
Total feed cost/pig (USD)	32.10	31.24	31.96	32.50	0.4
Feed cost/kg weight gain (USD)	0.626^{b}	0.621^{b}	0.662^{a}	0.678^{a}	0.006

[a,b] Means in the same row with different superscripts differ ($p<0.05$).

[*] Feed production cost for each diets were 211 USD/ton for CP 16% diet, 209 USD/ton for CP 15%+L diet, 217 USD/ton for CP 14%+LMT diet, 221 USD/ton for CP 13%+LMTT diet, 227 USD/ton for CP 12% diet, respectively.

[1] See table 4 for abbreviation.

[2] Abbreviations: L=lysine, LMT=lysine, methionine and threonine, LMTT=lysine, methionine, threonine and tryptophan.

[3] Pooled standard error.

regimen in both environmental and economical aspects.

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