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Effects of Lower Dietary Lysine and Energy Content on Carcass Characteristics and Meat Quality in Growing-finishing Pigs*

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ABSTRACT : Fifty-four PIC barrows were used to evaluate the effects of lower dietary lysine content and energy level on carcass characteristics and meat quality in slaughter pigs. Pigs were allotted to one of three treatments by body weight with six replicate pens in each treatment. The dietary treatments for body weights of 20-50 kg, 50-80 kg and 80-90 kg were as follows, respectively: control diet (digestible energy 14.22 MJ/kg, lysine/DE 0.67 g/MJ, 0.53 g/MJ and 0.42 g/MJ); a low lysine group (digestible energy 14.22 MJ/kg, lysine/DE 0.49, 0.38 and 0.30 g/MJ); and a low lysine-low energy group or low nutrient group (digestible energy 13.11 MJ/kg, lysine/DE 0.49, 0.38 and 0.30 g/MJ). The daily weight gain, daily feed intake and feed efficiency were calculated in the overall growth period (nearly 12 weeks). Meanwhile, carcass characteristics and meat quality were evaluated at 60 and 90 kg body weight respectively. During the overall growth trial, lowering dietary lysine and nutrient level both decreased weight gain ($p<0.05$) and feed efficiency ($p<0.01$). At 60 kg body weight, decreasing dietary lysine and nutrient level noticeably decreased dressing percentage ($p<0.01$) and back fat depth at last rib of PIC pigs ($p<0.01$), but enhanced marbling scores ($p<0.10$), intramuscular fat content ($p<0.10$) and water loss rate ($p<0.01$) of the *longissimus dorsi* muscle. At 90 kg body weight, lean percentage ($p<0.01$) was evidently reduced by both lowering lysine content and nutrient level in the diet. However, the shoulder back fat depth ($p<0.05$) and marbling scores of the loin eye muscle ($p<0.05$) were increased; Lowering dietary nutrient level could improve back fat depth of 10th rib ($p<0.01$) and last rib ($p<0.01$), intramuscular fat content ($p<0.10$), redness ($p<0.01$) and water loss rate of the loin eye muscle ($p<0.05$), but decrease loin area ($p<0.05$). Finally, when comparing the 60 kg and 90 kg slaughter weights, it was found that the shoulder back fat depth ($p<0.01$, $p<0.10$), 6th-7th rib ($p<0.01$, $p<0.01$), 10th-rib ($p<0.01$, $p<0.01$) and last rib back fat depth ($p<0.01$, $p<0.01$) of the low lysine and low nutrient group were all obviously increased comparing with the control group. Taken together, the results showed that decreasing dietary lysine content and nutrient level increased intramuscular fat content and water loss rate of *longissimus dorsi* muscle; On the other hand, both lowering dietary lysine and nutrient level markedly compensated to increase back fat deposition in the later finishing period (body weight from 60 to 90 kg) in contrast to the control group. (**Key Words :** Lysine, Energy, Carcass Characteristics, Meat Quality, Pig)

INTRODUCTION

In recent years, the carcass lean content of pigs has been increased tremendously by intense selection. However, consumer acceptance for pork have decreased because of poor meat quality (Witte et al., 2000; Edwards et al., 2003; Schwab et al., 2006). Besides genetic factors, the diet fed also has an important impact on meat quality (Anders et al., 1993). Generally, dietary protein or amino acid level, energy density and the ratio of lysine:energy primarily determine the deposition rate of protein and lipid in pig carcass (Szabó et al., 2001).

It has been widely accepted that higher marbling or intramuscular fat content meat positively influence the eating quality of pork (Barton et al., 1985; Bejerjolm et al., 1986; Fernandez et al., 1999; Fortin et al., 2005). Numerous studies have reported that intramuscular fat content was increased by feeding lysine-deficient diets or low lysine:energy ratios diet throughout the growing and finishing phases (Castell et al., 1994; Kerr et al., 1995; Cisneros et al., 1996; Blanchard et al., 1999; Szabó et al., 2001; Apple et al., 2004). However, when previous experimental diets were summarized, most studies that tested the effect of dietary lysine content and energy density were mostly higher than NRC recommendation levels and it is rare to find studies that focused on the effects of lower dietary lysine content and energy density on pork quality.

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Table 1. Basal diet composition for PIC growing-finishing pigs

Body weight (kg) / Treatment	20-50 kg			50-80 kg			80-90 kg		
	Control	LY	LN	Control	LY	LN	Control	LY	LN
Ingredients (%)									
Corn	58.00	57.49	57.49	49.90	49.90	49.90	54.60	54.60	54.60
Corn starch	0.87	1.93	7.00	4.50	4.50	10.00	4.50	4.50	10.00
Wheat bran	15.20	15.20	15.20	27.76	27.75	27.80	27.86	27.83	27.81
Soybean meal	16.50	16.50	16.50	9.00	9.00	9.00	4.20	4.20	4.20
Soybean oil	5.00	5.00	0.00	5.50	5.50	0.00	5.50	5.50	0.00
Dicalcium phosphate	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Salt	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
Limestone	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Zeolite	1.03	1.02	1.09	0.15	0.62	0.63	0.28	0.66	0.72
Mixed amino acids[a]	0.68	0.14	0.00	0.52	0.06	0.00	0.39	0.04	0.00
Vitamin premix[b]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Mineral premix[c]	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Antioxidant	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Anti-mould agent	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Bacitracin zinc	0.04	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Polymyxin	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Total composition (% as fed)[d]									
Digestible energy (MJ/kg)	14.22	14.22	13.11	14.22	14.22	13.11	14.22	14.22	13.11
Lysine (%)	0.94	0.69	0.62	0.75	0.55	0.49	0.61	0.44	0.39
Lysine/DE (g/MJ)	0.66	0.49	0.47	0.53	0.39	0.37	0.43	0.31	0.30
Crude protein (%)	14.70	14.54	14.39	12.21	11.92	11.87	10.50	10.21	10.16
Lysine (%)	0.94	0.67	0.60	0.75	0.53	0.47	0.60	0.42	0.38
Methionine, %	0.23	0.17	0.17	0.19	0.14	0.13	0.15	0.11	0.10
Methionine+cystine (%)	0.53	0.36	0.35	0.44	0.31	0.28	0.35	0.25	0.23
Threonine (%)	0.61	0.43	0.38	0.50	0.36	0.33	0.40	0.29	0.25
Tryptophan (%)	0.18	0.11	0.11	0.13	0.10	0.09	0.10	0.08	0.07
Isoleucine (%)	0.50	0.35	0.33	0.42	0.29	0.27	0.31	0.23	0.21

[a] LY and LN represented low lysine and low nutrient group respectively.

[b] Except for lysine according to experimental design, all other dietary essential amino acids maintained on NRC recommendation ratios relative to lysine.

[c] Provided per kilogram of complete diet: Vitamin A, 13,500 IU; Vitamin D_3, 3,600 IU; Vitamin E, 15 IU; Vitamin K_3, 3 mg; Vitamin B_1, 3 mg; Vitamin B_2, 7.8 mg; Vitamin B_6, 3 mg; Vitamin B_{12}, 2.4 mg; Folic acid, 1.5 mg; Biotin, 0.045 mg; Niacin, 30 mg; Calcium Pantothenate, 15 mg; Choline, 600 mg.

[d] Provided per kilogram of complete diet:

20-50 kg: Cu, 180 mg; Fe, 120 mg; Zn,120 mg; Mn,24 mg; Se,0.36 mg; I, 0.36 mg.

50-80 kg and 80-90 kg: Cu, 10 mg; Fe, 80 mg; Zn, 80 mg; Mn, 10 mg; Se, 0.3 mg; I, 0.3 mg.

[e] The digestible energy and lysine/DE are calculated values, other data are actually detected.

Therefore, the aim of the present experiment was to investigate the effect of lower dietary lysine level and energy density on carcass characteristics and meat quality in growing-finishing PIC barrows. An additional aim was to explore how the carcass characteristics and meat quality changes during the finishing phase.

MATERIALS AND METHODS

Animals, experimental diet and growth performance determination

A total of 54 PIC barrows with initial body weight of 20.33±1.86 kg were used in this experiment. Three barrows were housed in each pen and six replicate pens per treatment in a randomized complete block design. All pigs were housed in the same building with slatted floors in Chongqing Breeding Pig Farm (Chongqing, China). Each pen had a one-hole feeder and one nipple waterer. During a 7-day adjustment period, all pigs received a common diet (a mixture of a commercial weanling pig and experimental NRC diet). The dietary treatments were as follows: control diet (with NRC recommendation level, digestible energy 14.22 MJ/kg, lysine/DE 0.67 g/MJ, 0.53 g/MJ and 0.42 g/MJ for body weights of 20-50 kg, 50-80 kg and 80-90 kg, respectively); a low lysine group (digestible energy 14.22 MJ/kg, lysine/DE 0.49, 0.38 and 0.30 g/MJ for body weights of 20-50 kg, 50-80 kg and 80-90 kg, respectively); and a low lysine-low energy group (digestible energy 13.11 MJ/kg, lysine/DE 0.49, 0.38 and 0.30 g/MJ for body weights from 20-50 kg, 50-80 kg and 80-90 kg, respectively). The dietary energy density was altered by varying the levels of soybean oil and cornstarch. The lysine levels were adjusted by changing proportions of synthetic amino acids in the diets and the other essential amino acids were supplemented according to the ratio to lysine content in the NRC requirements. All pigs were allowed free access

to feed and water. Body weight and feeders were weighed at two-week intervals to calculate weight gain, feed intake and feed efficiency during the overall experiment period (nearly 12 weeks). When the pig body weight reached 60 kg or 90 kg, one pig from each replicate was selected for slaughter to determine carcass characteristics and meat quality.

Carcass meat quality evaluation

After the sixth week, when the average pig body weight reached around 60 kg (the first slaughter phase) and at approximately 12 weeks when the average body weight reached 90 kg (the second slaughter phase), one pig from every replicate was selected for transport to a local abattoir. After at least two hours rest, blood samples were collected and then the pigs were electrically stunned (250 V, 0.5 A, for 5 s), exsanguinated, and eviscerated according to standard commercial procedure. The carcass was split down the center of the vertebral column, which was approved by the Institutional Animal Care and Use Committee of China Agricultural University. Plasma was collected by centrifugation at 4,000×g for 10 min within 2 h after collection and stored at -20°C until analysis.

All the parameters were measured on the left side of each carcass, including hot carcass weight, carcass length (from the cramal tip of the aitch bone to the cranial edge of the first rib adjacent to the thoracic vertebra), shoulder back fat depth, average back fat depth, back fat depth of 6th-7th rib, 10th rib fat depth, last rib back fat depth, loin eye width and depth (loin eye area (cm^2) = loin eye width (cm)×depth (cm)×0.7). Subjective color and marbling scores on the longissimus dorsi muscle were evaluated on the 10th-11th rib surface according to NPPC (1999) guidelines. L*, a*, and b* values of objective color were determined by Colorimeter (Chromameter, CR410, Minolta, Japan) according to the standard method of CIE Lab system.

At 45 min postmortem, an incision was made on the longissimus dorsi muscle and initial muscle $pH^{45\ min}$ value was measured with a SPK pH meter (PH star, DK-2730, Herlev, Denmark). Meanwhile, the $pH^{24\ h}$ value was detected at 24 h postmortem in 4°C freezer.

The water loss rate of longissimus dorsi muscle at the 1st and 2nd lumbar vertebra was measured according to a modified method which had been made by Nanjing Agricultural University (China) based on Kauffman et al. (1986). A 1 cm slice of longissimus dorsi muscle covered by absorbent gauze was put in the middle of 18 layers of filter paper on each side, with the outer side attached to a hard plastic board. After applying a steady pressure with 35 kg for 5 minutes with a Soil Permission Dilatometer(WZ-II, Nanjing, China), then weighing the amount of absorbed water in the filter paper, the water loss ratewas calculated by the equation: (absorbed water weight/initial weight)×100%.

The meat samples from the longissimus dorsi muscle were first sheared into small tubes and freeze-dried and ground into powder. The moisture content was determined by drying at 105°C for 24 h. The determination of the intramuscular fat content of the longissimus dorsi muscle was conducted by the protocol of fat analysis (Association of Official Analytical Chemists, 1990) using a Tecator Soxtec Extraction System (Tecator AB, Hoganas, Sweden) (Fortin et al., 2005). The shear force of lumbar muscle and semitendinosus muscle was determined as outlined by Fortin (2005). Peak shear force (kg) was determined by using a digital-display muscle tenderness determination device (C-LM3, Harbin, China).

Blood samples were analyzed for plasma urea nitrogen (PUN) concentration with a TECHNICON RA-100 System (Tarrytown, NY, USA). Insulin was measured by Insulin Radioimmunoassay Kit from Beijing SINO-UK Institute of Biological Technology and the GC-911-γ-Radiation immunity arithmometer was purchased from Science and Technology Industry Corporation of China Scientific and Technical University. The glucose content of blood plasma was detected by Glucose Assay Kit purchased from Biosino Biotechnology Company Ltd. (Beijing, China).

Chemical analysis

Analyses for DM and CP were carried out according to AOAC (1990) methods. Lysine, threonine and isoleucine analyses of complete diets were by a Sykam Amino Acid Analyser (Sykam GmbH, Kleinostheim, Germany) following hydrolysis of the samples in 6 M HCl for 24 h at 100°C under an N atmosphere (Mason et al., 1980). The tryptophan content were analyzed after a alkaline hydrolysis method as described by Sato et al. (1987). The methionine and cysteine contents were determined as methionine sulfone and cysteic acid after oxidation with performic acid (AOAC, 1990) and then the oxidatized samples were detected same as the protocol of analyzing lysine content.

Statistical analyses

All data were analyzed as a randomized complete block design using the general linear model procedure of Statistical Analysis Systems (1999). Differences in the performance data, carcass characteristics, blood indexes and meat qualities among the three treatments was analyzed by Duncan's multiple-range tests following the finding of a significant *F*-value in the One-Way Analysis Of Variance model. Data are presented as the mean and pooled SEM. A one tailed Student's *t*-test (comparing the parameters between 60 and 90 kg) was used to determine how the lower lysine and energy diets influenced carcass characteristics and meat quality in the later finishing period. A probability value <0.05 was taken as statistical significance.

Table 2. The effects of different dietary lysine content and nutrient levels on pig growth performance

Treatment	Control	Low lysine	Low nutrient	SEM	p value
Overall 0-12 wks					
Daily gain (g)	867[a]	777[ab]	697[b]	41	<0.05
Daily intake (g)	1,964[b]	2,291[a]	2,096[ab]	104	0.12
Feed efficiency	0.44[a]	0.34[b]	0.33[b]	0.02	<0.01

[a, b, c] Within a column, means without a common superscript letter differ ($p<0.05$).

RESULTS AND DISCUSSION

Performance

From Table 2, it is apparent that lowering dietary lysine and energy level decreased both weight gain ($p<0.05$) and feed efficiency ($p<0.01$). Pigs fed the low lysine diet gained weight 10.3% slower than the control group while pigs fed low lysine-low energy diets gained weight 19.6% slower than the control. Feed efficiency declined 22.7% for pigs fed the low lysine diet while feed efficiency declined 25.0% for pigs fed the low lysine-low energy diet.

Consistent with our results, Szabó et al. (2001) identified that reducing the lysine: DE ratio from 0.50/0.43 to 0.36/0.30 (by about 28%) reduced body weight gain by 119 g/d from 30 to 60 kg and by 151 g/d from 60 to 105 kg body weight. Witte et al. (2000) reported that pigs fed lysine-deficient diet had a poorer feed efficiency than those fed to requirement ($p<0.01$); however, dietary lysine content did not influence average daily gain and feed intake. Likewise, Chang et al. (2005) also showed that the lysine deficiency resulted in, significantly ($p<0.05$), lighter body weights, smaller muscles and a slower growth rate.

Blood index

During the 60 kg body weight period (shown in Table 3), lowering dietary nutrient level significantly reduced plasma insulin level ($p<0.05$); moreover, the plasma insulin level of low nutrient level group was obviously lower than that of low lysine content group. At 90 kg body weight phase (shown in Table 3), the plasma urea nitrogen were increased markedly by lowering dietary nutrient level ($p<0.01$). Comparative analysis on 60 and 90 kg body weight period (shown in Table 6), under feeding NRC requirement diet the plasma insulin level ($p<0.01$) and plasma urea nitrogen (PUN) ($p<0.10$) concentration were decreased; In low lysine content group, plasma glucose level was decreased ($p<0.10$); Similarly, plasma glucose ($p<0.05$) and insulin level ($p<0.01$) were increased as well in low nutrient level group.

Some reports from the literature indicated that plasma insulin levels are low during energy restriction in most species (Grey et al., 1970; Trenkle, 1972); Besides, Young et al. (1973) certified that plasma insulin levels were significantly lower in protein-deprived rats; the same result also was founded in weaned pigs by Tola et al. (1976). From this experimental result, we could find the blood insulin concentration of low lysine and low nutrient groups in two body weight phases all lower than that of control group, especially for low nutrient group. The mechanism of insulin concentration changes maybe because of low dietary energy and protein level impaired pancreatic exocrine function. Likewise, Barbezat et al. (1968) also identified that chronic malnutrition could resulted in pancreatic exocrine function damage.

It is widely accepted that the PUN concentration can reflect the extent of amino acid breakdown and is negatively related to the utilization of dietary protein (Eggum et al., 1970). Some results showed that plasma urea nitrogen (PUN) concentrations decreased as lysine:DE ratio increasing and tended to decrease as the energy density increased (Lewis et al., 1980; Nam and Aherne et al., 1994; Smith et al., 1999). The previous results of plasma PUN in 90 kg slaughter period and comparisons between 60 and 90 kg in control group both represented the nitrogen deposition in the body would be decreased corresponding to the results of lean percentage changes. However, to our surprised was that the changes between 60 and 90 kg in low lysine and nutrient group not obviously, the possible reason was that the low dietary lysine content and nutrient level used in the

Table 3. The effects of different dietary lysine content and nutrient levels on pig blood indexes in 60 and 90 kg body weight periods

Items	Control	Low lysine	Low nutrient	SEM	p value
60 kg					
Glucose (mg/dl)	72.65	83.10	79.38	6.94	0.59
Insulin (μIU/ml)	2.32[a]	2.04[a]	0.65[b]	0.41	<0.10
PUN (mg/dl)	24.00	24.33	26.00	2.17	0.78
90 kg					
Glucose (mg/dl)	76.35	66.84	72.65	4.12	0.29
Insulin (μIU/ml)	3.10	2.49	1.76	0.49	0.24
PUN (mg/dl)	17.00[b]	20.00[b]	23.50[a]	1.30	<0.05

[a, b, c] Within a column, means without a common superscript letter differ ($p<0.05$).

Table 4. Effects of different dietary lysine content and nutrient levels on carcass characteristics and meat quality of 60 kg PIC pigs

Items	Control	Low lysine	Low nutrient	SEM	p value
Carcass length (cm)	83.71	84.83	85.00	0.97	0.60
Dressing (%)	69.51[a]	67.31[b]	66.22[b]	0.60	<0.01
Lean (%)	57.62	55.67	59.45	1.56	0.26
Shoulder back fat depth (cm)	3.73	3.40	3.31	0.21	0.34
Back fat depth of 6th-7th rib (cm)	2.18[a]	1.79[b]	1.94[ab]	0.12	0.10
10th-rib fat depth (cm)	1.81	1.65	1.60	0.13	0.55
Back fat depth of last rib (cm)	1.61[a]	1.37[b]	1.36[b]	0.08	<0.10
Loin area $(cm)^2$	25.51	24.81	23.81	1.05	0.53
pH $^{45\ min}$ value	6.40[a]	6.20[b]	6.33[a]	0.04	<0.05
pH $^{24\ h}$ value	5.53	5.51	5.49	0.04	0.73
Marbling [d]	1.64[a]	2.17[b]	2.11[b]	0.17	<0.10
Intramuscular fat (IMF, %)	1.05[a]	1.26[ab]	1.49[b]	0.14	<0.10
American color [e]	3.36	3.42	3.44	0.15	0.92
Lightness (L*) [f]	43.79	43.57	42.25	0.61	0.16
Redness (a*) [f]	14.00	14.96	14.67	0.43	0.33
Yellowness (b*) [f]	5.41[a]	5.20[ab]	4.80[b]	0.17	<0.05
Shear force of lumber muscle (kg)	3.70	3.31	3.22	0.24	0.30
Shear force of semitendinosus muscle (kg)	4.11[a]	3.41[b]	4.37[a]	0.22	<0.05
Water loss rate (%)	15.21[a]	18.68[b]	20.06[b]	0.88	<0.01

[a, b, c] Within a column, means without a common superscript letter differ ($p<0.05$).
[d] Marbling score: 1 = 1% intramuscular lipid and 10 = 10% intramuscular lipid (NPPC, 1999).
[e] American color score: 1 = pale pinkish gray and 6 = dark purplish red (NPPC, 1999).
[f] L* = measure of lightness to darkness; a* = measure of redness; b* = measure of yellowness.

experiment were both lower than NRC recommendation level, even the NRC recommendation level still was a maintenance nutrition level, thus the growth of PIC pigs might been limited by lower dietary nutrient level and resulted in the protein deposition potential could not be mostly exhibited, so we couldn't find the changes tendency just like observed in the control group.

Carcass characteristics and meat qualities

At the period of 60 kg body weight (shown in Table 4), lowering dietary lysine content and nutrient levels noticeably decreased dressing percentage ($p<0.01$), 6th-7th rib ($p<0.05$) and last rib ($p<0.10$) back fat depth of PIC pigs. Similarly, other point back fat depth also showed the same tendency but not significantly. Reducing dietary lysine

Table 5. Effects of different dietary lysine content and nutrient levels on carcass characteristics and meat quality of 90 kg PIC pigs

Items	Control	Low lysine	Low nutrient	SEM	p value
Carcass length (cm)	94.67	95.83	96.00	0.79	0.40
Dressing (%)	70.70	71.70	70.55	0.54	0.29
Lean (%)	58.67[a]	54.67[b]	53.82[b]	0.98	<0.01
Shoulder back fat depth (cm)	3.61[a]	4.03[b]	3.99[b]	0.12	<0.05
Back fat depth of 6th-7th rib (cm)	2.53	2.69	2.70	0.11	0.42
10th-rib fat depth (cm)	2.33[a]	2.32[a]	2.71[b]	0.11	<0.10
Back fat depth of last rib (cm)	1.93[a]	1.88[a]	2.33[b]	0.10	<0.05
Loin area (cm^2)	39.84[a]	36.65[ab]	34.12[b]	1.15	<0.05
pH $^{45\ min}$ value	6.29	6.34	6.38	0.06	0.59
pH $^{24\ h}$ value	5.61	5.65	5.67	0.02	0.14
Marbling[d]	2.50[a]	2.88[b]	2.86[b]	0.14	0.12
Intramuscular fat (IMF, %)	1.39[a]	1.35[a]	1.88[b]	0.16	<0.10
American color [e]	3.60	3.50	3.71	0.09	0.26
Lightness (L*) [f]	41.62	42.13	40.97	0.54	0.39
Redness (a*) [f]	15.03[a]	15.48[a]	16.51[b]	0.23	<0.01
Yellowness (b*) [f]	5.40	5.16	5.21	0.18	0.59
Shear force of lumber muscle (kg)	3.65	3.85	3.43	0.15	0.16
Shear force of semitendinosus muscle (kg)	4.79[a]	3.73[b]	4.35[a]	0.17	<0.01
Water loss rate (%)	16.59[a]	17.86[ab]	19.23[b]	0.70	<0.10

[a, b, c] Within a column, means without a common superscript letter differ ($p<0.05$).
[d] Marbling score: 1 = 1% intramuscular lipid and 10 = 10% intramuscular lipid (NPPC, 1999).
[e] American color score: 1 = pale pinkish gray and 6 = dark purplish red (NPPC, 1999).
[f] L* = measure of lightness to darkness; a* = measure of redness; b* = measure of yellowness.

content apparently decreased the shear force of semitendinosus muscle ($p<0.05$). The yellowness of the longissimus dorsi muscle was decreased by reducing dietary nutrient level ($p<0.05$). Besides, lowering dietary lysine content and nutrient level also enhanced marbling scores ($p<0.10$), intramuscular fat content ($p<0.10$) and water loss rate ($p<0.01$) of the longissimus dorsi muscle.

During 90 kg body weight (shown in Table 5), lean percentage ($p<0.01$) was evidently reduced and shoulder back depth ($p<0.05$), marbling scores of loin eye muscle ($p<0.05$) were enhanced by both lowering lysine content and nutrient level in the diet. Lowering dietary nutrient level could improve 10th rib ($p<0.10$) and last rib back fat depth ($p<0.05$), intramuscular fat content ($p<0.10$), redness ($p<0.01$) and water loss rate ($p<0.10$) of the loin eye muscle.

By comparison between the 60 kg and 90 kg body weight periods (shown in Table 6), It was found that the carcass length ($p<0.01$), dressing percentage ($p<0.01$) and loin area ($p<0.01$) of three treatment groups all had a obvious increase from 60 kg body weight to 90 kg period. The shoulder back fat depth ($p<0.10$), 6th-7th rib ($p<0.01$), 10th-rib ($p<0.01$), last rib back fat depth ($p<0.01$) of lowering lysine content and nutrient level treatment group were totally increased comparing with control group. Besides, the apparent marbling scores ($p<0.01$) and intramuscular fat content of longissimus dorsi muscle were improved with body weight increases.

Currently, it has been widely accepted that pork carcass fatness increases in response to elevating dietary ME or DE density (Lawrence et al., 1994; Nam and Aherne et al., 1994; Apple et al., 2004). About the effects of lysine:energy ratio on carcass fatness, generally, lowering the lysine:DE ratio increased fat tissue content in the body (Batterham et al., 1990; Castell et al., 1994; Nam and Aherne et al., 1994; Smith et al., 1999). This phenomena mainly because of the protein-deficient diets resulted in an increase in the amount of energy available for fat deposition (Cisneros et al., 1996).

Cromwell et al. (1978) and Ellis et al. (1996) reported that longissimus muscle (LM) area was increased by increasing dietary ME. Some researchers reported that LM area decreased slightly with increasing dietary energy density but hasn't significant difference (Matthews et al., 1998, 2003; Apple et al., 2004). LM area has been shown to increase in response to increase dietary lysine:energy (Grandhi and Cliplef, 1997; Cameron et al., 1999) and lysine level (Goodband et al., 1990; Witte et al., 2000) in the diets. Therefore, lean percentage has also been increased by increasing the lysine:energy ratio (Szabó et al., 2001; Apple et al., 2004) and lysine level (Dourmad et al., 1996; Witte et al., 2000) in pig diets.

The a* values are chromatic coordinates representing a change from green to red color. A higher a* value indicates a sample with more red color. The b* values are also chromatic coordinates, representing a change in color from

Table 6. Comparisons of carcass characteristics, meat qualities and blood indexes between 60 and 90 kg body weight in PIC pigs

Items	Control		p-value [a]	Low lysine		p-value [a]	Low nutrient		p-value [a]
	60 kg	90 kg		60 kg	90 kg		60 kg	90 kg	
Carcass length (cm)	83.71	94.67	<0.01	84.83	95.83	<0.01	85.00	96.00	<0.01
Dressing (%)	69.51	70.70	0.06	67.31	71.70	<0.01	66.22	70.55	<0.01
Lean (%)	57.62	58.67	0.46	55.67	54.67	<0.01	59.45	53.82	0.71
Shoulder backfat depth (cm)	3.73	3.61	0.52	3.40	4.03	<0.01	3.31	3.99	<0.01
Backfat depth of 6^{th}-7^{th} rib (cm)	2.18	2.53	0.06	1.79	2.69	<0.01	1.94	2.70	<0.01
10^{th}-rib fat depth (cm)	1.81	2.33	0.12	1.65	2.32	<0.01	1.60	2.71	<0.01
Backfat depth of last rib (cm)	1.61	1.93	<0.05	1.37	1.88	<0.01	1.36	2.33	<0.01
Loin area (cm^2)	25.51	39.84	<0.01	24.81	36.65	<0.01	23.81	34.12	<0.01
$pH^{45\ min}$ value	6.40	6.29	0.07	6.20	6.34	0.21	6.33	6.38	0.58
$PH^{24\ h}$ value	5.53	5.61	0.08	5.51	5.65	0.15	5.49	5.67	<0.01
Marbling	1.64	2.50	<0.01	2.17	2.88	<0.01	2.11	2.86	<0.05
Intramuscular fat (IMF, %)	1.05	1.39	0.12	1.26	1.35	0.68	1.49	1.88	0.10
American color [b]	3.36	3.60	0.16	3.42	3.50	0.66	3.44	3.71	0.17
Lightness (L*) [c]	43.79	41.62	<0.05	43.57	42.13	0.19	42.25	40.97	0.22
Redness (a*) [c]	14.00	15.03	<0.01	14.96	15.48	0.13	14.67	16.51	0.06
Yellowness (b*) [c]	5.41	5.40	0.41	5.20	5.16	0.63	4.80	5.21	0.15
Shear force of lumber muscle (kg)	3.70	3.65	0.81	3.31	3.85	0.15	3.22	3.43	0.63
Shear force of semitendinosus muscle (kg)	4.11	4.79	0.59	3.41	3.73	0.64	4.37	4.35	<0.05
Water loss rate (%)	15.21	16.59	0.40	18.68	17.86	0.48	20.08	19.23	0.84
Glucose (mg/dl)	78.80	79.00	0.96	83.10	67.00	0.02	85.70	65.00	0.10
Insulin (μIU/ml)	1.99	3.47	<0.01	2.04	3.36	<0.01	0.65	1.76	0.18
PUN (mg/dl)	26.14	21.50	0.09	24.33	23.57	0.77	26.00	24.20	0.42

[a] Levels of significances is $p<0.05$.

[b] American color score: 1 = pale pinkish gray and 6 = dark purplish red (NPPC, 1999).

[c] L* = measure of lightness to darkness; a* = measure of redness; b* = measure of yellowness.

blue to yellow. The higher b* value, the more yellow the sample is in color (Real et al., 2002). In present studies, low nutrient stimulated the increase of yellowness of the longissimus dorsi muscle at 60 kg body weight period ($p<0.05$) and improved redness value at 90 kg body weight period ($p<0.05$). But when comparing the objective color values between 60 and 90 kg body weight, we concluded that the lightness of control group decreased ($p<0.05$) and redness increased markedly ($p<0.01$). The redness of low nutrient group was enhanced ($p<0.10$) from 60 kg to 90 kg body weight slaughter period.

According to the relationship between the dietary energy density and intramuscular fat content of longissimus dorsi muscle, many studies had different results. Liu et al. (2007) reported that dietary energy level has a linear relationship with intramuscular fat, meanwhile, dietary energy level regulates intramuscular lipid accumulation by modulating the mRNA of FAS and HSL together rather than individually. In agreement with the results from the present results, numerous studies had also shown that intramuscular fat content was increased by feeding protein or lysine-deficient diets (Goodband et al., 1990; Witte et al., 2000; Szabó et al., 2001; Apple et al., 2004) and decreased lysine:energy ratio (Castell et al., 1994; Grandhi and Cliplef, 1997; Cameron et al., 1999) throughout the growing and finishing phases. Katsumata et al. (2007) used a low lysine diet (lysine content was 0.40%) meeting approximately 70% of the requirement of lysine was given to finishing gilts for two months. The results showed that IMF contents in longissimus dorsi muscle of the pigs given the low lysine diet were twice higher than those of the gilts fed on a control diet (lysine content was 0.65%). However, Cromwell et al. (1978) and Le Dividich et al. (1987) certified that intramuscular fat content increased with increasing dietary energy density. Other studies showed that dietary energy level had no effect on marbling scores and intramuscular fat content (Seerley et al., 1978; Coffey et al., 1982; Myer et al., 1992). Ensuring ultimate pH value ($pH^{24\,h}$ value) of muscle below 6.0 is one of the most significant factors implicated in determining the shelf life quality of meat (Martin et al., 1997). From our results, we can notice that the ultimate pH value were all less than 6.0, specifically, in 60 kg slaughter body weight period lowering dietary lysine content decreased the $pH^{45\,min}$ value; From 60 to 90 kg body weight period, the $pH^{45\,min}$ value ($p<0.10$) was decreased, the $pH^{24\,h}$ value of control ($p<0.10$) and low nutrient group ($p<0.05$) both have been increased.

From Table 4 and 5, we could conclude that lowering dietary lysine content evidently decreased the shear force of semitendinosus muscle in 60 and 90 kg slaughter body weight period ($p<0.05$, $p<0.01$) and thus contributed to improve meat quality. Similarly, Apple et al. (2004) showed that there was a linear increase ($p<0.01$) in shear force of cooked LM chops as lysine:ME increased in the finishing diet. A bigger water loss rate can make considerable commercial losses in meat production. In present experimental results, both lowering dietary lysine content and nutrient level increased water loss rate in 60 kg and 90 kg period, especially for lowering nutrient level affected more obviously. Whereas, there also had some disagreements with dietary lysine or lysine:energy ratio had no influence on drip loss percent (Castell et al., 1994; Witte et al., 2000). The table 6 showed that decreasing dietary lysine content and nutrient level in late finishing were more inclined to stimulating back fat deposition of PIC pigs. Abdul et al. (1993) identified that the impressive gains in body fat during recovery from malnutrition may result not only from unbalanced diets on excess dietary intake, but also from a transitory enhancement in the efficiency of food utilization and a shift in energy partitioning in favor of an acceleration for the replenishment of fat stores.

In summary, although lowering dietary lysine content and nutrient under NRC requirement decreased growth performance of PIC pigs, but contributed to stimulate intramuscular fat content of longissimus dorsi muscle and improved marbling scores in growing-finishing period. A negative effect on water loss rate of longissimus dorsi muscle maybe was what we wouldn't like to see. The most surprised result was that in later finishing period lowering lysine and nutrient level group exhibited a obvious compensatory fat deposition (both in back fat and intramuscular fat content) in contrast to control group.

IMPLICATIONS

It was generally accepted that intramuscular fat content has a positive influence on the meat quality and visible sensory attribute which were important to affect customer to make a determination on purchasing. Results of present study indicated that although lowering dietary lysine content and nutrient level both decreased growth performance significantly but it could contributed to noticeably increased marbling scores or intramuscular fat content of longissimus dorsi muscle both in 60 kg and 90 kg body weight period. Especially, under the conditions of low nutrient level (lower dietary energy and lysine content), higher intramuscular fat content tended to be more formed in PIC barrows. Moreover, this experiment also reported that when low lysine content and nutrient level diet were fed for PIC pigs, it was that late finishing period (body weight from 60 to 90 kg) is the crucial period for intramuscular fat and back fat deposition. This result was similar to the result of previous research results, but the pig's gender, diet and experiment subject they used still have some differences with us. Totally, our experimental result was a helpful validation and supplement for previous

studies. Further works will be considered to study which group of genes regulating fat deposition in later finishing phase and explore how the diet influenced these gene's mRNA expression which will provided a valuable direction to improve meat quality by using diet or used them as a genetic marker for selection in pig breeding.

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