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Effect of Dietary Lysine Restriction and Energy Density on Performance, Nutrient Digestibility and Meat Quality in Finishing Pigs

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ABSTRACT : This experiment evaluated the effects of dietary lysine restriction and energy density on growth performance, nutrient digestibility and meat quality of finishing pigs. A 2×2 factorial arrangement of treatments was utilized in a randomized complete block (RCB) design, and factor 1 was lysine restriction and factor 2 was energy density. The control diet was formulated to contain 3.265 Mcal of ME/kg, 0.75% lysine in the early-finishing phase and 3.265 Mcal of ME/kg, 0.60% lysine in the late-finishing phase and other nutrients met or exceeded NRC (1998) standards. Compared to the control diet (CON), lysine levels of experimental diets were restricted to 15% (treatment EL, EEL) or 30% (treatment ELL, EELL), whereas energy level of experimental diets was increased by 0.100 or 0.200 Mcal of ME/kg. A total of 100 crossbred pigs ([Yorkshire×Landrace]×Duroc), with average initial body weight of 58.47±1.42 kg, were allotted to 5 dietary treatments based on sex and body weight. Each treatment had 5 replicates with 4 pigs (two barrows and two gilts) per pen. ADG, ADFI and feed efficiency were calculated in an 8-week growth trial. In the late finishing period (5-8 weeks), pigs fed ELL or EELL diets had decreased ADG and feed efficiency ($p<0.01$), however, when the EEL diet was provided, a similar growth performance was observed compared to those fed the CON diet during the whole experimental period ($p>0.05$). In a metabolic trial, 15 pigs were used to evaluate the effect of dietary lysine restriction and energy density on nutrient digestibility. The digestibility of dry matter, crude fat and crude ash was not improved by restricting dietary lysine or energy density. However, crude protein digestibility was decreased ($p<0.05$) as dietary lysine was restricted. When dietary lysine was restricted, fecal nitrogen was increased whereas nitrogen retention was decreased. BUN concentration was affected by dietary lysine restriction; treatments ELL and EELL had higher BUN values than other treatments ($p<0.01$). Carcass characteristics and meat quality were measured when average body weight of pigs reached 107.83±1.50 kg. Treatment ELL had higher last rib backfat depth ($p<0.05$) than treatment CON, but ELL and EEL did not differ significantly. The ELL and EEL treatments had higher ($p<0.05$) subjective marbling score than treatment CON. Treatment EEL showed higher *longissimus* fat content than treatment EL and CON ($p<0.01$). The results indicated that finishing pigs fed a diet with 15% lysine restriction and 3.465 Mcal of ME/kg energy density had no detrimental effects on growth performance and N utilization, and could achieve substantial increases in marbling and *longissimus* fat content of pork. (**Key Words :** Lysine, Dietary Energy, Growth, Meat Quality, Finishing Pig)

INTRODUCTION

The carcass lean content of pigs has dramatically increased over recent years and has resulted to a corresponding reduction in intramuscular fat and marbling (Rincker et al., 2008). However, increasing intramuscular fat content is generally considered as a means to enhance consumer acceptability of pork chops in many countries, particularly South Korea (Schwab et al., 2006). Furthermore, in case of Japanese pork market, marbling score has been considered the most important factor for pricing the pork and prices of high marbled pork loin are even more two times than normal pork loin (Kenji, 2002). The relationship between intramuscular fat and pork eating quality has not been clearly established. Several studies suggested a favorable relationship among intramuscular fat, juiciness and tenderness of pork (Castell et al., 1994), and other studies investigated the threshold or minimum level for marbling that is required to ensure good eating quality (DeVol et al., 1988). Because of these specifications, the most promising approach to increasing intramuscular fat is via genetic selection and nutritional management (Ellis et al., 1996).

There are a number of reports demonstrating increases

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in intramuscular fat levels from feeding of protein deficient diets throughout the growing and finishing periods (Castell et al., 1994). However, these studies also reported high carcass fat levels and low feed efficiency from the use of protein deficient diets, and therefore such diets are unlikely to be economical in most situations. However, intramuscular fat content was increased by feeding lysine deficient diet or diets with low lysine:energy ratios (Zhang et al., 2008). On the other hand, numerous studies have reported that the efficiency of digestible lysine for growth was close to 70%, with the available results ranging between 50 and 77% in growing pigs (Bikker et al., 1994); however, the efficiency of digestible lysine for finishing-pig's growth and carcass characteristics has not been fully elucidated. Consequently, this study was conducted to evaluate the effects of lower dietary lysine and higher energy density on growth performance, nutrient digestibility, and pork quality of finishing pigs.

MATERIALS AND METHODS

Experimental design and growth trial

An experiment was conducted to evaluate the effects of restricted lysine with higher energy density in finishing pigs' diet on growth and pork quality. A 2×2 factorial arrangement of treatments was used in a randomized complete block (RCB) design, with a NRC (1998) recommendation diet as the control treatment. The formula and chemical composition of experimental diets are presented in Table 1 and 2.

The dietary treatments for body weight of early- and late-finishing pigs were: i) CON (NRC recommendation, 1998: 3.265 Mcal of ME/kg, 0.75% lysine in early-finishing phase diet and 0.60% lysine in late-finishing phase diet); ii) EL (3.365 Mcal of ME/kg, lysine level restricted to 15% of level in basal diet); iii) ELL (3.365 Mcal of ME/kg, lysine level restricted to 30%); iv) EEL (3.465 Mcal of ME/kg, lysine level restricted to 15%); v) EELL (3.465 Mcal of ME/kg, lysine level restricted to 30%). A total of 100 crossbred pigs ([Yorkshire×Landrace]×Duroc), with average initial body weight of 58.47±1.42 kg, were allotted to 5 dietary treatments based on sex and body weight. Each treatment had 5 replicates with 4 pigs (two barrows and two gilts) per pen. Pigs were housed in conventional facilities with a half-slatted concrete floor (1.60×3.00 m^2). During the 8 weeks feeding trial, pigs were allowed *ad libitum* access to diets and water. Body weight and feed intake were recorded at 4^{th} and 8^{th} week. Average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G:F ratio) were calculated.

Table 1. Ingredient and nutrient composition of the experimental diets in early finishing phase (0-4 weeks)

Treatment	CON	EL	ELL	EEL	EELL
ME (Mcal/kg)	3.265	+0.100	+0.100	+0.200	+0.200
Lysine (%)	0.75/0.60	0.64/0.51	0.53/0.42	0.64/0.51	0.53/0.42
Corn	73.67	72.99	72.85	71.97	71.74
Soybean meal-46	12.00	8.39	5.84	9.01	6.45
Wheat bran	2.00	2.04	3.17	0.68	1.91
Molasses	0.70	0.70	0.70	0.70	0.70
Copra meal	5.00	5.00	5.00	5.00	5.00
Corn gluten meal	4.66	7.29	8.91	7.29	8.91
Soy oil	0.00	1.64	1.63	3.40	3.40
Limestone	0.38	0.33	0.32	0.27	0.26
TCP	0.89	0.97	1.01	1.03	1.06
L-lysine-HCl	0.20	0.15	0.07	0.15	0.07
Salt	0.30	0.30	0.30	0.30	0.30
Vit.Mix.[1]	0.10	0.10	0.10	0.10	0.10
Min.Mix.[2]	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00
Chemical composition[3]					
ME (Mcal/kg)	3.232	3.328	3.335	3.426	3.436
Crude protein (%)	15.54	15.51	15.40	15.52	15.43
Lysine (%)	0.75	0.64	0.54	0.62	0.52
Calcium (%)	0.46	0.54	0.52	0.46	0.51
Phosphorus (%)	0.47	0.46	0.46	0.45	0.44
Lysine/ME (g/Mcal)	2.32	1.92	1.62	1.81	1.51

[1] Provided the following per kilogram of diet: vitamin A, 8,000.00 IU; vitamin D, 1,600.00 IU; vitamin E, 17.40 IU; vitamin K_3, 2.40 mg; vitamin B_2, 3.20 mg; Pantothenate, 8.00 mg; Niacin,16.00 mg; Biotin,0.1 mg; Ethoxquin,12.00 mg; vitamin B_{12},12.00 g.

[2] Provided the following per kilogram of diet: Fe, 79.57 mg; Cu, 68.68 mg; Zn, 37.74 mg; Mn, 15.50 mg; Co, 0.16 mg; Ca, 0.18 mg.

[3] Analyzed values.

Table 2. Ingredient and nutrient composition of the experimental diets in late finishing phase (5-8 weeks)

Treatment	CON	EL	ELL	EEL	EELL
ME (Mcal/kg)	3.265	+0.100	+0.100	+0.200	+0.200
Lysine (%)	0.75/0.60	0.64/0.51	0.53/0.42	0.64/0.51	0.53/0.42
Corn	77.93	76.53	75.83	74.78	73.98
Soybean meal-46	13.57	9.01	4.51	9.62	4.50
Wheat bran	1.13	2.30	4.86	1.61	4.54
Molasses	0.70	0.70	0.70	0.70	0.70
Copra meal	5.00	5.00	5.00	5.00	5.00
Corn gluten meal	0.06	3.08	5.66	3.02	5.96
Soy oil	0.00	1.74	1.78	3.62	3.66
Limestone	0.46	0.42	0.44	0.42	0.44
TCP	0.64	0.71	0.71	0.71	0.71
L-lysine-HCl	0.01	0.01	0.01	0.01	0.01
Salt	0.30	0.30	0.30	0.30	0.30
Vit. Mix.[1]	0.10	0.10	0.10	0.10	0.10
Min. Mix.[2]	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00
Chemical composition[3]					
ME (Mcal/kg)	3.225	3.315	3.306	3.413	3.402
Crude protein (%)	13.20	13.23	13.22	13.26	13.24
Lysine (%)	0.62	0.50	0.40	0.53	0.43
Calcium (%)	0.48	0.44	0.46	0.46	0.46
Phosphorus (%)	0.41	0.42	0.39	0.40	0.44
Lysine/ME (g/Mcal)	1.92	1.60	1.30	1.49	1.23

[1] Provided the following per kilogram of diet: vitamin A, 8,000.00 IU; vitamin D, 1,600.00 IU; vitamin E, 17.40 IU; vitamin K_3, 2.40 mg; vitamin B_2, 3.20 mg; Pantothenate, 8.00 mg; Niacin,16.00 mg; Biotin,0.1 mg; Ethoxquin,12.00 mg; vitamin B_{12},12.00 g.
[2] Provided the following per kilogram of diet: Fe, 79.57 mg; Cu, 68.68 mg; Zn, 37.74 mg; Mn, 15.50 mg; Co, 0.16 mg; Ca, 0.18 mg.
[3] Analyzed values.

Blood samples were collected from the anterior vena cava of 6 pigs per treatment at 4 weeks interval. The blood sample was collected in disposable glass tubes; then centrifuged for 15 min at 3,000 rpm on 4°C (Eppendorf centrifuge 5810R, Germany). The serum was carefully separated, frozen and analyzed for blood urea nitrogen concentration, using a blood analyzer (Ciba-Corning model, Express Plus, Ciba Corning Diagnostics Co.).

Metabolism trial

Fifteen barrows (62.97±0.71 kg average initial body weight) were housed individually in a metabolic crate (slatted floors made of plastic, 0.93×1.53 m^2). Pigs were allotted to 5 treatments with 3 replicates in a completely randomized design. After 7 d adjustment to the experimental diets, pigs were subjected to 5 d of collection period. During collection period, pigs were fed their treatment diet of 500 g twice a day (08:00 and 20:00), and water provided *ad libitum*. Total collected excreta were pooled, sealed and stored at -20°C until analyzed. Collected fecal samples were dried in an air-forced drying oven at 60°C for 72 h, and ground into 1 mm particles in a Wiley mill for chemical analysis. Total urine was collected daily in a plastic container containing 50 ml of 4N H_2SO_4 (Duksan pure chemicals co., Ltd., Gyunggido, Korea) for prevention of nitrogen evaporation from urine and was frozen during the 5 day collection period for nitrogen retention analyses.

Carcass characteristics and meat quality

After completion of the finishing period, pigs fed experimental diet until slaughtered. When the average body weight reached market weight, 4 barrows and 4 gilts from each treatment were selected with similar body weights (107.83±1.50 kg) for transport to a local commercial abattoir. After at least 2 h rest, pigs were slaughtered according to industry accepted procedures. Meat samples were collected from longissimus muscle nearby 9th and 10th ribs on right side of carcass.

At 45 min postmortem, the longissimus muscle pH was measured using pH meter (IQ150, IQ instrument, CA, USA), and the pH_{24} value was detected at 24 h post-mortem in 4°C freezer. Commission International de l'Eclairage (CIE) L*, a*, and b* values were determined from a mean of three random readings made with a Hunter chromameter (CR 300, Minolta, Tokyo, Japan).

Drip loss, shear force, pork color and marbling score were measured at 24 h postmortem as followed. Drip loss percent was measured following a modified suspension procedure of Honikel et al. (1986) and filter-paper fluid uptake method (Kauffman et al., 1986). To calculate the cooking loss, longissimus muscle was packed in polyethylene bags and heated in a water bath until their core temperature reached 72°C and weighed before and after cooking. Pork color and marbling score were measured based on the National Pork Producers Council (NPPC, 1999) color standards.

Chemical analyses

Chemical analyses of proximate nutrients in diets, feces, and urine were conducted by the methods of AOAC (1995). The longissimus muscle was trimmed of connective tissue and external fat prior to homogenizing. Proximate analysis procedures for moisture and fat were conducted in duplicate on the homogenized sample using procedures described by Novakofski et al. (1989). Other nutrient analysis of longissimus muscle was conducted by the methods of the AOAC (1995).

Statistical analyses

Statistical analysis was performed by either a one-way analysis of variance (ANOVA) or a two-way ANOVA followed by the Least Significant Difference (LSD) test (SAS, 2006). Differences among treatments were determined by one-way ANOVA test. And except control treatment, other four treatments were analyzed by two-way ANOVA with energy density and lysine level. The pen was considered the experimental unit for performance data, whereas individual pig data served as the experimental unit in nutrient digestibility and carcass meat quality evaluation data. Differences with probability levels of $p<0.05$ were considered significant difference.

RESULTS AND DISCUSSION

Growth performance

The effects of dietary lysine and energy density on the growth performance of finishing pigs are shown in Table 3. During late finishing period, lysine restriction caused linear decrease of ADG and G:F ratio numerically. When pigs were fed diets which had 30% restricted lysine (ELL, EELL) showed significantly lower ADG and feed efficiency ($p<0.01$) compared to pigs fed CON diet. Castell et al. (1994) similarly reported that feed efficiency was decreased linearly as the lysine:energy ratio increased in swine diets, and G:F ratio had been shown to increase in response to

Table 3. Effect of dietary lysine restriction and energy density on the growth performance in finishing pigs

	CON[1]	EL	ELL	EEL	EELL	SEM[2]	Probability		
							ME	Lys	Lys×ME
Body weight (kg)									
Initial	58.47	58.47	58.44	58.45	58.51	1.26	-	-	-
4 week	84.41	81.19	81.09	83.12	81.71	1.42	0.44	0.65	0.69
8 week	103.77	97.89	95.86	100.84	95.04	1.61	0.67	0.13	0.46
Early finishing (0-4 weeks)									
ADG (g)	926	811	809	881	828	23.90	0.45	0.64	0.66
ADFI (g)	2,697	2,429	2,508	2,515	2,553	40.94	0.55	0.60	0.85
G:F ratio	0.343	0.329	0.323	0.350	0.324	0.01	0.34	0.18	0.39
Late finishing (5-8 weeks)									
ADG (g)	717^{A}	619^{AB}	547^{BC}	656^{AB}	494^{C}	23.74	0.84	0.01	0.26
ADFI (g)	2,700	2,504	2,421	2,530	2,363	41.92	0.89	0.28	0.72
G:F ratio	0.265^{A}	0.245^{AB}	0.226^{BC}	0.259^{A}	0.209^{C}	0.01	0.86	0.01	0.08
Total (0-8 weeks)									
ADG (g)	824	717	680	771	664	21.70	0.68	0.13	0.44
ADFI (g)	2,717	2,466	2,465	2,523	2,460	36.48	0.81	0.76	0.77
G:F ratio	0.303^{A}	0.287^{AB}	0.276^{B}	0.305^{A}	0.270^{B}	0.01	0.42	0.01	0.11
BUN (mg/dl)									
Initial	10.8	10.8	10.8	10.8	10.8	0.63	-	-	-
Early finishing	12.9^{B}	14.1^{B}	17.0^{A}	13.8^{B}	17.3^{A}	0.53	1.00	0.001	0.71
Late finishing	11.4^{b}	12.2^{b}	17.2^{a}	13.5^{ab}	17.4^{a}	0.85	0.68	0.01	0.75

[1] CON = NRC(1998) requirement/3.265 Mcal of ME/kg, Lysine-0.75% (early finishing),0.60% (late finishing); EL = CON+0.100 Mcal of ME/kg-Lysine 15% restriction to NRC requirement; ELL = CON+0.100 Mcal of ME/kg-lysine 30% restriction to NRC requirement; EEL = CON+0.200 Mcal of ME/kg-lysine 15% restriction to NRC requirement; EELL = CON+0.200 Mcal of ME/kg-lysine 30% restriction to NRC requirement.

[2] Standard error of mean.

[A, B, C] Means in the same row with different superscript letters differ significantly ($p<0.01$).

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

increasing lysine levels (Friesen et al., 1994). Moreover, across the entire 8-week feeding trial, neither energy density nor lysine×energy interaction affected (p>0.10) growth performance during the whole experimental period. The G:F ratio was affected by dietary lysine level, while treatment EEL improved G:F ratio compared to EL and EELL (p<0.01). However, ADG and ADFI were not affected by dietary treatments (p>0.10). It was clear that increasing dietary energy improved feed efficiency in pigs. In accord with the results of the present trial, Witte et al. (2000) reported that pigs fed lysine-deficient diet had a poorer feed efficiency than those fed diet met their nutrient requirement (p<0.01). Dietary lysine content, however, did not influence ADG and ADFI. Likewise, Zhang et al. (2008) also demonstrated that pigs fed low dietary lysine diet decreased feed efficiency (p<0.01). Similar ADFI responses were reported by Campbell and Taverner (1988), who found no difference in voluntary feed intake of pig fed iso-energetic diets varying in protein content. In contrast, Smith et al. (1999) observed decreased ADFI as the energy density of diets was increased. When pigs were fed 30% lysine restricted treatment diets (ELL and EELL), decreased ADG were observed (p<0.01) and these results demonstrated that decrease of lysine over 30% in diet affected ADG more than 15% restriction of dietary lysine in late finishing pigs. However, with *ad libitum* feeding and the same genotype, growth performance of finishing pigs was not affected by 15% restriction of dietary lysine if additional dietary energy (0.100 or 0.200 Mcal of ME/kg) was provided.

Serum BUN concentration

All pigs had consistent BUN concentration patterns (Table 3). Serum BUN concentration has been used as an indicator of maximal amino acid utilization (Eggum, 1970) and it was related to the status of protein metabolism and retained dietary nitrogen in the animal (Hahn et al., 1995). Numerous researchers reported that BUN concentrations were increased as lysine:energy ratio decreased (Smith et al., 1999). Similar results were observed in this study. Although there were no significant differences, BUN concentration tended to increase when pigs were fed EL and EEL diets compared to CON treatment. And pigs fed ELL and EELL diets had significantly higher BUN value during early (p<0.01) and late (p<0.05) finishing period of experiment compared to other treatments. Particularly the concentration of serum BUN increased when lysine content of experimental diet was restricted to 30% of NRC recommendation level. This result can be explained that lysine level was more restricted, resulting in unbalanced amino acid composition in the diet, the ability of protein synthesis decreased and then unavailable amino acids are destroyed, transported in blood and excreted as the form of urinary nitrogen.

Nutrient digestibility

The effect of dietary lysine and energy density on the nutrient digestibility and N utilization is presented in Table 4. The digestibility of dry matter, crude fat, and crude ash was not affected by restricted lysine level or energy density. However, crude protein digestibility was decreased by dietary lysine restriction (p<0.05). These results were in agreement with Cho et al. (2008) who reported that in pigs fed high-energy diets, increasing lysine:energy ratio improved crude protein digestibility. In contrast, Noblet et

Table 4. Effect of dietary lysine restriction and energy density on the nutrient digestibility in finishing pigs[1]

	CON[2]	EL	ELL	EEL	EELL	SEM[3]	Probability		
							ME	Lys	Lys×ME
Mean digestibility (%)									
Dry matter	85.42	87.00	85.85	86.56	87.30	0.30	0.44	0.75	0.17
ME	87.74	89.15	88.13	88.35	88.94	0.25	0.99	0.64	0.11
Crude Protein	82.83	82.38	79.09	82.49	79.37	0.59	0.86	0.02	0.94
Crude fat	55.28	56.90	52.30	52.82	53.18	0.93	0.99	0.97	0.63
Crude fiber	69.62	78.84	74.10	75.02	73.27	0.71	0.80	0.35	0.70
Lysine	82.65^{A}	80.01^{AB}	73.60^{C}	79.83^{AB}	75.68^{BC}	1.09	0.50	0.01	0.42
N-retention/d (g)									
N-intake	24.64	24.37	24.01	24.84	23.71	0.20	0.81	0.12	0.32
Fecal N	4.22	4.29	5.02	4.35	4.90	0.13	0.90	0.03	0.72
Urinary-N	4.75	6.23	7.41	7.75	8.38	0.51	0.20	0.34	0.77
N retention	15.67	13.85	11.57	12.74	10.44	0.63	0.38	0.05	0.99

[1] 15 pigs with an initial average weight of 62.19±2.63 kg.

[2] CON = NRC (1998) requirement/3.265 Mcal of ME/kg, Lysine-0.75% (early finishing),0.60% (late finishing); EL = CON+0.100 Mcal of ME/kg-Lysine 15% restriction to NRC requirement; ELL = CON+0.100 Mcal of ME/kg-lysine 30% restriction to NRC requirement; EEL = CON+0.200 Mcal of ME/kg-lysine 15% restriction to NRC requirement; EELL = CON+0.200 Mcal of ME/kg-lysine 30% restriction to NRC requirement.

[3] Standard error of mean.

[A, B, C] Means in the same row with different superscript letters differ significantly (p<0.01).

Table 5. Effect of dietary lysine restriction and energy density on carcass characteristics of longissimus muscle of finishing pigs[1]

	CON[2]	EL	ELL	EEL	EELL	SEM[3]	Probability		
							ME	Lys	Lys×ME
Carcass weight (kg)	79.13	79.75	80.63	80.63	79.25	0.39	0.79	0.79	0.23
Loin eye area (cm^2)	46.40	45.79	44.07	45.36	44.50	1.42	1.00	0.70	0.90
Last rib fat (mm)	17.75^{b}	17.88^{b}	23.75^{a}	20.13^{ab}	20.50^{ab}	0.75	0.73	0.04	0.07
NPPC meat color	2.81	2.74	2.46	2.95	2.64	0.08	0.27	0.10	0.91
NPPC marbling[4]	2.14^{b}	2.43^{ab}	3.11^{a}	3.00^{a}	2.83^{ab}	0.12	0.56	0.30	0.09

[1] Each treatment represents 8 pigs which weighed final body weight average 107.83±1.50 kg.
[2] CON = NRC (1998) requirement/3.265 Mcal of ME/kg, Lysine-0.75% (early finishing), 0.60% (late finishing); EL = CON+0.100 Mcal of ME/kg-Lysine 15% restriction to NRC requirement; ELL = CON+0.100 Mcal of ME/kg-lysine 30% restriction to NRC requirement; EEL = CON+0.200 Mcal of ME/kg-lysine 15% restriction to NRC requirement; EELL = CON+0.200 Mcal of ME/kg-lysine 30% restriction to NRC requirement.
[3] Standard error of mean.
[4] Marbling score: 1 = 1% intramuscular lipid and 10 = 10% intramuscular lipid (NPPC, 1999).
[a, b] Means in the same row with different superscript letters differ significantly ($p<0.05$).

al. (1987) demonstrated that lysine addition in low protein diet did not affect protein digestibility. And dietary lysine restriction increased fecal nitrogen and decreased nitrogen retention. The results of this study indicated that dietary lysine restriction lower the digestibility of protein and nitrogen retention and this result is in agreement with the results of growth performance which ADG and G:F ratio were decreased by dietary lysine restriction.

Carcass characteristics and meat quality

The effects of dietary lysine content and energy density on carcass characteristics are presented in Table 5. Carcass weights and subjective color were not affected by dietary treatments. Ellis et al. (1996) reported that longissimus muscle area was increased by increasing dietary energy content. But other studies demonstrated that longissimus muscle area was not affected by energy density (Matthews et al., 2003; Apple et al., 2004). Similar result was found in this study, wherein longissimus muscle area was not affected by dietary energy density or lysine content. The last rib backfat depth ($p<0.05$) of treatment ELL linearly increased (+6.00 and +5.87 mm) compared with CON and EL groups. The last rib backfat depth was affected by restricted lysine content ($p<0.05$). This result agreed with Castell et al. (1994) who reported that average backfat decreased linearly by increasing Lysine:ME ratio. Energy density did not affect carcass characteristics of longissimus muscle. However, tendency of lysine×energy interaction were observed in NPPC marbling score ($p = 0.09$) and last rib backfat depth ($p = 0.07$). In contrast, numerous researchers reported that pork carcass fatness increased in response to elevating dietary energy level (Myer et al., 1992) or energy intake (Ellis et al., 1996).

Dietary lysine level and energy density did not affect the pork quality trait measured except for longissimus fat content (Table 6). Hunter L* values were higher when finishing pigs were fed lysine deficient (ELL) diet, indicating paler muscle color in this treatment. These results were similar to the results of previous studies, wherein energy density in finishing diet of pigs did not affect longissmus pH, drip loss percent (Matthews et al., 2003), color or firmness (Matthews et al., 1998). And most researches had shown similar results that formulating diets based on CP, lysine, or lysine:energy ratio did not affect muscle pH, drip loss percent (Szabo et al., 2001), or other measures of water holding capacity (Goerl et al., 1995), subjective color scores (Witte et al., 2000), and L* values (Cameron et al., 1999). Witte et al. (2000) indicated that dietary lysine content did not alter cooking loss, which was consistent with results of the present study.

Additionally, moisture, protein and ash content of longissimus muscle did not differ among all treatments (Table 6), however, with increasing dietary energy density, pigs fed ELL and EEL diets had higher longissimus fat content than pigs in CON group ($p<0.01$). And the interactive effect of dietary lysine level and energy density was also detected on longissimus fat content ($p<0.05$). The results indicated that decreasing the lysine:ME ratio of diets for pigs improved longissimus fat content. In agreement with results from the present study, researchers have observed that marbling and intramuscular lipid content increased with increasing dietary energy density (Le Dividich et al., 1987), lowering the lysine:energy ratio (Smith et al., 1999) and decreasing dietary lysine level (Katsumata et al., 2007).

IMPLICATION

The increase in intramuscular fat level is generally considered as a means to enhance the acceptability of pork, particularly in Korea. Restriction of lysine during finishing period resulted in an increase of marbling score and longissimus fat content, especially when provided 15% restricted lysine diet with additional 0.200 Mcal of ME/kg. And overall, dietary lysine restriction to 15% of NRC

Table 6. Effect of dietary lysine restriction and energy density on meat quality of longissimus muscle of finishing pigs[1]

	CON[2]	EL	ELL	EEL	EELL	SEM[3]	Probability		
							ME	Lys	Lys×ME
$pH_{45\ min}$	6.22	6.23	6.24	6.26	6.25	0.01	0.37	1.00	0.43
$pH_{24\ h}$	5.72	5.62	5.60	5.86	5.62	0.02	0.47	0.41	0.43
Drip loss (%)	3.02	2.92	2.76	2.75	2.80	0.16	0.87	0.88	0.79
Cooking loss (%)	28.88	28.63	27.60	27.18	29.09	0.57	0.99	0.72	0.25
Lightness (L*)[4]	49.23	48.63	52.54	50.39	51.19	0.50	0.55	0.12	0.37
Redness (a*)[4]	7.32	7.21	7.69	7.64	7.67	0.16	0.61	0.53	0.57
Yellowness (b*)[4]	2.75	2.48	3.25	3.24	2.96	0.14	0.48	0.45	0.12
Moisture, DM (%)	72.51	72.52	71.86	71.90	71.96	0.11	0.29	0.22	0.12
Total lipid, DM (%)	1.92^{C}	2.15^{BC}	2.92^{A}	2.96^{A}	2.68^{AB}	0.12	0.23	0.31	0.03
Crude protein, DM (%)	24.26	23.85	24.09	23.88	23.96	0.10	0.81	0.49	0.74
Crude Ash, DM (%)	1.31	1.47	1.13	1.26	1.41	0.05	0.86	0.69	0.09

[1] Each treatment represents 8 pigs which weighed final body weight average 107.83±1.50 kg.

[2] CON = NRC (1998) requirement/3.265 Mcal of ME/kg, Lysine-0.75% (early finishing), 0.60% (late finishing); EL = CON+0.100 Mcal of ME/kg-Lysine 15% restriction to NRC requirement; ELL = CON+0.100 Mcal of ME/kg-lysine 30% restriction to NRC requirement; EEL = CON+0.200 Mcal of ME/kg-lysine 15% restriction to NRC requirement; EELL = CON+0.200 Mcal of ME/kg-lysine 30% restriction to NRC requirement.

[3] Standard error of mean.

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

[A, B, C] Means in the same row with different superscript letters differ significantly ($p<0.01$).

(1998) requirement and 3.465 Mcal of ME/kg of metabolism energy (as-fed basis) may have no detrimental effect on growth performance. Moreover, this optimal design may be acceptable for high marbling pork product by nutrition-conscious consumers.

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