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Effects of Dietary Energy Level on Growth Efficiency and Carcass Quality Traits of Finishing Pigs

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ABSTRACT

A total of 96 non-lean-type (Yorkshire × Landrace) × Duroc gilts and barrows weighing approximately 80 kg were randomly allocated to 24 pens under a 2 (sex) × 3 [diet; 3.4, 3.2, and 3.0 Mcal DE/kg {'high'-, 'medium'-, and 'low'-energy diets (HE, ME, and LE), respectively}] factorial arrangement of treatments. All animals were slaughtered approximately at 115 kg, after which carcass quality traits and grades and physicochemical and sensory characteristics of the loin related to meat quality were analyzed. The ADG and gain:feed were not affected by the sex or dietary treatment, whereas ADFI was greater in the ME vs HE group. Backfat thickness was greater in barrows vs gilts and also in ME and HE vs LE only in barrows. Enumerated carcass marbling and quality grade, which were highly correlated (r=0.56; P<0.01), were greater in barrows vs gilts. Physicochemical characteristics including the color, pH, drip loss and contents of moisture, protein, and fat of fresh loin, as well as sensory characteristics of fresh and cooked loin, were not affected by the sex or dietary treatment, except for shear force for cooked loin which was greater (P<0.05) in LE and ME vs HE. In conclusion, it is thought that ME is comparable to HE in terms of the effect on growth and carcass quality of finishing pigs, but that the relative effect of LE vs ME needs to be further studied.
(**Key words :** Finishing pig, Diet, Growth, Carcass, Meat Quality)

INTRODUCTION

The plane of nutrition or dietary energy level is a most significant factor that determines the growth rate of the lean and fat of the pig (Han, 2000; McFarland, 2003). With increasing dietary energy level, total energy intake usually increases, accompanied by an increase in the rate of weight gain as well as the adipocity (Chung et al., 1981; Chang and Chung, 1985; Kim et al., 2005). Currently, the dietary energy densities for finishing pigs recommended by major institutes worldwide are fairly variable ranging from as low as 3.1 Mcal DE/kg (ARC, 1981; SCA, 1987) to 3.3 Mcal (JRC, 1998) or 3.4 Mcal DE/kg (NRC, 1998; RDA, 2007), although actual DE values of domestically available commercial finisher diets are mostly greater than 3.4 Mcal/kg.

Lee et al. (2000, 2002) have reported that lean-type pigs fed a low-energy diet containing 2.95 Mcal DE/kg had a lesser growth rate than those fed a high-energy diet containing 3.5 Mcal DE/kg during a finishing period between 60- and 105-kg body weights. More lately, Lee et al. (2007) have also reported that a 'medium'- and a 'high'-energy diets containing 3.2 and 3.4 Mcal DE/kg, respectively, were comparable in feed efficiency as well as in their effects on growth and carcass quality characteristics of lean-type pigs fed the respective diets from 90 kg to 125 or 135 kg. In contrast, in the study of Park et al. (2009), a 'low'-energy diet containing 3.0 Mcal DE/kg was not as effective as the medium-energy diet in supporting weight gain as well as feed efficiency in finishing pigs from 80 kg through 110 to 138 kg. Of note, the carcass marbling and quality grade were superior in the low- vs medium-energy diet in this study, suggesting that a low-energy diet may have some beneficial effects on carcass quality in compensation for its reduced effectiveness on weight gain and its efficiency. The effects of increasing dietary energy level between 3.0 and 3.4 Mcal

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DE/kg, however, are less than clear because relative effects of the low-, medium-, and high-energy diets have not been investigated within a same feeding trial. It is also unknown whether the relative effects of the medium- and low-energy diets vs the high-energy observed in the previous studies will hold true in non-lean pigs within a narrow range of market weights between 110 and 120 kg where the carcass yield grade is best under the current grading criteria (MAF, 2007). The present study was therefore undertaken to investigate the effects of dietary energy level on growth and its efficiency as well as carcass quality traits of non-lean finishing pigs at the optimal slaughter weight.

MATERIALS AND METHODS

1. Feeding and slaughtering

A total of 96 gilts and barrows born to Yorkshire × Landrace dams and Duroc sires were randomly allocated to twenty-four 6.6 m^2 pens approximately at 150-d age and 80-kg body weight under a 2 (sex) × 3 (diet) factorial arrangement of treatments, with four pens per each sex × diet combination and four animals per pen. The animals assigned to each dietary treatment were provided *ad libitum* with water and one of the three diets, i.e. 'high,'-, 'medium,'- and 'low'-energy diets (Table 1), containing 100%, 94%, and 88%, respectively, of the energy level (3.4 Mcal DE/kg) recommended by NRC (1998). The animals were slaughtered at approximately 115 kg by the pen unit at the abattoir of Pusan and Kyungnam Cooperative Swine Farms Association following 1.5-h transportation and overnight lairage; this was repeated four times until all animals were slaughtered. The carcass was chilled overnight at 4℃ and fabricated according to the

Table 1. Ingredient and chemical composition of the diet (as-fed basis)

Item	'High' energy	'Medium' Energy	'Low' energy
Ingredients, %			
Corn	65.46	67.86	48.56
Wheat bran	2.00	4.86	28.90
Soybean meal (44%)	19.53	18.07	13.51
Rapeseed meal	3.00	3.00	3.00
Molasses	4.00	4.00	4.00
Limestone	0.61	0.68	0.79
Dicalcium phosphate	1.06	0.93	0.60
Salt	0.25	0.25	0.25
Vitamin premix[a]	0.10	0.10	0.10
Mineral premix[b]	0.10	0.10	0.10
Animal fat	3.76	—	—
L-Lysine	0.13	0.15	0.18
Total	100.00	100.00	100.00
Calculated chemical composition			
DE, Mcal/kg	3.40	3.20	3.00
Crude protein, %	15.50	15.50	15.50
Lysine, %	0.90	0.90	0.90
Crude fat, %	6.72	3.18	3.28
Crude fiber, %	3.67	3.88	5.04
Crude ash, %	4.82	4.81	5.15
Ca, %	0.60	0.60	0.60
P, %	0.55	0.55	0.61

[a] Provided per kg of diet: 8,100 IU vitamin A, 1,200 IU vitamin D_3, 45 IU vitamin E, 2.25 mg vitamin K, 1.5 mg thiamin, 0.6 mg riboflavin, 2.55 mg pyridoxine, 0.03 mg vitamin B_{12}, 19.5 mg pantothenic acid, 39 mg niacin, 0.09 mg biotin, and 0.75 mg folic acid.

[b] Provided per kg of diet: 102.7 mg $FeSO_4$, 0.442 mg $CoSO_4$, 67 mg $CuSO_4$, 54.18 mg $MnSO_4$, 69 mg $ZnSO_4$, 0.546 mg $CaIO_3$, and 0.338 mg Na_2SeO_3.

MAF (2005) standard. Backfat thickness was measured on the cold carcass between the last rib and the first lumbar and also between the 11th and 12th ribs. The average of the two backfat measurements was adjusted for a 115-kg live weight according to the method suggested by NSIF (1997) as previously described (Lee et al., 2002; Park et al., 2007).

2. Physicochemical analysis and sensory evaluation for the longissimus muscle

Forty-eight loins from as many median-weight animals representing 24 pens slaughtered on a selected day received the physicochemical analysis and sensory evaluation. Muscle and fat color and chemical composition including moisture, protein, and fat of the loin were determined by the CIE (1978) L* (lightness), a* (redness) and b* (yellowness) standards and by the AOAC (1990) procedures, respectively. The 24-h pH, drip loss and water-holding capacity of fresh loin as well as sensory characteristics and shear force for fresh and cooked loin were analyzed and evaluated as previously described (Lee et al., 2002; Moon et al., 2006; Yang et al., 2006).

3. Statistical Analysis

All data were analyzed using the General Linear Model procedure of SAS (SAS Inst. Inc., Cary, NC). The model included main effects sex and dietary energy level as well as their two-way interaction. The pen was the experimental unit in all the analyses except for that of correlation in which individual animal was the unit.

RESULTS

1. Growth performance and carcass quality traits and grades

Average daily gain (ADG) did not differ (P>0.05) between gilts and barrows (Table 2). The ADG tended to be greater in the ‘medium’-energy diet (ME) group (0.76 kg) than in the ‘low’-energy diet (LE) group (0.69 kg; P=0.06) as well as in the ‘high’-energy diet (HE) group (0.71 kg; P=0.15), although the dietary effect was not significant (P=0.14). The ADFI was greater (P<0.05) in the ME (3.02 kg) than in HE group (2.63 kg), whereas gain: feed was not influenced by the sex (P=0.876) or dietary treatment (P=0.051). Backfat thickness adjusted for a 115-kg live weight was much greater (P<0.01) in barrows (24.1 mm) vs gilts (20.9 mm). Moreover, backfat thickness did not differ among the three dietary groups in gilts, whereas in barrows, this variable was much lower (P<0.01) in LE vs ME and HE. Mean carcass weight was greater in gilts (89.0 kg) than in barrows (86.6 kg), which was largely due to a greater mean final weight in the former (117.1 kg) vs the latter (114.9 kg). Dressing percentage did

Table 2. Growth performance of finishing gilts and barrows on three diets differing in the energy level

Item	Gilts			Barrows			Pooled SE	Significance (S, E)[d]
	HE[a]	ME[b]	LE[c]	HE[a]	ME[b]	LE[c]		
Initial wt, kg	80.6	79.8	79.9	79.9	79.8	80.4	0.4	
Final wt, kg	115.3	120.6	115.4	112.7	115.0	116.9	1.7	
ADG, kg	0.74	0.78	0.68	0.67	0.73	0.69	0.04	
ADFI, kg	2.70	3.12	2.85	2.56	2.93	2.76	0.14	E*
Gain : feed	0.274	0.252	0.241	0.262	0.259	0.250	0.010	
Backfat[e], mm	20.1	21.2	21.3	25.7	25.5	21.1	1.0	S**, S×E*
Carcass wt, kg	87.4	92.4	87.3	85.6	86.7	87.4	1.3	S*
Dressing, %	75.8	76.6	75.6	76.0	75.4	74.8	0.8	

[a,b,c] Received the high-energy (HE), medium-energy (ME), and low-energy (LE) diets containing 3.4, 3.2, and 3.0 Mcal DE/kg, respectively. Data are means of four pens.

[d] S, sex; E, energy level.

[e] Average of the measurements between the 11th and 12th ribs and between the last rib and the 1st lumbar was adjusted for a 115-kg live weight.

* P < 0.05. ** P < 0.01.

not differ between the two sexes, nor was it affected by the dietary treatment.

All carcasses received No. 3 to 5 of the meat color standard corresponding to the highest grade, and accordingly this quality trait was not affected by the sex or dietary treatment (Table 3). When the carcass yield grades A, B, C, and D were assigned 4, 3, 2, and 1 points of an arbitrary grade unit, respectively, the grade point did not differ between the sexes or dietary groups. In contrast, carcass marbling and quality grade, upon enumeration as for the yield grade, were greater ($P<0.01$) in barrows than in gilts (2.10 vs 1.52 and 2.85 vs 2.44 in the former and latter, respectively). As such, how BFT, marbling, and quality grade in gilts, barrows, and total animals were related to each other was analyzed, results of which are described below.

The quality grade point, as speculated, was highly correlated ($P<0.01$) with the marbling point in both sexes as well as in total animals (Table 4). Furthermore, the quality grade was also correlated with BFT in total animals and barrows ($P<0.01$), although in gilts, these two variables were not correlated ($P=0.33$). Similarly, the marbling point was significantly correlated with BFT in total animals ($P<0.01$) and barrows ($P<0.05$), but not in gilts ($P=0.10$). These results were exactly reproducible when the pen instead of the individual animal was used as the unit of the variable in the correlation analysis.

2. Physicochemical and sensory characteristics of the loin

None of the characteristics like lightness (L*), pH, and drip loss of the loin, which are major determinants of the normal RFN (reddish-pink, firm, and non-exudative) vs abnormal DFD (dark, firm, and dry) or PSE (pale, soft, and exudative) carcass (Warner et al., 1997; Joo et al., 1999), was influenced by the sex or dietary treatment (Table 5). Moreover, none of the other physicochemical characteristics measured in the present study, except for shear force, including the redness (a*), water-holding capacity, cooking loss, and contents of moisture, fat, and protein differed between the sexes or dietary groups. In shear force, the LE

Table 4. Pearson's correlations between backfat thickness (BFT) and the enumerated marbling and quality grade points of the carcass

	Marbling[a]		Quality grade[a]	
	r	p	r	p
Total animals (n=96)				
BFT	0.32	<0.01	0.31	<0.01
Marbling	–		0.56	<0.01
Gilts (n=48)				
BFT	0.19	0.10	0.12	0.33
Marbling	–		0.52	<0.01
Barrows (n=48)				
BFT	0.26	0.03	0.33	<0.01
Marbling	–		0.51	<0.01

[a] See the legend to Table 3 for details regarding how each variable was enumerated.

Table 3. Effects of dietary energy level on carcass quality characteristics and grades of finishing gilts and barrows

Item	Gilts			Barrows			Pooled SE	Significance
	HE[a]	ME[b]	LE[c]	HE[a]	ME[b]	LE[c]		
Meat color[d]	4.0	4.0	4.0	4.0	4.0	4.0	0	
Marbling[e]	1.38	1.63	1.56	1.88	2.31	2.10	0.16	Sex**
Yield grade[f]	3.45	3.28	3.53	3.40	3.10	3.68	0.20	
Quality grade[g]	2.40	2.40	2.53	2.80	2.83	2.93	0.13	Sex**

[a,b,c] Received the high-energy (HE), medium-energy (ME), and low-energy (LE) diets containing 3.4, 3.2, and 3.0 Mcal DE/kg, respectively. Data are means of four pens.

[d] No. 3~5, No. 2 or 6, and No. 1 or 7 of the MAF (2007) color standard corresponding to the quality grades 1^+ & 1, 2, and 3 were assigned 4, 2, and 1 points of arbitrary grade unit, respectively.

[e] No. 4 or 5, No. 2 or 3, and No. 1 of the MAF (2007) marbling standard corresponding to the quality grades 1^+ or 1, 2, and 3, respectively, were assigned 4, 2, and 1 points of an arbitrary grade unit, respectively.

[f] Grades A, B, C and D (MAF, 2007) were assigned 4, 3, 2 and 1 points of an arbitrary grade unit, respectively.

[g] Grades 1^+, 1, 2, and 3 (MAF, 2007) were assigned 4, 3, 2, and 1 points of an arbitrary grade unit, respectively.

** $P<0.01$.

and ME groups exhibited a greater values (4.35 and 4.18 kg/cm^2, respectively) than the HE group (3.60 kg/cm^2; P<0.05).

Sensory characteristics of fresh loin related to meat quality, including color, aroma, off-flavor, drip, marbling, and overall acceptability, did not differ between the sexes or dietary groups (Table 6). Moreover, the juiciness and tenderness in addition to color, aroma, off flavor, and the acceptability for cooked loin also were not affected by the sex or dietary treatment.

DISCUSSION

The rate of weight gain of the present animals was lower compared with those of the previous studies (Lee et al., 2006; Park et al., 2007, 2009). For instance, ADG of the animals fed the medium energy diet (ME; 3.2 Mcal DE/kg) in the present study was lower than those in the studies cited above by 9%, 6%, and 14%, respectively. Conversely, the 110-kg live wt-adjusted backfat thickness (BFT) of the ME group of the present study was greater than those of the cited studies by 16%, 9%, and 17%, respectively, which suggests that the reduced growth rate of the present animals is attributable to a diminished growth efficiency resulting from their greater fat deposition.

The greater ADFI in the ME vs HE group, as well as the tendency of a greater ADG in the former reflecting the relative ADFI, is thought to have resulted in similar gain:feed and BFT between the two groups in the present study. These results implicate that the ME and HE are comparable in their influences on growth and are considered to be similar to those of the previous study (Lee et al., 2007), in which all these four variables were not different between the two groups. Moreover, the 10.5% greater ADG in the ME vs LE group, which reflects a greater total energy intake in the former, also was similar to an 11.1% greater ADG in the former (P<0.01) observed in the study of Park et al. (2009), although the statistical difference between the ME and LE groups in the present study was rather insignificant. However, the lack of difference in gain:feed between the ME and LE groups in the present study (0.255 vs 0.242; P=0.21) was different from the significantly greater feed efficiency in the former in the previous study (0.268 vs 0.239; P<0.01). Nevertheless, these results for the ME and

Table 5. Effects of dietary energy level on physicochemical characteristics of the *longissimus* muscle of the finishing pigs

Item	Gilts			Barrows			Pooled	Significance
	HE[a]	ME[b]	LE[c]	HE[a]	ME[b]	LE[c]	SE	
Color								
CIE L*	46.1	46.0	46.3	45.5	46.7	46.7	0.8	
CIE a*	6.37	6.12	6.08	6.98	6.31	6.60	0.31	
CIE b*	3.24	3.23	2.99	3.36	3.14	3.46	0.23	
24-h pH	5.73	5.75	5.75	5.82	5.82	5.73	0.06	
Drip loss, %	0.97	0.76	0.74	0.72	1.04	0.88	0.19	
WHC[d], %	66.1	55.5	58.0	59.5	62.3	56.4	3.5	
Cooking loss, %	37.0	37.0	36.4	36.4	37.6	37.3	0.9	
Shear force[e], kg/cm^2	3.62	4.21	4.13	3.58	4.15	4.56	0.26	Energy level*
Chemical composition								
Moisture, %	74.2	73.9	74.1	74.2	74.4	74.3	0.2	
Crude fat, %	1.96	2.07	2.16	2.13	2.27	1.82	0.19	
Crude protein, %	23.1	22.7	23.0	22.6	22.6	23.1	0.4	

[a,b,c] Received the high-energy (HE), medium-energy (ME), and low-energy (LE) diets containing 3.4, 3.2, and 3.0 Mcal DE/kg, respectively. Data are means of four pens.

[d] Water-holding capacity.

[e] Measured on cooked meat.

* P<0.05.

Table 6. Sensory quality characteristics of fresh and cooked loin of the finishing pigs

Item	Gilts			Barrows			Pooled SE	Significance
	HE[a]	ME[b]	LE[c]	HE[a]	ME[b]	LE[c]		
Fresh loin								
Color[d]	5.83	5.84	5.83	6.23	5.50	5.34	0.30	
Aroma[d]	4.19	3.81	4.00	3.98	3.94	3.92	0.10	
Off-flavor[e]	3.03	2.77	2.88	2.88	2.92	2.80	0.09	
Drip[e]	5.05	4.67	4.77	4.83	5.02	5.16	0.22	
Marbling[d]	4.53	4.88	4.83	5.14	4.66	4.38	0.37	
Acceptability[d]	4.88	4.95	5.20	5.30	4.97	4.59	0.24	
Cooked loin								
Color[d]	5.00	4.89	4.68	5.16	4.75	4.71	0.19	
Aroma[d]	3.82	3.73	3.55	3.84	3.73	3.73	0.10	
Off-flavor[e]	3.06	3.16	3.13	3.21	3.18	3.16	0.10	
Juiciness[d]	5.05	5.20	4.95	5.14	4.93	4.59	0.17	
Tenderness[d]	4.71	4.98	4.86	5.23	4.98	4.89	0.19	
Acceptability[d]	4.75	4.86	4.80	5.14	4.93	4.57	0.17	

[a,b,c] Received the high-energy (HE), medium-energy (ME), and low-energy (LE) diets containing 3.4, 3.2, and 3.0 Mcal DE/kg, respectively. Data are means of four pens.
[d,e] Evaluated by eight sensory panelists according to a 9-point hedonic scale.
[d] Greater values indicate "darker," "stronger," and "greater/more/superior" in color, aroma, and marbling/juiciness/tenderness/acceptability, respectively.
[e] Greater values indicate "more" meaning "worse" in terms of quality.

LE groups, as a whole, are thought to have conformed to the known trend that with increasing dietary energy level, growth rate, feed efficiency, and BFT increase and feed intake decreases (Chung et al., 1981; Chang and Chung, 1985). It should also be acknowledged that effects of the dietary energy level on growth and its efficiency are variable to some extent depending on the magnitude of the incremental energy, developmental stage of the pigs, environmental conditions, etc. (Chung et al., 1981; Coffey et al., 1982; Hale et al., 1986; Lee et al., 2000, 2002).

The greater carcass marbling and quality grade points in the barrow vs gilt are consistent with previous results (Park et al., 2009). Further, the significant correlation between these two carcass quality variables was also consistent with a result which was observed in the previous study (r=0.80; P<0.01) but was not reported therein. These results implicate that among the major criteria for grading the carcass quality (MAF, 2007), i.e. meat color, fat color and quality, texture, and marbling of the whole carcass, and the quality of the belly including the thickness of the whole cut and its fat layers and the fat:lean balance, marbling score is probably the most significant determinant of the final grade. On the other hand, the greater marbling and quality grade points in the LE vs ME group observed in the previous study (Park et al., 2009) were not apparent in the present study. This suggests that a long period may be necessary for a low-energy diet to exert its beneficial effects on these quality variables, not only because marbling increases with age as well as with adipose tissue growth (Huff-Lonergan et al., 2003), but because the dietary effects on the variables were apparent only when the age at a fixed slaughter weight increased significantly by feeding the LE vs ME in the previous study.

The lack of differences between HE and ME groups in physicochemical characteristics of the loin, including CIE L* and a* values, pH, drip loss and contents of protein, fat and protein, were consistent with previous results (Park et al., 2007), even though the average slaughter weight was 14-kg less in the present study. Similarly, consistent with previous results (Park et al., 2009) except for shear force, the ME group was not different from the LE group in these characteristics in the present study. Collectively, these results are interpreted to suggest that physicochemical characteristics of the muscle are not significantly influenced by the dietary energy level between 3.0 and 3.4 Mcal DE/kg, although the shear force, which had been greater in the LE vs ME group in the previous study, was not different between these two groups in the present study. There is no definitive answer to these inconsistent results of the shear force, but the inconsistency is partly attributable to an inherent variability of the methodology itself, as could be presumed from inconsistently reported results regarding the effect of slaughter weight on this variable, which was positive (Leach et al., 1996), non-significant (Cisneros et al., 1996), or even negative (Jin et al., 2004).

The lack of the effect of the dietary energy level on all the sensory quality traits of the fresh and cooked loin evaluated in the present study were mostly consistent with previous results (Park et al., 2009). However, the greater aroma score in the LE vs ME group in the fresh loin as well as the greater aroma and off-flavor scores for the ME vs LE group in the cooked loin observed at a 110-kg slaughter weight in the previous study was not detected in the present study. There's no firm reason for this inconsistency at present, but as in some physicochemical characteristics including the shear force, this inconsistency is thought to have resulted partly from a relatively large variation of the sensory evaluation itself.

In conclusion, the present ME (3.2 Mcal DE/kg) is judged to be comparable to HE (3.4 Mcal DE/kg) in its effects on growth and growth efficiency as well as on physicochemical characteristics of the meat of finishing pigs. More studies are necessary, however, to delineate the relative effects of LE (3.0 Mcal DE/kg) vs ME on growth and its efficiency as well as those of the dietary energy level between 3.0 and 3.4 Mcal DE/kg on carcass quality and physicochemical and sensory characteristics related to meat quality in finishing pigs.

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