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Relationships of Muscle Fiber Characteristics to Dietary Energy Density, Slaughter Weight, and Muscle Quality Traits in Finishing Pigs

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ABSTRACT

The present study was conducted to investigate the relationships of muscle fiber characteristics to dietary energy density [3.0 (Low-E) vs. 3.2 (Med-E) Mcal DE/kg)] and slaughter weight [SW; 110, 125, and 138 kg] in finishing pigs (gilt vs. barrow) using a 2×3×2 factorial treatment design. Forty-one *longissimus dorsi* muscle (LM) samples were analyzed histochemically, with growth performance and physicochemical data for the 41 animals and their LM out of 192 animals and 72 LM used in a previous study retrospectively included. The ADG was less (P<0.01) in the Low-E than in the Med-E group (0.93 vs. 0.73 kg) whereas lightness (L*) and redness (a*) of LM were greater in the Low-E group SW did not influence these variables. The diameter and perimeter of the type I (slow-oxidative), type IIA (fast oxido-glycolytic) and type IIB (fast glycolytic) fibers increased with increasing SW whereas densities of the fibers decreased. However, the number and area percentages of the fiber types were not influenced by SW or dietary energy density. The percentage and per-mm^2 density of type IIB fibers were negatively correlated with SW (r = −0.33 and −0.57, with P<0.05 and <0.01, respectively), whereas type I fiber number percentage was positively correlated with SW (r = 0.31; P<0.05). Marbling score was negatively correlated (P<0.05) with type I (r = −0.36) and type IIB (r = −0.39) fiber densities. The a* was correlated (P<0.01) with both type I and type IIB fiber number percentages in the opposite way (r = 0.42 and −0.47, respectively). However, L* (lightness), drip loss and pH_{24h} were not correlated with the fiber number percentage or density of any fiber type. Collectively, results indicate that muscle fibers grow by hypertrophy during the late finishing period, but that fiber characteristics other than the size are not significantly influenced by dietary energy density or SW.

(**Key words :** Finishing pig, Slaughter weight, Diet, Muscle fiber, Meat quality)

INTRODUCTION

Skeletal muscle fibers are generally classified into ‘slow-oxidative’ or type I, ‘fast oxido-glycolytic’ (‘intermediate’) or type IIA, and ‘fast glycolytic’ or IIB (or IIX) according to the twitching and metabolic characteristics of the fiber (Schiaffino and Reggiani, 1996; Lee et al., 2010). The total number, size and density of different muscle fiber types as well as fiber-type composition are important histochemical characteristics of skeletal muscle, because these characteristics can influence the quality of fresh meat as well as cooked meat after the conversion of the muscle to meat (Karlsson et al., 1999; Rehfeldt et al., 2000; Joo and Kim, 2011).

The total number of muscle fibers in the pig is attained during late fetal life (Stickland and Goldspink, 1973), after which all muscle fibers grow solely by hypertrophy. At birth, all pig muscles contain only type I fibers (Karlssson et al., 1999), the number of which decreases during postnatal development while the number of type IIB fibers transformed from the former increases. The cross-sectional area of the porcine muscle fiber, an index of muscular hypertrophy, appears to increase almost at a constant rate between 25- and 90-kg body weight and at a reduced rate above 90 kg (Karlsson et al., 1999).

Muscle fiber characteristics are influenced by nutrition as well. Muscle fiber hypertrophy is impaired by restricting feed intake regardless of the pig growth stage, whereas the effect of restricted feeding on fiber-type composition appears to vary depending on the growth stage (Solomon et al, 1988; Harrison et al., 1996; Bee et al., 2007). Harrison et al. (1996) and Bee et al. (2007) have reported that the fiber-type composition of *longissimus dorsi* muscle (LM) did not change due to feed restriction in post-weaning and growing-finishing pigs, respectively. However, in the study of Solomon et al.

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(1988), restricted feeding resulted in fewer type IIB fibers and more type IIA fibers in LM of grower pigs. With respect to pork quality traits, Candek-Potokar et al. (1998) have reported that a 30% restriction in feed intake during the growing-finishing period caused a decrease in intra-muscular fat content and redness [CIE (1978) a*] and an increase in drip loss of LM. To our knowledge, effects of the plane of nutrition or dietary energy density on muscle fiber characteristics have not been reported.

We have previously studied the effects of dietary energy density [3.2 Mal DE/kg {medium energy (ME)} vs. 3.0 Mcal DE/kg {low energy (LE)}] and slaughter weight (SW; 110, 125, and 138 kg) on growth performance and muscle and meat quality traits in finishing pigs (Park et al., 2009). Provision of the LE vs. ME diet resulted in reduced ADG, greater marbling and lightness of LM as well as greater LM redness apparently associated with more days on feed to reach the target SW, without influencing other meat quality traits including pH and drip loss as well as the incidence of PSE; SW did not influence these physicochemical characteristics. The present study was conducted to investigate to what extent muscle fiber characteristics of LM taken from these animals were influenced by dietary energy density and SW as related to muscle quality traits.

MATERIALS AND METHODS

1. Animals

The animals used in the present study were described previously (Park et al., 2009). Briefly, a total of 192 (Yorkshire × Landrace) × Duroc gilts and barrows weighing 80.2 ± 0.2kg were divided randomly into 12 groups under a 2 (sex) × 2 (diet) × 3 (SW) factorial arrangement of treatments. The animals were fed either a 'low'-energy diet (LE) containing 3.0 Mcal DE/kg or a 'medium'-energy diet (ME) containing 3.2 Mcal DE/kg (Table 1). All animals were slaughtered at 110, 125, or 138 kg on several slaughter days, after which 72 LM taken from chilled carcasses were analyzed physicochemically in the previous study (Park et al., 2009). Forty-one LM samples, which had been taken from as many carcasses on two selected slaughter days and stored frozen, were histochemically analyzed in the present study as described below. As such, growth performance and physico-chemical characteristics data for the 41 animals and their LM obtained in the previous study were retrospectively included in the present study.

Table 1. Composition of the experimental diets (as-fed basis)

Item	'Medium' Energy	'Low' energy
Ingredients, %		
Corn	67.89	49.21
Wheat bran	4.86	30.00
Soybean meal (44%)	18.06	11.78
Rapeseed meal	3.00	3.00
Molasses	4.00	4.00
Limestone	0.67	0.73
Dicalcium phosphate	0.92	0.60
Salt	0.25	0.25
Vitamin premix[a]	0.10	0.10
Mineral premix[b]	0.10	0.10
L-Lysine	0.15	0.23
Total	100.00	100.00
Calculated chemical composition		
DE, Mcal/kg	3.20	3.00
Crude protein, %	15.50	15.00
Lysine, %	0.90	0.90
Crude fat, %	3.19	3.32
Crude fiber, %	3.94	5.05
Crude ash, %	4.58	5.03
Ca, %	0.60	0.67
P, %	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.

2. Physicochemical and histochemical analyses

Approximately 5-gm LM sample was taken within an hour *postmortem* at the last rib of the 41 selected animals consisting of 12 sex × diet × SW combinatorial groups, each of which was represented by three or four animals. The muscle samples were frozen in isopentane which had been chilled within liquid nitrogen, transported to the lab and stored at −80℃ until used for histochemical analyses.

Muscle fiber characteristics were analyzed histochemically as previously described by Hwang et al. (2010). Briefly, 10 μm-thick serial muscle sections were prepared using a cryostat microtome (HM525, Microm GmbH, Walldorf, Germany) at −20℃ and mounted on glass slides. The specimens were stained and classified into types I, IIA and IIB according to the procedure of Brook and Kaiser (1970). The per cent number and area, density, diameter and perimeter of the three types of muscle fibers were analyzed microscopically using an image analysis program (Image-Pro plus 5.1, Media Cybernetics Inc., Bethesda, MD, USA).

3. Statistical analysis

All numerical data were analyzed using GLM of SAS (2002). Means were separated using the PDIFF option.

RESULTS

1. Growth performance and physicochemical characteristics of LM

The ADG of the animals included in the present study was less ($P<0.01$) in the LE (0.73 ± 0.01 kg) than in the ME (0.93 ± 0.02 kg) group (Table 2). Backfat thickness was less ($P<0.01$) in the LE (19.9 ± 0.79 mm) vs. ME (24.3 ± 1.14 mm) group and was also less in the 110-kg SW than in the 125-

Table 2. Effects of dietary energy density and slaughter weight on growth performance and physicochemical characteristics of the *longissimus dorsi* muscle of finishing gilts and barrows

Item	Gilts[1)]						Barrows[1)]		
	3,200 kcal DE/kg			3,000 kcal DE/kg			3,200 kcal DE/kg		
	110 kg	125 kg	138 kg	110 kg	125 kg	138 kg	110 kg	125 kg	138 kg
Growth performance									
Initial wt, kg	83.3±2.3	78.9±3.3	74.3±3.3	79.2±1.7	79.3±1.5	78.3±1.7	82.5±1.9	78.0±1.3	80.1±1.7
Final wt (SW), kg	107.6±2.2	124.1±3.2	136.4±3.2	107.2±1.6	124.0±1.4	137.3±1.6	107.2±1.8	125.3±1.3	137.3±1.6
ADG, kg	0.93±0.04	0.96±0.06	0.91±0.06	0.70±0.03	0.73±0.03	0.72±0.03	0.95±0.03	1.00±0.02	0.83±0.03
Backfat thinkness[3)], mm	19.5±2.7	24.2±3.8	28.4±3.8	17.2±1.9	19.2±1.7	20.6±1.9	20.9±2.2	26.1±1.6	26.7±1.9
Physiochemical characteristics of the *longissimus dorsi* muscle									
IMF[4)]	1.50±0.52	1.00±0.74	2.00±0.74	1.75±0.37	1.80±0.33	2.00±0.37	2.00±0.43	1.83±0.30	2.25±0.37
CIE L*	54.8±1.9	52.5±2.7	51.7±2.7	54.8±1.3	53.9±1.2	58.2±1.3	52.4±1.5	52.0±1.1	50.4±1.3
CIE a*	7.42±0.94	7.69±1.33	6.06±1.33	8.72±0.67	9.94±0.60	9.03±0.67	6.94±0.77	7.32±0.54	7.96±0.67
Drip loss, %	1.92±0.81	2.92±1.14	2.27±1.14	2.60±0.57	0.98±0.51	3.17±0.57	1.08±0.66	1.45±0.47	1.43±0.57
pH_{24h}	5.59±0.09	5.53±0.13	5.64±0.13	5.58±0.06	5.62±0.06	5.61±0.06	5.82±0.07	5.59±0.05	5.63±0.06

Item	Barrows[1)]			*P* value[2)]						
	3,000 kcal DE/kg									
	110 kg	125 kg	138 kg	S	D	SW	S×D	S×SW	D×SW	S×D×SW
Growth performance										
Initial wt, kg	79.7±1.7	77.3±1.7	79.2±1.9	0.54	0.48	0.08	0.44	0.23	0.28	0.50
Final wt (SW), kg	108.2±1.6	123.8±1.6	142.2±1.8	0.30	0.49	<0.01	0.56	0.62	0.44	0.66
ADG, kg	0.71±0.03	0.76±0.03	0.77±0.03	0.62	<0.01	0.09	0.33	0.59	0.07	0.31
Backfat thinkness[3)], mm	19.1±1.9	22.7±1.9	20.3±2.2	0.42	<0.01	0.02	0.68	0.58	0.35	0.98
Physiochemical characteristics of the *longissimus dorsi* muscle										
IMF[4)]	1.75±0.37	2.25±0.37	3.33±0.43	<0.05	0.16	0.10	0.90	0.69	0.58	0.44
CIE L*	53.2±1.3	54.1±1.3	57.5±1.5	0.29	<0.01	0.56	0.72	0.71	0.03	1.00
CIE a*	8.03±0.67	8.24±0.67	7.12±0.77	0.28	0.01	0.46	0.08	0.71	0.91	0.33
Drip loss, %	1.19±0.57	1.15±0.57	0.65±0.66	<0.01	0.59	0.89	0.81	0.63	0.30	0.29
pH_{24h}	5.67±0.06	5.66±0.06	5.73±0.07	0.07	0.76	0.52	0.93	0.50	0.33	0.51

1) Data are LS means ± SEM of three or four animals in each dietary energy density × slaughter weight combination in each sex.
2) S, sex; D, dietary energy density; SW, slaughter weight.
3) Adjusted for the targeted SW.
4) Inter-muscular fat content scored by the carcass grading officer according to a 4-point arbitrary whole number scale.

and 138-kg SW groups (19.2 ± 1.1, 23.1 ± 1.2, and 24.0 ± 1.3 mm for 110-, 125-, and 138-kg SW groups, respectively).

The intra-muscular fat or marbling score was greater numerically, but not statistically (P = 0.16), in the LE than in the ME group (2.15 ± 0.15 vs. 1.76 ± 0.22). The lightness [CIE (1978) L*] and redness (a*) of LM were greater in the LE vs. ME group (P<0.01 and P<0.05, respectively). Drip loss was less in barrows than in gilts (P<0.01). However, pH was not influenced by sex, dietary energy density, or SW.

2. Distribution of types I, IIA and IIB of muscle fibers

Cross-sections of the LM specimens were microscopically examined to determine the percentage and size of the three types of muscle fibers (Fig. 1 Table 3). The per-mm^2 density of the type I fiber was greater (P<0.05) in gilts (47.3 ± 2.6 fibers/mm^2) than in barrows (38.7 ± 2.2 fibers/mm^2). The density of this fiber type decreased apparently with increasing SW (45.1 ± 3.0, 43.9 ± 2.8, and 40.1 ± 3.0 for 110-kg, 125-kg, and 138-kg SW, respectively), but the effect of SW was not significant (P = 0.48). Instead, sex × diet and diet × SW interactions as well as a sex× diet × SW three-way interaction were significant. The density of type IIA fibers was not influenced by sex, dietary energy density, or SW.

Table 3. Effects of dietary energy density and slaughter weight on the number and composition of muscle cell types of finishing gilts and barrows

Item	Gilts[1]						Barrows[1]		
	3,200 kcal DE/kg			3,000 kcal DE/kg			3,200 kcal DE/kg		
	110 kg	125 kg	138 kg	110 kg	125 kg	138 kg	110 kg	125 kg	138 kg
Muscle fiber density, number of fibers/mm^2									
Type I	58.3±18.6	46.7±8.3	24.2±13.0	42.9±10.8	53.3±10.9	58.4±8.5	43.8±5.0	41.5±9.7	41.0±15.3
Type IIA	16.0±12.0	23.6±19.8	20.5±2.8	23.8±9.9	24.5±8.4	21.3±2.9	22.5±13.1	22.6±6.0	15.7±3.3
Type IIB	348.4±43.8	281.9±26.4	229.3±0.2	293.3±38.1	235.2±30.3	221.0±33.9	338.1±126.0	245.3±55.9	253.2±45.3
Fiber number composition, %									
Type I	13.7±2.8	13.3±0.3	8.7±4.4	11.9±3.1	17.1±3.0	19.5±1.1	11.8±4.3	14.2±5.7	13.3±3.8
Type IIA	4.0±3.3	6.3±4.6	7.5±1.4	6.5±2.1	7.8±2.4	7.3±1.8	5.3±1.3	7.5±2.0	5.1±0.3
Type IIB	82.4±0.6	80.4±5.0	83.7±3.1	81.6±4.5	75.0±4.6	73.3±1.6	82.8±3.1	78.3±6.9	81.7±4.0
Fiber area composition of the muscular cross-section, %									
Type I	10.2±2.6	10.0±1.2	6.1±2.5	7.7±2.0	12.4±4.4	12.2±1.6	9.0±2.4	9.1±2.5	9.7±3.4
Type IIA	3.2±2.8	4.7±3.2	4.9±0.9	4.5±1.8	5.6±1.9	5.7±2.5	4.3±1.0	4.6±1.5	3.7±1.2
Type IIB	86.7±0.1	85.4±1.9	89.1±1.7	87.7±3.7	82.0±5.4	82.2±3.5	86.6±1.4	86.3±3.0	86.6±4.2

Item	Barrows[1]			*P* value[2]						
	3,000 kcal DE/kg									
	110 kg	125 kg	138 kg	S	D	SW	S×D	S×SW	D×SW	S×D×SW
Muscle fiber density, number of fibers/mm^2										
Type I	35.4±10.2	33.8±7.7	36.8±6.3	0.02	0.81	0.48	0.03	0.45	<0.01	0.04
Type IIA	25.7±7.8	27.9±5.1	18.8±12.4	0.84	0.21	0.26	0.90	0.53	0.88	0.78
Type IIB	279.0±24.1	274.3±30.6	213.3±18.9	0.95	0.07	<0.01	0.68	0.87	0.45	0.34
Fiber number composition, %										
Type I	10.4±2.3	10.3±3.4	13.6±1.2	0.13	0.26	0.36	0.01	0.72	0.04	0.17
Type IIA	7.5±2.3	8.3±1.2	7.0±4.1	0.78	0.06	0.19	0.80	0.33	0.67	0.69
Type IIB	82.1±1.5	81.5±2.9	79.4±5.1	0.27	0.06	0.13	0.05	0.86	0.21	0.40
Fiber area composition of the muscular cross-section, %										
Type I	7.8±1.7	7.5±2.1	9.6±1.2	0.25	0.53	0.57	0.09	0.23	0.09	0.22
Type IIA	4.9±1.4	5.9±0.8	4.4±2.3	0.86	0.11	0.39	0.87	0.39	0.96	0.92
Type IIB	87.3±1.5	86.7±2.5	86.0±3.4	0.32	0.19	0.34	0.15	0.49	0.26	0.47

[1] Data are LS means ± SEM of three or four animals in each dietary energy density × slaughter weight combination in each sex.
[2] S, sex; D, dietary energy density; SW, slaughter weight.

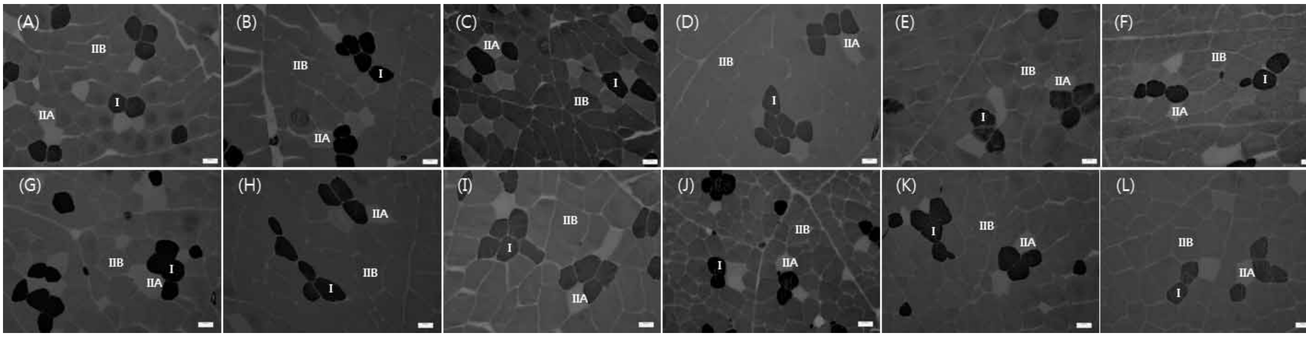

Fig. 1. Distribution of muscle fiber types in the *longissimus dorsi* muscle (LM) of the finishing pig. Finishing gilts (A through F) and barrows (G through L) were fed a low-energy diet (3,000 kcal DE/kg; A, C, E, G, I, and K) or a medium-energy diet (3,200 kcal DE/kg; B, D, F, H, J, and L) and slaughtered at 110 kg (A, D, G, and J), 125 kg (B, E, H, and K), or 138 kg (C, F, I, and L). Specimens of the LM cross-sections from the pigs were incubated with an ATPase substrate which develops into different colors distinctive of types I, IIA, and IIB muscle fibers, respectively, after which the density, diameter, and perimeter of each type of muscle fiber were analyzed using an image analysis program under a light microscope at 100-fold magnification. Representative results are shown in the figure.

The type IIB fiber density did not differ between the two sexes whereas it tended to be less ($P = 0.06$) in ME (59.6 ± 1.2 fibers/mm^2) than in LE (62.7 ± 1.0 fibers/mm^2) group. In addition, type IIB fiber density decreased ($P<0.01$) between 110-kg SW (314.7 ± 14.0 fibers/mm^2) and 125-kg SW (259.2 ± 12.8 fibers/mm^2), but it did not decrease further ($P = 0.12$) between 125- and 138-kg SW (229.2 ± 14.0 fibers/mm^2).

The percentage of the number of type I fibers was greater in the LE (16.2 ± 1.0%) than in the ME (11.9 ± 1.5%) group in gilts, but such a difference was not observed in barrows (11.4 ± 1.1% and 13.1 ± 1.0% for LE and ME, respectively). In addition, the type I fiber percentage was greater in the 138-kg SW (16.6 ± 1.4%) vs. 110-kg SW (11.2 ± 1.3%) group ($P<0.01$) when the animals were fed the LE diet, but not when fed the ME diet (12.7 ± 1.6%, 13.7 ± 1.5%, and 11.0 ± 1.5%, for 110-kg, 125-kg, and 138-kg SW, respectively). However, the percentages of type IIA and IIB fibers were not influenced by sex, dietary energy density, or SW. The percentages of areas of the three fiber types occupying the muscular cross-section also were not influenced by sex, dietary energy density, or SW.

3. Sizes of the muscle fiber types

The diameter of type I muscle fibers increased with the increase of SW (Table 4). It was greater ($P<0.01$) in the 138-kg SW (54.7 ± 1.4 μm) than in the 110-kg SW (48.5 ± 1.4 μm) group and tended to be greater ($P = 0.10$) in the 138- vs. 125-kg SW (51.7 ± 1.3 μm) group. The diameter of the type IIA fiber also increased apparently with increasing SW; however, it only tended to be greater ($P = 0.06$) in the 138-kg SW (54.2 ± 2.0 μm) vs. 110-kg SW group (48.7 ± 2.0 μm), but not vs. the 125-kg SW (50.4 ± 1.8 μm) group ($P = 0.18$). The increase of muscle fiber diameter associated with the increase in SW was most apparent in the type IIB fiber. The diameter of this fiber type increased ($P<0.05$) between 110-kg (56.3 ± 1.4 μm) and 125-kg (61.1 ± 1.3 μm) SW and again between the 125- and 138-kg SW (66.0 ± 1.4 μm).

Like the fiber diameter, the perimeter of the type I fiber was greater in the 138-kg SW (191.2 ± 5.0 μm) vs. 110-kg SW (170.3 ± 5.0 μm) group ($P<0.01$), but not vs. the 125-kg SW (180.6 ± 4.5 μm) group ($P = 0.13$). Type IIA fiber perimeter was greater ($P<0.05$) in the 138-kg SW (207.4 ± 8.4 μm) vs. 110-kg SW (181.7 ± 8.4 μm) group, but not vs. the 125-kg SW (198.6 ± 7.7 μm) group, although the SW effect was not significant ($P = 0.11$). Type IIB fiber perimeter tended to increase between 110-kg (216.4 ± 5.8 μm) and 125-kg (231.8 ± 5.3 μm) SW ($P = 0.06$) and subsequently increased significantly ($P<0.05$) between 125- and 138-kg (252.8 ± 5.8 μm) SW. Moreover, type IIB fiber perimeter was greater ($P<0.05$) in the LE (240.7 ± 4.1 μm) than in the ME (226.8 ± 5.0 μm) group.

4. Relationships of muscle fiber characteristics to growth and muscle quality variables

Correlations between muscle fiber characteristics and growth as well as muscle quality variables are shown in

Table 4. Effects of dietary energy density and slaughter weight on the size of muscle cell types of finishing gilts and barrows

Item	Gilts[1)]						Barrows[1)]		
	3,200 kcal DE/kg			3,000 kcal DE/kg			3,200 kcal DE/kg		
	110 kg	125 kg	138 kg	110 kg	125 kg	138 kg	110 kg	125 kg	138 kg
Fiber diameter, μm									
Type I	45.3±2.0	51.4±8.1	56.2±4.2	46.9±1.8	52.5±5.1	50.8±6.5	49.2±4.2	51.0±2.7	54.3±3.4
Type IIA	47.6±5.2	49.8±6.7	52.7±1.5	48.0±5.4	52.0±5.2	54.9±8.5	50.2±9.1	49.5±6.5	54.0±10.0
Type IIB	52.6±4.2	57.4±3.6	66.3±0.8	58.5±2.8	63.8±3.5	65.3±4.3	54.6±9.1	63.0±7.0	63.5±6.4
Fiber perimeter, μm									
Type I	161.2±4.5	179.2±25.1	196.3±18.4	165.3±6.4	186.2±18.3	177.2±24.6	173.7±19.6	179.8±9.4	187.4±13.4
Type IIA	174.0±10.8	226.5±50.5	223.2±45.2	179.5±27.6	200.5±22.9	204.6±33.6	193.6±41.2	185.2±18.7	196.4±39.9
Type IIB	203.4±14.7	225.4±15.0	254.5±11.1	225.3±12.9	246.5±16.6	253.6±17.8	209.8±40.5	225.6±19.2	242.0±21.4

Item	Barrows[1)]			*P* value[2)]						
	3,000 kcal DE/kg									
	110 kg	125 kg	138 kg	S	D	SW	S×D	S×SW	D×SW	S×D×SW
Fiber diameter, μm										
Type I	52.7±4.6	51.8±5.5	57.6±7.7	0.16	0.60	0.01	0.27	0.36	0.65	0.47
Type IIA	49.2±9.2	50.5±4.6	55.3±4.3	0.78	0.63	0.16	0.80	0.87	0.92	1.00
Type IIB	59.4±2.6	60.2±3.0	69.1±3.1	0.54	0.06	<0.01	0.70	0.98	0.63	0.14
Fiber perimeter, μm										
Type I	181.2±16.9	177.4±18.1	203.7±25.8	0.27	0.69	<0.01	0.39	0.38	0.88	0.25
Type IIA	179.9±33.5	182.0±13.6	205.2±8.9	0.25	0.41	0.11	0.59	0.23	0.87	0.56
Type IIB	227.3±11.1	229.9±25.7	261.3±13.1	0.74	0.04	<0.01	0.98	0.73	0.81	0.50

[1)] Data are means ± SEM of three or four animals in each dietary energy density × slaughter weight combination in each sex.
[2)] S, sex; D, dietary energy density; SW, slaughter weight.

Table 5. The percentage of the number of type I fibers in LM was positively correlated with SW (r = 0.31; P<0.05) and redness (a* r = 0.42; P<0.01) of LM. The density of this fiber type was negatively correlated with the intramuscular fat (marbling) score (r = −0.36; P<0.05). The area percentage of type IIA fibers was correlated with redness (a*; r = 0.33; P<0.05). The percentage of type IIB fibers was negatively correlated not only with SW (r = −0.33; P<0.05) but with a* (r = −0.47; P<0.01), which was also negatively correlated with the fiber area percentage (r = −0.39; P<0.05). Moreover, the type IIB fiber density was negatively correlated with SW (r = −0.57; P<0.01) and intramuscular fat score (r = −0.39; P<0.05).

DISCUSSION

The reduced ADG in the LE compared to that in the ME group as well as greater backfat thickness in the 125- and 138-kg SW groups vs. 110-kw SW group in the present study was consistent with previously reported results obtained from 192 animals (Park et al., 2009), out of which 41 animals were retrospectively included in the present study. Moreover, the greater L* and a* in the LE vs. ME group in the present study also was consistent with previous results. The greater marbling score in the LE vs. ME group (a difference of 0.39 arbitrary unit), which was not significant (P = 0.16) seemingly due to relatively large SEM, was similar to the previous results obtained with 72 LM samples (2.11 and 1.75 for LE and ME groups, respectively; P<0.01). Overall, the effects of dietary energy density and SW on growth performance variables and physicochemical characteristics of the 41 animals and their LM used in the present study were consistent with those obtained from 192 animals and 72 LM in the study reported previously (Park et al., 2009).

The present results regarding muscle fiber characteristics indicate that cellular hypertrophy during the late finishing period resulted in an increase in fiber diameter and perimeter

Table 5. Pearson's correlation coefficients between muscle fiber and quality characteristics of *longissimus dorsi* muscle and the live animal and carcass measurements

	Slaughter weight	ADG	Backfat thickness	IMF[1)]	Lightness (L*)	Redness (a*)	Drip loss	pH_{24h}
Type I fiber								
Number percentage	0.31*	−0.09	−0.08	−0.04	0.10	0.42**	0.11	−0.12
Area percentage	0.27	−0.10	−0.09	−0.08	0.12	0.30	0.04	−0.19
Density	0.00	−0.09	−0.29	−0.36*	0.11	0.30	0.27	−0.20
Type IIA fiber								
Number percentage	0.12	−0.12	0.01	0.03	0.12	0.23	−0.01	−0.17
Area percentage	0.12	−0.20	−0.06	−0.06	0.17	0.33*	0.01	−0.13
Density	−0.17	−0.09	−0.12	−0.18	0.05	0.08	0.07	−0.11
Type IIB fiber								
Number percentage	−0.33*	0.13	0.07	0.03	−0.15	−0.47**	−0.09	0.18
Area percentage	−0.27	0.17	0.11	0.10	−0.17	−0.39*	−0.04	0.21
Density	−0.57**	0.13	−0.19	−0.39*	−0.10	−0.29	0.09	0.05

1) Intramuscular fat content scored by the carcass grading officer according to a 4-point whole number scale.
* P<0.05; ** P<0.01.

and a decrease in fiber density in all types of muscle fibers, which is consistent with previous results (Candek-Potokar et al., 1999; Ryu and Kim, 2005). Moreover, the lack of difference between gilts and barrows in fiber number and area composition, as well as the lack of change in the percentage of all the three fiber types with increasing SW, was also consistent with previous results (Larzul et al., 1997; Bee et al., 2007).

Provision of a low energy-dense diet is comparable to restricted feeding in a sense, in that total net energy intake and ADG are reduced compared with those when feeding a normal energy-dense diet and *ad libitum* feeding (Lee et al., 2002; Park and Lee, 2011). In this context, the lack of an effect of dietary energy density on the composition and diameter of all the muscle fiber types in the present study was similar to the lack of an effect of restricted feeding on these characteristics when the animals were slaughtered at a fixed body weight instead of a fixed age following dietary treatment (Bee et al., 2007). This implicates that reduced energy intake may simply cause decreased muscle fiber hypertrophy without influencing the fiber-type composition. The sex × diet, diet × SW, and sex × diet × SW interactions in the type I fiber density were also noteworthy in the present study, but given the limited number of replicates, these interactions were unexplainable.

The negative correlation of type IIB fiber density with SW, which was reflective of the increase in muscle fiber size with increasing body weight, was consistent with the results of Ryu et al. (2004). However, the positive correlation between the type I fiber number percentage and SW as well as its biological significance remains to be further studied. The negative correlations between type IIB fiber number and area percentages with LM redness were consistent with the results of Ryu and Kim (2005). However, the positive correlation between the percentage of type I fibers and LM redness was not consistent with the lack of correlation between these two variables reported by Ryu and Kim (2006). In addition, the redness and type I fiber area percentage were not correlated in the present study whereas in Ryu and Kim (2005), these two variables were negatively correlated. It thus appears that that the influence of fiber-type distribution on LM redness is inconsistent or circumstantial.

The quality traits of fresh meat mainly represented by intramuscular fat content, water holding capacity, and color are known to be influenced by muscle fiber characteristics (Nam et al., 2009; Hwang et al., 2010; Joo and Kim, 2011). In this regard, it was noteworthy that marbling score was negatively correlated with type I and IIB fiber densities, implicating that there was less intramuscular fat when the muscle was densely packed with muscle fibers. With respect to water holding capacity, the known high drip loss in muscle exhibiting a higher type IIB number percentage (Warner et al., 1997; Joo et al., 1999; Rehfeldt et al., 2000) was not apparent in the present study, as indicated by the lack of correlation between these two characteristics. It is also known that muscles having higher type IIB fiber percentages exhibit higher L* and lower pH measurements, which are direct causes of PSE (Rehfeldt et al., 2000; Ryu and Kim, 2006). However, these traits were not influenced by dietary energy density or SW (data not shown) and were not correlated with the type IIB fiber number percentage, which is presumed to have resulted primarily from the overall low drip loss and normal L* and pH of the present LM. Taken together, results indicate that neither muscle quality traits nor muscle fiber characteristics other than fiber size of finishing pigs are significantly influenced by dietary energy density or SW between 110 and 138 kg.

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