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Effects of dietary energy and crude protein levels on growth performance, blood profiles, and carcass traits in growing-finishing pigs

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Abstract

This experiment was conducted to evaluate the effect of dietary energy and crude protein (CP) levels on growth performance, blood profiles, and carcass traits in growing-finishing pigs. A total of 180 crossbred pigs ([Yorkshire × Landrace] × Duroc) with an average body weight of 30.96 ± 3.068 kg were used for a 12-week feeding trial. Experimental pigs were allotted to a 2 × 3 factorial arrangement using a randomized complete block (RCB) design. The first factor was two levels of dietary metabolizable energy (ME) density (13.40 MJ/kg or 13.82 MJ/kg), and the second factor was three dietary CP levels based on subdivision of growing-finishing phases (high: 18%/16.3%/16.3%/13.2% middle: 17%/15.3%/15.3%/12.2% and low: 16%/14.3%/14.3%/11.2%). Average daily gain (ADG) and gain-feed ratio (G:F ratio) decreased as dietary CP level was decreased linearly (linear, $p < 0.05$; $p < 0.05$, respectively) in the early growing period, and G:F ration also decreased as dietary CP level was decreased linearly (linearly, $p < 0.05$) over the whole growing phase. Over the entire experimental period, G:F ratio decreased as dietary ME level decreased ($p = 0.01$). Blood urea nitrogen (BUN) concentration was increased as dietary energy level decreased in growing period ($p < 0.01$). During finishing period, total protein concentration was decreased by lower dietary energy level ($p < 0.05$). In this study, there were no significant differences in proximate factors, physiochemical properties, muscle TBARS assay results, pH changes, or color of pork by dietary treatments. However, saturated fatty acid (SFA) increased ($p < 0.01$) and polyunsaturated fatty acid (PUFA) decreased ($p < 0.05$) when ME was decreased by 0.42 MJ/kg in growing-finishing pig diets. In addition, monounsaturated fatty acid (MUFA) tended to increase when CP level was decreased in growing-finishing pig diets ($p = 0.06$). A growing-finishing diet of 13.82 MJ/kg diet of ME with the high CP level can improve growth performance and show better fatty acids composition of pork.

Keywords: Energy, Crude protein, Growth performance, Blood profiles, Carcass traits, Growing-finishing pigs

Background

Supplying adequate nutrients has been noted as the most important factor in pig production in the swine industry. Several studies have reported that insufficient nutrients can limit the growth potential of animals, while excessive nutrients can increase economic profitability but cause environmental pollution [1–3]. Nieto et al. [4] demonstrated that growth was based on the deposition of proteins

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and lipids in pigs. Therefore, dietary energy and crude protein (CP) levels play a major role in growth performance.

Nutrient requirements defined by the NRC were revised from 1998 to 2012 [5,6], especially protein. NRC 2012 recommends a lower CP level (CP calculated from N by multiplying by 100/16 or 6.25) than NRC 1998 in growing-finishing pigs (NRC 1998: 18%–13.2%; NRC 2012: 15.7%–10.4%).

Insufficient nutrients or excessive nutrients may reduce growth production in swine [7–10]. Pigs fed a low-energy diet had decreased total energy intake and growth performance [11–13] while excessive intake of CP increased N excretion [7–9]. Using low-CP diets can reduce feed costs, N excretion, and plasma urea N in swine [14,15].

Whittemore [16] showed that the pigs had the highest weight gain in the growing period, and fat deposition was greater than protein deposition in the finishing period. The most important factor to maximize muscle development in growing pigs is to provide optimal protein and amino acid levels [17]. However, finishing feeds need to be formulated keeping fat deposition in mind, as this can affect carcass fatness and pork quality [18].

This experiment was conducted to evaluate the effects of subdivision of the growing-finishing phases with different dietary protein levels and different dietary energy densities on growth performance, blood profiles, and pork quality.

Materials and Method

Experimental animals and management

All experimental procedures involving animals were conducted in accordance with the Animal Experimental Guidelines provided by the Seoul National University Institutional Animal Care and Use Committee (SNUIACUC; SNU-160819-9). A total of 180 crossbred pigs ([Yorkshire × Landrace] × Duroc) with an average body weight (BW) of 30.96 ± 3.068 kg were used for a 12-week feeding trial. Pigs were reared at the Seoul National University experimental farm. Three male pigs and three female pigs were assigned to each pen of a growing facility based on BW, and pigs in each pen were maintained until the end of experiment. Pigs were randomly

Table 1. Formula and chemical compositions of diets in early growing pigs

Energy	ME 13.40 MJ/kg			ME 13.82 MJ/kg		
CP (%)	High	Middle	Low	High	Middle	Low
Total	100.00	100.00	100.00	100.00	100.00	100.00
Ingredient (%)						
Corn	66.55	69.27	71.85	63.53	66.59	69.60
Soybean meal	23.10	20.30	17.53	23.50	20.74	18.02
Wheat bran	3.99	4.01	4.02	3.99	3.96	3.98
Palm kernel meal	3.04	3.05	3.04	3.07	3.03	3.04
Tallow	1.18	1.11	1.05	3.50	3.44	3.37
Mono-dicalcium phosphate	2.50	2.52	2.56	2.50	2.55	2.55
Limestone	0.31	0.30	0.29	0.30	0.30	0.31
L-Lysine-HCl (78%)	0.03	0.12	0.21	0.02	0.11	0.20
DL-Methionine (99%)	0.01	0.02	0.03	0.01	0.02	0.03
Vit. Mix[1)]	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[2)]	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Chemical composition[3)]						
Metabolizable energy (MJ/kg)	13.40	13.40	13.40	13.82	13.82	13.82
Crude protein (%)	16.30	15.30	14.30	16.30	15.30	14.30
Total lysine (%)	0.95	0.95	0.95	0.95	0.95	0.95
Total methionine (%)	0.27	0.27	0.27	0.27	0.27	0.27
Calcium (%)	0.66	0.66	0.66	0.66	0.66	0.66
Total phosphorus (%)	0.56	0.56	0.56	0.56	0.56	0.56

[1)]Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,800 IU; vitamin E, 60 IU; vitamin K_3, 2 mg; thiamine, 2.00 mg; riboflavin, 7.0 mg; pantothenic acid, 25 mg; niacin, 27 mg; pyridoxine, 3 mg; d-biotin, 0.2 mg; folic acid, 1 mg; vitamin B_{12}, 0.03 mg.

[2)]Provided per kg of diet. Minerals per kg of complete diet: Se, 0.3 mg; I, 1 mg; Mn, 51.6 mg; Cu, 105 mg; Fe, 150 mg; Zn, 72 mg; Co, 0.5 mg.

[3)]Calculated value.

CP, crude protein; ME, metabolizable energy.

allotted to their respective treatments by an experimental animal allotment program [19]. Pigs were reared in growing-finishing (2.60 × 2.84 m) facilities for 12 weeks. Feed and water were provided *ad libitum* during the entire experimental period by a 6-hole stainless feeder and two nipples installed in each pen.

Experimental design and diet

Experimental pigs were allotted to a 2 × 3 factorial arrangement in randomized complete block (RCB) design. The first factor was two levels of dietary metabolizable energy (ME) density (13.40 MJ/kg or 13.82 MJ/kg) and the second factor was three dietary CP levels based on subdivision of growing-finishing phases (high: 18%/16.3%/16.3%/13.2% middle: 17%/15.3%/15.3%/12.2% and low: 16%/14.3%/14.3%/11.2%).

Experimental diets were formulated for four phases: the early growing phase (0–3 weeks), the late growing phase (4–6 weeks), the early finishing phase (7–9 weeks), and the late finishing phase (10–12 weeks). All nutrients in the experimental diets except ME and CP were met or exceeded the nutrient requirements of the NRC [5]. Formula and chemical compositions of the experimental diets are provided in Tables 1, 2, 3, and 4.

Growth performance

Body weight and feed consumption were recorded at 0, 3, 6, 9, and 12 weeks to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F ratio).

Blood analysis

Blood samples were taken from the jugular vein of six randomly selected pigs in each treatment to measure blood urea nitrogen (BUN), glucose, and total protein during growing and finishing phages. All blood samples were collected in serum tubes (SST™ II Advance, BD Vacutainer®, Becton Dickinson, Plymouth, UK). Collected blood samples were centrifuged for 15 min at 6,048 × g at 4℃ (5810R, Eppendorf, Hamburg, Germany). Serum was carefully transferred to 1.5 mL plastic tubes and stored at –20℃ until analysis. BUN (kinetic UV assay, Roche, Germany) and glucose (enzymatic kinetic assay, Roche, Germany) concentrations

Table 2. Formula and chemical compositions of the diets of late growing pigs

Energy	ME 13.40 MJ/kg			ME 13.82 MJ/kg		
CP (%)	High	Middle	Low	High	Middle	Low
Total	100.00	100.00	100.00	100.00	100.00	100.00
Ingredient (%)						
Corn	66.09	68.86	71.62	63.37	66.11	68.92
Soybean meal	22.74	20.00	17.24	23.17	20.42	17.63
Wheat bran	3.97	3.99	4.03	4.00	4.00	3.98
Palm kernel meal	3.11	2.99	2.89	3.06	3.01	2.95
Tallow	0.83	0.76	0.69	3.15	3.08	3.00
Mono-dicalcium phosphate	2.30	2.35	2.39	2.32	2.35	2.38
Limestone	0.24	0.23	0.22	0.22	0.22	0.22
L-Lysine-HCl (78%)	0.19	0.28	0.37	0.18	0.27	0.37
DL-Methionine (99%)	0.03	0.04	0.05	0.03	0.04	0.05
Vit. Mix[1)]	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[2)]	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Chemical composition[3)]						
Metabolizable energy (MJ/kg)	13.40	13.40	13.40	13.82	13.82	13.82
Crude protein (%)	16.30	15.30	14.30	16.30	15.30	14.30
Total lysine (%)	0.95	0.95	0.95	0.95	0.95	0.95
Total methionine (%)	0.27	0.27	0.27	0.27	0.27	0.27
Calcium (%)	0.59	0.59	0.59	0.59	0.59	0.59
Total phosphorus (%)	0.52	0.52	0.52	0.52	0.52	0.52

[1)]Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,800 IU; vitamin E, 60 IU; vitamin K_3, 2 mg; thiamine, 2.00 mg; riboflavin, 7.0 mg; pantothenic acid, 25 mg; niacin, 27 mg; pyridoxine, 3 mg; d-biotin, 0.2 mg; folic acid, 1 mg; vitamin B_{12}, 0.03 mg.

[2)]Provided per kg of diet. Minerals per kg of complete diet: Se, 0.3 mg; I, 1 mg; Mn, 51.6 mg; Cu, 105 mg; Fe, 150 mg; Zn, 72 mg; Co, 0.5 mg.

[3)]Calculated value.

CP, crude protein; ME, metabolizable energy.

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Table 3. Formula and chemical compositions of the diets of early finishing pigs

Energy	ME 13.40 MJ/kg			ME 13.82 MJ/kg		
CP (%)	High	Middle	Low	High	Middle	Low
Total	100.00	100.00	100.00	100.00	100.00	100.00
Ingredient (%)						
Corn	69.15	71.87	74.45	66.13	69.19	72.20
Soybean meal	20.50	17.70	14.93	20.90	18.14	15.42
Wheat bran	3.99	3.97	4.22	3.99	3.95	3.90
Palm kernel meal	3.03	3.05	2.86	3.29	3.01	2.73
Tallow	0.62	0.55	0.53	2.99	2.86	2.75
Mono-dicalcium phosphate	2.05	2.05	2.10	2.05	2.05	2.10
Limestone	0.15	0.18	0.18	0.15	0.18	0.18
L-Lysine-HCl (78%)	0.01	0.11	0.20	0.00	0.10	0.19
DL-Methionine (99%)	0.00	0.02	0.03	0.00	0.02	0.03
Vit. Mix[1)]	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[2)]	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Chemical composition[3)]						
Metabolizable energy (MJ/kg)	13.40	13.40	13.40	13.82	13.82	13.82
Crude protein (%)	15.30	14.30	13.30	15.30	14.30	13.30
Total lysine (%)	0.82	0.82	0.82	0.82	0.82	0.82
Total methionine (%)	0.25	0.25	0.25	0.25	0.25	0.25
Calcium (%)	0.52	0.52	0.52	0.52	0.52	0.52
Total phosphorus (%)	0.47	0.47	0.47	0.47	0.47	0.47

1)Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,800 IU; vitamin E, 60 IU; vitamin K_3, 2 mg; thiamine, 2.00 mg; riboflavin, 7.0 mg; pantothenic acid, 25 mg; niacin, 27 mg; pyridoxine, 3 mg; d-biotin, 0.2 mg; folic acid, 1 mg; vitamin B_{12}, 0.03 mg.

2)Provided per kg of diet. Minerals per kg of complete diet: Se, 0.15 mg; I, 0.3 mg; Mn, 37 mg; Cu, 11 mg; Fe, 150 mg; Zn, 85 mg; Co, 2 mg.

3)Calculated value.

CP, crude protein; ME, metabolizable energy.

were analyzed using a blood analyzer. Total protein concentration was measured by a kinetic colorimetry assay using a blood analyzer (Modular analytics, PE, Roche, Germany).

Carcass traits

At the end of experiment, four pigs from each treatment group were selected and slaughtered at average 113.42kg ± 1.307 for carcass analysis. Pork samples were collected nearby the 10th rib on the right side of the carcass. After chilling, 30 minutes after slaughter was regarded as the initial time. The pH was measured at 0, 3, 6, 12, and 24 hours and the color of the *longissimus* muscle was measured at the initial time and 24 hours later. The pork samples were always stored in the freezer (4℃). The pH was measured using a pH meter (Model 720, Thermo Orion, Fullerton, CA, USA) and pork color was measured by CIE color L*, a*, and b* values using a CR300 (Minolta Camera Co., Osaka, Japan). Chemical analysis of pork samples was conducted using the AOAC method [20].

Water holding capacity of pork was measured by the centrifuge method. *Longissimus* muscles were ground and sampled in a filter tube, then heated in water bath at 80℃ for 20 min and centrifuged for 10 min at 2,688 × g at 10℃ (5810R, Eppendorf, Hamburg, Germany). To calculate cooking loss, *longissimus* muscles were packed in a polyethylene bag that was then heated in a water bath until the core temperature reached 72℃ and weighed before and after cooking. After heating, samples were cored (0.5 inch in diameter) parallel to the muscle fiber and the cores were used to measure shear force using a salter (Warner Barzler Shear, Norwood, MA, USA). Cooking loss, shear force, and water holding capacity of pork were analyzed by the Animal Origin Food Science laboratory, Seoul National University.

Lipids in pork samples were extracted from duplicate 10 g samples with chloroform: methanol (2.1, v/v) [21] on a shaking incubator (25℃, 8.064 × g) for 24 hours. Extracted lipids were filtered with filter paper (Whatman TM No.4, Buckinghamshire, UK). Twenty-five milliliters of 0.88% NaCl was added to the filtered sample, which was then centrifuged at 2,090 × g for 10 min (Continent 512R, Hanil Co., Ltd., Incheon, Korea). The supernatant

Table 4. Formula and chemical compositions of the diets of late finishing pigs

Energy	ME 13.40 MJ/kg			ME 13.82 MJ/kg		
CP (%)	High	Middle	Low	High	Middle	Low
Total	100.00	100.00	100.00	100.00	100.00	100.00
Ingredient (%)						
Corn	75.13	77.74	80.44	72.13	75.06	78.12
Soybean meal	15.10	12.33	9.56	15.50	12.77	10.03
Wheat bran	3.97	4.00	4.02	3.92	3.99	4.04
Palm kernel meal	3.02	3.02	3.03	3.30	2.97	2.63
Tallow	0.28	0.24	0.18	2.65	2.56	2.42
Mono-dicalcium phosphate	1.85	1.90	1.90	1.85	1.90	1.90
Limestone	0.14	0.15	0.16	0.15	0.15	0.15
L-Lysine-HCl (78%)	0.01	0.10	0.19	0.00	0.09	0.18
DL-Methionine (99%)	0.00	0.01	0.02	0.00	0.01	0.03
Vit. Mix[1)]	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[2)]	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Chemical composition[3)]						
Metabolizable energy (MJ/kg)	13.40	13.40	13.40	13.82	13.82	13.82
Crude protein (%)	13.20	12.20	11.20	13.20	12.20	11.20
Total lysine (%)	0.60	0.60	0.60	0.60	0.60	0.60
Total methionine (%)	0.21	0.21	0.21	0.21	0.21	0.21
Calcium (%)	0.46	0.46	0.46	0.46	0.46	0.46
Total phosphorus (%)	0.43	0.43	0.43	0.43	0.43	0.43

[1)]Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,800 IU; vitamin E, 60 IU; vitamin K_3, 2 mg; thiamine, 2.00 mg; riboflavin, 7.0 mg; pantothenic acid, 25 mg; niacin, 27 mg; pyridoxine, 3 mg; d-biotin, 0.2 mg; folic acid, 1 mg; vitamin B_{12}, 0.03 mg.

[2)]Provided per kg of diet. Minerals per kg of complete diet: Se, 0.15 mg; I, 0.3 mg; Mn, 37 mg; Cu, 11 mg; Fe, 150 mg; Zn, 85 mg; Co, 2 mg.

[3)]Calculated value.

CP, crude protein; ME, metabolizable energy.

was separated and pork lipids were concentrated using N_2 gas at 45℃. After concentrating the lipids, 0.1 g of lipids was transferred to a 15 mL tube with 1 mL of internal standard (1 mg of undecanoic acid in 1 mL of iso-octane) and 1.5 mL of 0.5 N methanolic NaOH. Samples were heated in a water bath at 85℃ for 10 min and cooled to room temperature. After cooling, 2 mL of 14% BF_3-methanol was added and then the heating process was repeated one more time. Then, 2 mL of iso-octane and 1 mL saturated NaCl were added, and the sample was centrifuged at 4,200 × g for 3 min (Continent 512R, Hanil Co., Ltd., Incheon, Korea). Upper layer containing fatty acid methyl esters (FAMEs) was dehydrated with anhydrous sodium sulfate and transferred to a vial. The sample in the vial was analyzed using a gas chromatograph (HP 7890, Agilent Technologies, Santa Clara, CA, USA) with a split ratio of 50:1. A capillary column (DB-23, 60 m × 250 μm × 0.25 μm, Agilent, Santa Clara, CA, USA) was used. The injector and detector temperatures were maintained at 250℃ and 280℃, respectively. Column oven temperature was varied as follows: 50℃ for 1 min, increased to 130℃ at 25℃/min, 170℃ at 8℃ /min, then held at 215℃ after increasing to this this temperature at 1.5℃/min. Nitrogen was used as a carrier gas at linear flow of 4 mL/min. Individual FAMEs were identified by comparison of relative retention times of peaks from samples with those of external standards (37 FAME mix and CLA mix, Supelco, Bellefonte, PA, USA) calculated based on the Korean Food Standards Codex (MFDS, 2017).

Statistical analysis

Data for the various groups were compared by least squares mean comparisons and evaluated using general linear models (GLMs) in SAS (SAS Institute Inc., Cary, NC, USA). Every pen was used as one unit in the feeding trial, and individual pigs were considered experimental units with regard to analysis of blood profiles and carcass qualities. Orthogonal polynomial contrasts were used to detect linear and quadratic responses to CP levels when the significance of the CP effect was evaluated. The treatment effect was considered to be significant if $p < 0.01$ or $p < 0.05$ while $0.05 < p$ and $p < 0.10$ was considered to indicated a trend in the treatment effect.

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Results and Discussion

Growth performance

The effect of dietary energy and CP levels on growth performance are presented in Table 5. Average daily gain and G:F ratio decreased linearly as dietary CP level was decreased (linear, $p < 0.05$; $p < 0.05$, respectively) in the early growing phase, and G:F ratio decreased linearly as dietary CP level was decreased (linear, $p < 0.05$) over the entire growing phase. In the growing period, pigs showed the highest weight gain due to muscle development [16]. Dietary CP and amino acid levels affect protein deposition [16,22]. Several studies have demonstrated that ADG and G:F ratio decreased as CP level increased in the growing phase [10,23]. In this study, dietary energy density did not have any significant effect on growth performance during the growing period, consistent with the study of Kil and colleagues [24].

Dietary energy and protein levels did not differ significantly among groups in the finishing period. Similar to our findings, Kerr et al. [10] represented that a 0.42 MJ decrease in NE/kg and 4% CP in 88.3 –109.7 kg pigs did not significantly affect growth performance. Kil et al. [24] reported that a 1.26 MJ/kg decrease in ME in the finishing pig diet had no effect on growth performance.

However, G:F ratio decreased when dietary ME level was decreased ($p = 0.01$). Furthermore, BW and ADG showed significant

Table 5. Effects of dietary energy and crude protein levels on growth performance in growing-finishing pigs

Energy	ME 13.40 MJ/kg			ME 13.82 MJ/kg			SEM	*p*-value		
CP (%)	High	Middle	Low	High	Middle	Low		ME	CP	M × C
Body weight (kg)										
Initial	30.97	30.95	30.97	30.95	30.95	30.95	0.854	-	-	-
3 wks	42.86	40.59	41.17	43.48	42.73	40.37	1.012	0.77	0.66	0.86
6 wks	63.03	62.26	62.64	66.92	63.66	59.77	1.369	0.78	0.57	0.63
9 wks	80.78	83.03	82.56	87.06	84.65	78.87	1.553	0.67	0.66	0.47
12 wks	100.19[c]	104.10[b]	102.78[b]	108.17[a]	106.05[ab]	99.62[c]	1.602	0.50	0.61	0.40
ADG (g)										
0–3 wks[L]	567	459	486	597	561	448	19.4	0.38	0.04	0.29
4–6 wks	960	1,032	1,023	1,116	997	924	32.2	0.91	0.73	0.28
0–6 wks	763	745	754	857	779	686	18.7	0.59	0.14	0.19
7–9 wks	845	989	948	959	1,000	910	30.9	0.66	0.50	0.62
10–12 wks	924	1,003	963	1,005	1,019	988	16.9	0.26	0.53	0.71
7–12 wks	885	996	956	982	1,009	949	16.1	0.27	0.19	0.37
0–12 wks	824[c]	871[b]	855[bc]	919[a]	894[ab]	818[c]	12.2	0.24	0.23	0.07
ADFI (g)										
0–3 wks	1,462	1,366	1,434	1,390	1,450	1,340	40.1	0.75	0.93	0.66
4–6 wks	2,280	2,304	2,490	2,350	2,378	2,164	12.3	0.51	0.97	0.15
0–6 wks	1,872	1,834	1,960	1,872	1,912	1,752	39.2	0.60	0.98	0.35
7–9 wks	2.674	2,770	3,032	2,786	2,798	2,620	60.2	0.46	0.81	0.19
10–12 wks	3,522	3,580	3,748	3,512	3,662	3,204	72.8	0.29	0.70	0.18
7–12 wks	3,100	3,176	3,390	3,150	3,230	2,910	63.8	0.33	0.88	0.17
0–12 wks	2,486	2,506	2,674	2,512	2,570	2,334	49.6	0.42	0.94	0.22
G:F ratio										
0–3 wks[L]	0.390	0.340	0.340	0.434	0.388	0.338	0.0118	0.18	0.03	0.58
4–6 wks	0.426	0.448	0.408	0.478	0.422	0.422	0.0112	0.56	0.42	0.39
0–6 wks[L]	0.416	0.406	0.382	0.456	0.408	0.390	0.0083	0.18	0.02	0.52
7–9 wks	0.316	0.362	0.314	0.344	0.358	0.350	0.0094	0.31	0.38	0.67
10–12 wks	0.266	0.280	0.256	0.290	0.278	0.328	0.0973	0.12	0.80	0.30
7–12 wks	0.286	0.314	0.284	0.312	0.312	0.336	0.0073	0.09	0.71	0.33
0–12 wks	0.334	0.350	0.322	0.368	0.348	0.356	0.0046	0.01	0.43	0.13

[L]Linear response ($p < 0.05$) to dietary CP levels when a significant CP effect was detected.

[a–c]means with different superscripts in the same row differ significantly ($p < 0.05$).

CP, crude protein; ME, metabolizable energy; SEM, standard error of the mean; ADG, average daily gain; ADFI, average daily feed intake.

differences over the course of the experiment ($p < 0.05$), and 13.82 MJ/kg and the high CP level resulted in the highest BW and ADG among the six treatments.

Blood profiles

The effects of dietary energy and CP levels on blood profiles are presented in Table 6. There were no significant differences in glucose and total protein concentrations when pigs were fed different dietary ME and CP levels during the growing period, but BUN concentration increased with a decrease in dietary ME ($p < 0.01$). In the finishing period, total protein concentration decreased when pigs were fed lower dietary ME concentrations ($p < 0.05$).

Ammonia is produced by the body after eating protein and the liver produces urea as a waste product of protein digestion. Urea nitrogen is a waste product that is released by the liver and then filtered out of the blood by the kidneys [25,26]. Therefore, BUN is used as a standard index for evaluating protein quality or excessive protein intake [27,28]. Fuller et al. [29] demonstrated that feeding animals carbohydrates could increase protein deposition. BUN level is affected by N intake [30], and has a negative correlations with ADG and G:F ratio [26]. In this study, BUN concentration decreased because pigs were fed more energy, which likely improved protein deposition and utilization.

Suboptimal protein intake can decrease the levels of blood total protein [31]. Matthews et al. [32] represented that total protein concentration increased when protein utilization by pigs was improved. In this experiment showed that total protein concentration decreased as ME level in the diet was decreased during the finishing period. This is consistent with the decrease in the G:F ratio with a decrease in dietary ME.

Carcass traits

The effect of dietary energy and CP levels on carcass traits are presented in Table 7. In this study, there were no significant differences in moisture, CP, crude fat, or crude ash according to diet. Other studies have reported similar results; Kil et al. [33] showed there was no significant difference in CP and crude fat in pork when pigs were fed diets with different GE (18.34–16.20 MJ/kg). Stewart et al. [34] showed that adding soybean hulls and wheat middling to 30% could improve CP levels in growing-finishing pigs (growing diets: 17.83%–20.30%; finishing diets: 12.44%–15.21%) but this had no significant effects on moisture, CP, crude fat, or crude ash in the resulting pork.

The effect of dietary energy and CP levels on physiochemical properties of the meat are presented in Table 8. Variations in diet had no detrimental effects on cooking loss, shear force, or water holding capacity. These results are consistent with those of Apple et al. [18] who demonstrated that cooking loss was not affected by different levels of ME (14.57–13.82 MJ/kg). Madeira et al. [35] represented that decreasing CP level in the finishing diet (16%–13%) had no effect on cooking loss. Additionally, Widmer et al. [36] reported that decreasing CP in the growing-finishing period by 4% had no effect on cooking loss. Meng et al. [37] demonstrated that decreasing energy (ME: 14.65–14.24 MJ/kg) and CP levels (growing period: 18%–17% and finishing period: 16%–15%) had no effects on water holding capacity or cooking loss. Widmer et al. [36] represented that decreasing energy (growing period: 1.68 MJ/kg of ME and finishing period: 0.82 MJ/kg of ME) and CP level (growing period: 21.3%–15.34%; early finishing period: 18.76%–15.34% and late finishing period: 13.64%–11.24%) had no effects on cooking loss and shear force.

Table 9 shows the effect of energy and CP levels on muscle. TBARS is an index of fat oxidation. Madsen et al. [38] found that the process of fat oxidation could be accelerated in the logissimus by the intake of crude fat. In this study, a decrease in ME of 0.42 MJ/kg and in CP of 2% had no significant effect on muscle

Table 6. Effects of dietary energy and crude protein levels on blood profiles in growing-finishing pigs

Energy	ME 13.40 MJ/kg			ME 13.82 MJ/kg			SEM	*p*-value		
CP (%)	High	Middle	Low	High	Middle	Low		ME	CP	M × C
Blood urea nitrogen (BUN) (mmol/L)										
6 wks	4.61	4.17	4.11	3.36	3.29	4.03	0.144	< 0.01	0.71	0.31
12 wks[L]	4.92	4.03	3.83	4.41	4.81	3.46	0.187	0.93	0.07	0.28
Glucose (mmol/L)										
6 wks	46.26	45.12	48.48	50.33	46.18	42.28	0.662	0.37	0.27	0.26
12 wks	42.28	46.45	45.24	45.89	46.17	48.94	0.547	0.54	0.84	0.16
Total protein (g/L)										
6 wks	67.51	67.30	65.32	69.18	67.31	63.71	0.743	1.00	0.10	0.65
12 wks	67.02	65.50	67.31	70.02	69.24	68.48	0.601	0.04	0.73	0.68

[L]Linear response ($p < 0.05$) to dietary CP levels when a significant CP effect was detected.

CP, crude protein; ME, metabolizable energy; SEM, standard error of the mean; BUN, blood urea nitrogen.

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Table 7. Effect of dietary energy and crude protein levels on proximate analysis of *longissimus* muscles in growing-finishing pigs

Energy	ME 13.40 MJ/kg			ME 13.82 MJ/kg			SEM	*p*-value		
CP (%)	High	Middle	Low	High	Middle	Low		ME	CP	M × C
Proximate analysis (%)										
Moisture	74.73	73.81	74.21	72.97	74.07	73.18	0.247	0.10	0.91	0.25
Crude ash	1.19	1.29	1.15	1.07	0.95	1.21	0.720	0.16	0.99	0.15
Crude protein	23.37	23.36	22.84	23.10	23.35	23.50	0.231	0.82	0.96	0.74
Crude fat	2.40	4.03	3.12	3.46	1.63	1.74	0.352	0.20	0.82	0.13

CP, crude protein; ME, metabolizable energy; SEM, standard error of the mean.

Table 8. Effect of dietary energy and crude protein levels on physiochemical properties of *longissimus* muscles from growing-finishing pigs

Energy	ME 13.40 MJ/kg			ME 13.82 MJ/kg			SEM	*p*-value		
CP (%)	High	Middle	Low	High	Middle	Low		ME	CP	M × C
Physiochemical property										
WHC (%)[1)]	68.89	67.48	68.94	69.23	70.57	71.69	0.592	0.10	0.61	0.59
Shear force (kg/0.5 inch)	7.59	7.23	7.45	7.64	6.94	7.34	0.261	0.84	0.75	0.97
Cooking loss (%)	31.85	31.07	31.36	31.23	30.83	30.22	0.293	0.30	0.59	0.83

[1)]Water holding capacity.

CP, crude protein; ME, metabolizable energy; SEM, standard error of the mean.

Table 9. Effect of dietary energy and crude protein levels on TBARS assay of *longissimus* muscles from growing-finishing pigs

Energy	ME 13.40 MJ/kg			ME 13.82 MJ/kg			SEM	*p*-value		
CP (%)	High	Middle	Low	High	Middle	Low		ME	CP	M × C
TBARS (mgMA/kg)										
Day 0	0.23	0.22	0.23	0.24	0.23	0.22	0.004	0.70	0.56	0.69
Day 5	0.24	0.22	0.21	0.21	0.22	0.21	0.004	0.21	0.44	0.53
Day 7	0.57	0.56	0.57	0.56	0.55	0.55	0.007	0.50	0.97	0.93

CP, crude protein; ME, metabolizable energy; SEM, standard error of the mean.

Table 10. Effect of dietary energy and crude protein levels on fatty acid composition of *longissimus* muscles from growing-finishing pigs

Energy	ME 13.40 MJ/kg			ME 13.82 MJ/kg			SEM	*p*-value		
CP (%)	High	Middle	Low	High	Middle	Low		ME	CP	M × C
Fatty acid composition (%)										
SFA	39.08	40.69	39.67	37.75	37.24	37.39	0.427	< 0.01	0.82	0.53
MUFA	41.37	39.14	42.23	40.86	40.46	41.77	0.366	0.86	0.06	0.47
PUFA	19.56	20.17	18.10	21.40	22.30	20.84	0.512	0.03	0.35	0.93

CP, crude protein; ME, metabolizable energy; SEM, standard error of the mean; SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

TBARS assay. Other studies have also reported that a decrease in ME and CP levels had no effects on TBARS assay [35,37].

Table 10 shows the effects of energy and CP levels on fatty acid composition in growing-finishing pig diets. Saturated fatty acid (SFA) increased ($p < 0.01$) and polyunsaturated fatty acid (PUFA) decreased ($p < 0.05$) as ME was decreased by 0.42 MJ/kg in growing-finishing pig diets. In addition, monounsaturated fatty acid (MUFA) content tended to increase when CP level was decreased in growing-finishing pig diets ($p = 0.06$). European Food Safe Authority (EFSA) recommend that for food to be considered healthy, it should have a low content of SFA [39]. Feed ingredients and nutrition composition can also affect fatty acid composition in pork [40,41]. Nemechek et al. [42] and Davis et al. [43] demonstrated that SFA content could be decreased and PUFA content could be increased by decreasing tallow levels or decreasing ME by 0.42 MJ/kg (13.82–13.40 MJ/kg) in growing-finishing diets.

Bessa et al. [44] and Madeira et al. [35] represented no significant differences in MUFA as CP levels were decreased by 3%–4% in growing-finishing pig diets. The discrepancy between this study and previous studies may due to the high CP level in our study. In summary, this experiment showed that 13.82 MJ/kg of ME in a growing-finishing pig diet can improve fatty acids composition of pork.

The change in pH after slaughter is a very important factor affecting the freshness, tenderness, color, texture, and storage of pork. In this study, there were no significant differences in pH at 0 and 24 hours after slaughter (Table 11). This result is in accordance with Apple et al. [18], Widmer et al. [36], Prandini et al. [45], and Madeira et al. [35] who reported that the pH at 0 and 24 hours after slaughter were not affected by ME (14.57–13.82 MJ/kg and 15.49–13.82 J/kg) or CP level (17.7%–14.5% and 16%–13%).

Meat color results are shown in Table 12. There were no significant differences in L*, a*, or b* values as ME level was decreased by 0.42 MJ/kg or CP concentration was decreased by 2%. Apple et al. [18] and Hinson et al. [47] also demonstrated that decreasing energy level in the diet did not affect meat color (14.57–13.82 MJ/kg ME and 14.65–13.40 MJ/kg ME, respectively). In addition, Prandini et al. [45] and Madeira et al. [35] represented that decreasing CP level in diet did not affect meat color (17.7%–14.5% and 16%–13%, respectively).

Conclusions

An ME of 13.82 MJ/kg in growing-finishing pig diets increased

Table 11. Effect of dietary energy and crude protein levels on the pH of *longissimus* muscles from growing-finishing pigs

Energy	ME 13.40 MJ/kg			ME 13.82 MJ/kg			SEM	*p*-value		
CP (%)	High	Middle	Low	High	Middle	Low		ME	CP	M × C
pH										
0 hours	6.05	6.05	6.11	6.14	6.07	5.84	0.040	0.21	0.45	0.16
3 hours	5.64	5.75	5.68	5.70	5.66	5.51	0.030	0.22	0.31	0.27
6 hours	5.58	5.64	5.58	5.56	5.54	5.51	0.016	0.08	0.49	0.59
12 hours	5.62	5.62	5.62	5.62	5.58	5.62	0.019	0.72	0.87	0.90
24 hours	5.60	5.64	5.60	5.63	5.59	5.66	0.016	0.74	0.93	0.42

CP, crude protein; ME, metabolizable energy; SEM, standard error of the mean.

Table 12. Effect of dietary energy and crude protein levels on color of *longissimus* muscles from growing-finishing pigs

Energy	ME 13.40 MJ/kg			ME 13.82 MJ/kg			SEM	*p*-value		
CP (%)	High	Middle	Low	High	Middle	Low		ME	CP	M × C
CIE value, L*										
0 hours	39.34	38.93	38.88	40.72	39.21	39.61	0.356	0.30	0.55	0.84
3 hours	39.53	40.19	39.97	39.69	38.43	40.11	0.392	0.86	0.95	0.38
6 hours	40.73	40.38	40.07	41.07	40.86	42.14	0.515	0.40	0.94	0.78
12 hours	43.97	41.76	43.02	43.38	43.39	44.34	0.434	0.40	0.53	0.57
24 hours	44.89	45.82	45.11	46.08	45.53	44.54	0.367	0.89	0.66	0.63
CIE value, a*										
0 hours	1.83	1.22	1.73	1.54	1.93	1.87	0.101	0.35	0.66	0.15
3 hours	1.87	1.89	2.48	2.41	2.18	2.40	0.120	0.31	0.39	0.58
6 hours	2.06	2.18	2.86	2.78	2.43	2.70	0.123	0.28	0.26	0.35
12 hours	3.14	2.56	3.42	3.23	3.01	3.21	0.105	0.60	0.11	0.43
24 hours	4.11	3.73	4.26	4.20	4.37	4.13	0.132	0.49	0.92	0.53
CIE value, b*										
0 hours	4.30	3.66	3.90	4.12	4.17	4.02	0.083	0.36	0.29	0.24
3 hours	4.36	4.55	4.54	4.72	4.29	4.54	0.095	0.89	0.86	0.47
6 hours	4.64	4.57	4.93	5.22	4.70	5.10	0.127	0.28	0.48	0.74
12 hours	5.60	5.15	5.76	5.65	5.48	5.93	0.103	0.38	0.14	0.86
24 hours	6.34	6.12	6.59	6.71	6.70	6.37	0.121	0.42	0.98	0.51

CP, crude protein; ME, metabolizable energy; SEM, standard error of the mean.

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the G:F ratio over the entire experimental period, SFA concentration in the *longissimus* muscles and blood total protein level in the finishing period, while decreasing BUN concentration during the growing period.

When CP level was decreased in growing-finishing pig diets, blood total protein during the growing phase and BUN during the finishing period were decreased, but MUFA level tended to increase.

In summary, a growing-finishing diet of 13.82 MJ/kg ME with the high CP level (18%/16.3%/15.3%/13.2%) can improve growth performance and show better fatty acids composition of pork.

Competing interests

No potential conflict of interest relevant to this article was reported.

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Availability of data and material

Upon reasonable request, the datasets of this study can be available from the corresponding author.

Authors' contributions

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Methodology: Han TH, Jin YH.
Software: Kim BO, Do SH.
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Ethics approval and consent to participate

All experimental procedures involving animals were conducted in accordance with the Animal Experimental Guidelines provided by the Seoul National University Institutional Animal Care and Use Committee (SNUIACUC; SNU-160819-9).

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