Effects of the plane of nutrition during the latter grower and entire finisher phases on grow-finish pig performance in summer

Seung Won Yang[1], Myeong Hyeon Kim[1], Jung-Seok Choi[2], Sang-Keun Jin[1,3], Man-Jong Park[1], Young-Min Song[1] and Chul Young Lee[1,3*]

[1]Department of Animal Resources Technology, Gyeongnam National University of Science and Technology, Jinju 52725, Korea
[2]Swine Science and Technology Center, Gyeongnam National University of Science and Technology, Jinju 52725, Korea
[3]Regional Animal Industry Center, Gyeongnam National University of Science and Technology, Jinju 52725, Korea

Abstract

The present study was undertaken to investigate the effects of the plane of nutrition (PN) for growing-finishing pigs on growth performance and meat quality in summer. One hundred and two barrows and 102 gilts weighing approximately 44 kg were placed on a high-, medium-, or low-plane grower diet (HPG, MPG, or LPG) with ME and lysine concentrations ranging from 3.33 to 3.40 Mcal/kg and 0.93% to 1.15%, respectively, for 29 days in 6 replicates (pens) in total. Pigs from each grower pen were divided into two finisher pens and provided with a high-plane finisher diet (HPF) containing 3.40 Mcal ME and 9.5 g lysine/kg and a low-plane finisher diet (LPF; 3.25 Mcal ME and 8 g lysine/kg), respectively, up to approximately 110 kg, and slaughtered. Growth performance of the pigs, including average daily gain (ADG), average daily feed intake (ADFI), and gain:feed ratio, was not influenced by the grower-phase PN during any of the grower phase, a 31-d finisher phase I, and ensuing phase II. However, both the ADG and gain:feed ratio were greater ($p < 0.05$) for the HPF group than for the LPF group during the finisher phase I (748 vs. 653 g with SEM = 13 g and 0.333 vs. 0.299 with SEM = 0.008, respectively). The ADG, but not gain:feed ratio, was greater for the HPF group vs. LPF during the finisher phase II (673 vs. 623 g with SEM = 15 g for ADG and 0.322 vs. 0.323 with SEM = 0.005 for the gain:feed ratio). The carcass backfat thickness (BFT) was greater for the LPF group vs. HPF within the pigs which had been placed on LPG during the grower phase, but not within the pigs from the HPG or MPG group. Physicochemical characteristics of the *longissimus dorsi* muscle (LM) and sensory quality attributes of fresh and cooked LM were not influenced by either the grower-phase or finisher-phase PN. In conclusion, high PN is necessary for finishing pigs during the hot season to minimize the reduced rate of weight gain and also to prevent the increase of BFT that could result from low PN.

Keywords: Backfat, Growing-finishing pig, Growth, Meat quality, Plane of nutrition, Summer

Introduction

The weight gain of the pig, which basically consists of lean and fat gains, is determined by the intakes of energy and lysine, the first limiting amino acid in the pig [1, 2]. The intakes of energy and lysine increase with the increases of the dietary energy concen-

tration and lysine:calorie ratio, respectively [3–5]. The feed intake, however, decreases with increasing dietary energy concentration and therefore, the lysine content of the pig diet is mostly increased in proportion to the energy density at a fixed lysine:calorie ratio to preclude a decrease of lysine intake due to increasing energy density [1, 4]. With respect to the gain, the rate of protein synthesis and hence lean gain increase with increasing dietary lysine:calorie ratio within a certain range, whereas fat deposition increases when the lysine:calorie ratio is suboptimal [3, 4, 6].

The feed intake as well as weight gain of the pig decreases with increasing ambient temperature above the 'thermoneutrality' [7–9]. Nevertheless, the gain:feed ratio and body fat percentage of the pig during the hot summer season are not much different from those during winter, because the fat gain:energy intake ratio of the animal under a high temperature increases as a result of decreased heat production [2]. The protein gain:energy intake ratio, however, is lower at a high temperature than at the thermoneutrality, for which reason, the negative effect of the reduced feed intake on weight gain is amplified at the high temperature, especially when the dietary lysine:calorie ratio is suboptimal [10]. On the other hand, the effect of increasing lysine:calorie ratio on the increase of weight gain, lean percentage, and feed efficiency, as well as on the decrease of the body fat percentage [4, 11], is higher at the high temperature than at the thermoneutrality [11]. Therefore, the feed manufacturers generally increase the lysine:calorie ratio as well as the energy density of the pig diet during the hot season to minimize the negative effect of the high temperature on feed intake.

In a preceding study of ours performed in winter [12], pigs which were fed grower phase I and II diets with medium planes of nutrition (MPN) and low planes of nutrition (LPN) during 24–43 and 43–72 kg of body weight, respectively, and subsequently fed a same MPN finisher diet, reached a 115-kg market weight 4.5 and 6.5 days later, respectively, than those reared on high-PN diets throughout the growing-finishing period. Moreover, the MPN and LPN pigs exhibited a compensatory growth during the grower phase II and early finisher phase, respectively, with an increased backfat thickness (BFT) at slaughter for the LPN pigs vs. HPN. These results for the MPN and LPN pigs are likely to have result-

ed from insufficient nutrition, but it was not clear when they were on the putative nutritional insufficiency. The present study was therefore performed to investigate the effects of PN during the grower phase II and onward on growth performance in summer by placing the pigs reared on HPN up to the end of the grower phase I on varying PN during the grower phase II and subsequently on HPN or LPN during the finisher phase.

Materials and Methods

Experimental diets and animals
All experimental protocols involving animals of the present study were approved by the Institutional Animal Care and Use Committee (IACUC) of Gyeongnam National University of Science and Technology (2018-4). All experimental animals were provided with commercial diets throughout the feeding trial, which began from May 21, 2018 on a commercial pig farm. A total of 204 95-day-old (Landrace × Yorkshire) × Duroc pigs consisting of equal numbers of barrows and gilts weighing approximately 24 kg were randomly allotted to 6 pens according to the sex, with 34 pigs per pen, such that each of three dietary groups with high, medium, and low planes of nutrition (HPN, MPN, and LPN, respectively) had one pen for each sex (Table 1). After provision of the designated grower diet for 29 d, pigs from each pen were divided into two finisher pens and fed two finisher diets with HPN and LPN, respectively, up to the end of the feeding trial.

The body weights of the animals were measured on the beginning day of the experiment (d 0) and the last days of the grower phase and the finisher phase I on d 29 and 60, respectively, as well as on the last day of the feeding trial on d 90 or 92 prior to slaughter depending on the pen, with the final weights of 74 outgrown pigs measured on d 83. The feed intake was measured on d 29 and 60 for all pens as well as on d 90 or 92. The experimental animals were transported to a local abattoir on the following day of termination of the feeding trial or measurement of the final weight and slaughtered after lairage for 3 h or longer. The BFT was corrected for a 112-kg body weight using 0.26 and 0.19 mm per kg body weight for the barrow and gilt, respectively, as described previously

Table 1. Energy and lysine concentrations of the experimental diets (as-fed basis)

| Item | Grower phase | | | | | | Finisher phase | |
| | HP[1] | | MP[2] | | LP[3] | | HP | LP |
	P 1[4]	P 2[5]	P 1	P 2	P 1	P 2		
ME (Mcal/kg)	3.35	3.40	3.33	3.38	3.25	3.30	3.40	3.25
Total lysine (%)	1.10	1.15	1.02	1.07	0.93	0.97	0.95	0.80
Lysine:ME (g/Mcal)	3.29	3.39	3.06	3.17	2.86	2.94	2.80	2.46

[1–3]Commercial diets with high, medium, and low planes of nutrition, respectively.

[4,5]Periods 1 and 2 of the grower phase, respectively; provided for the first 11 and subsequent 18 days, respectively.

HP, high plane; MP, medium plane; LP, low plane.

[13].

Analyses of the physicochemical and sensory characteristics of muscle

The left-side *longissimus dorsi* muscle (LM) was cut from the chilled carcasses of a total of 36 animals, with 3 animals form each of the 3 (grower PN) × 2 (sex) × 2 (finisher PN) combination, which had been selected from those with medial final weights. Physicochemical characteristics of LM including the color by the CIE [14] standards, water holding capacity, drip loss, shear force, cohesiveness, springiness, gumminess, and chemical composition were measured or determined as described previously [15–17]. Sensory quality attributes of fresh LM and cooked LM were also evaluated according to a 9-notch whole number scale also as previously described [16–18].

Statistical analysis

All data were analyzed using the 'Statistics' package of the SAS program (SAS Inst., Inc., Cary, NC, USA). The pen and the individual animal were the experimental units in all growth performance variables and the variables for the carcass and LM, respectively. The growth performance data of the grower phase were analyzed using the MIXED procedure, with the variation associated with the sex partitioned into the random effect, after confirmation of the non-significance of the sex effect in all variables. The growth performance variables for the finisher phase and the *post-mortem* variables were analyzed using the General Linear Model procedure. The grower PN, sex, and finisher PN were included in the model as main effects for the growth performance variables. The interaction between the sex and finisher PN was also included in the model, but other interactions, which were non-significant, were excluded from the model. In the model for the *postmortem* variables, the main effects, as well as all possible two-way interactions and a three-way interaction, were included. In all analyses,

the significance was defined as $p < 0.05$.

Results

Growth performance

The effect of the grower-phase PN (GPN) was not significant in any of the average daily gain (ADG), average daily feed intake (ADFI), gain:feed ratio, daily ME intake, and weight gain:ME intake ratio (Table 2). Effects of the daily lysine intake and gain:lysine ratio also were not significant in ANOVA ($p = 0.09$ for both), but it was noteworthy that the former was greater for the HP group than for the LP group ($p < 0.05$) whereas the latter was greater for the LP group ($p < 0.05$).

The GPN did not exert any significant effect on any of ADG, ADFI, gain:feed ratio, daily ME intake, gain:ME ratio, daily lysine intake, gain:lysine gario during the finisher phase I (Table 3). The ADG during the 31-d finisher phase I was greater for the barrow and the high-plane finisher diet (HPF) group than for the gilt and the low-plane finisher diet (LPF) group, respectively (747 vs. 654 g with SEM = 13 g and 748 vs. 653 g with SEM = 13 g, respectively). The gain:feed ratio, which was not different between the barrow and gilt groups, was greater for the HPF group vs. LPF. The daily ME intake was greater for the barrow vs. gilt, with no difference between the HPF and LPF groups, but the gain:ME ratio did not differ between the two sexes or finisher-phase PN (FPN) groups. The daily lysine intake was greater for the barrow vs. gilt (20.9 vs. 18.3 g with SEM = 0.6 g) as well as for the HPF vs. LPF group (21.6 vs. 17.5 g with SEM = 0.6 g), but the gain:lysine ratio was greater for the LPF group vs. HPF (37.4 vs. 34.7 with SEM = 0.8), with no difference between the sexes.

During the finisher phase II, GPN had no effect on any of the growth performance variables measured in the present study as in the finisher phase I. The ADG during the finisher phase II did not differ between the two sexes or FPN groups. The estimated number

Table 2. Effects of the plane of nutrition on growth performance of the grow-finish pigs during the latter grower phase

Item	HP[1]	MP[1]	LP[1]	SEM	*p*-value
Initial weight (kg)	44.7	43.7	43.0	0.6	0.15
Final weight (kg)	71.0	69.4	68.3	0.8	0.07
ADG (g)	906	886	842	13	0.20
ADFI (kg)	2.03	1.98	2.03	0.05	0.79
Gain:feed	0.446	0.447	0.430	0.011	0.57
ME intake (Mcal/d)	6.86	6.66	6.65	0.22	0.69
Gain:ME (g/Mcal)	132.1	133.1	131.1	2.7	0.88
Lysine intake (g/d)	23.0	20.8	19.3	0.7	0.09
Gain:lysine (g/g)	39.4	42.6	45.1	0.9	0.09

[1]Data are least squares means of two replicates (pens) of 34 pigs.

HP, high plane; MP, medium plane; LP, low plane; SEM, standard error of mean; ADG, average daily gain; ADFI, average daily feed intake; ME, metabolizable energy.

Table 3. Effects of the plane of nutrition (PN) during the grower and finisher phases on growth performance of the growing-finishing pigs during the finisher phase

| Item | PN during the rower phase | | | | | PN by sex during the finisher phase | | | | | | | |
| | HP[1] | MP[1] | LP[1] | SEM | p-value | Barrow | | Gilt | | SEM | p-value | | |
						HP[2]	LP[2]	HP[2]	LP[2]		S	PN	S × PN
Phase I[3]													
Initial wt (kg)	71.0	69.4	68.2	1.0	0.26	68.9	67.2	71.2	70.8	1.2	< 0.01	0.44	0.85
Final wt (kg)	92.1	91.5	90.2	1.3	0.61	93.5	88.9	93.0	89.6	1.5	0.98	0.04	0.73
ADG (g)	681	712	710	15	0.30	793	701	703	605	18	< 0.01	< 0.01	0.75
ADFI (kg)	2.18	2.29	2.20	0.10	0.71	2.37	2.35	2.14	2.03	0.11	0.05	0.57	0.66
Gain:feed	0.308	0.312	0.322	0.010	0.50	0.337	0.298	0.329	0.300	0.011	0.99	0.02	0.90
ME intake (Mcal/d)	7.34	7.61	7.31	0.28	0.71	8.18	7.65	7.28	6.58	0.32	0.02	0.11	0.80
Gain:ME (g/Mcal)	92.7	93.8	97.0	2.5	0.51	97.2	91.8	96.8	92.2	2.9	1.00	0.14	0.90
Lysine intake (g/d)	19.3	20.1	19.3	0.8	0.67	22.9	18.8	20.4	16.2	0.9	0.03	< 0.01	0.95
Gain:lysine (g/g)	35.4	35.8	36.9	1.0	0.54	34.7	37.3	34.6	37.5	1.1	1.00	0.05	0.90
Phase II[4]													
Final wt (kg)	109.3	110.0	109.4	1.2	0.88	112.3	107.5	111.1	107.3	1.4	0.63	0.02	0.70
ADG (g)	622	651	669	19	0.31	698	633	647	612	22	0.16	0.07	0.53
Age to 110 kg[5] (d)	185.2	184.5	185.4	2.7	0.97	179.4	188.3	182.3	190.2	3.2	0.49	0.04	0.89
ADFI (kg)	1.97	2.00	2.09	0.08	0.57	2.24	2.09	1.95	1.80	0.09	0.02	0.13	0.98
Gain:feed	0.317	0.328	0.322	0.009	0.74	0.312	0.304	0.331	0.342	0.011	0.04	0.89	0.42
ME intake (Mcal/d)	6.54	6.66	6.94	0.26	0.55	7.61	6.78	6.63	5.84	0.30	0.02	0.03	0.96
Gain:ME (g/Mcal)	95.5	98.7	97.0	2.8	0.74	91.9	93.6	97.6	105.3	3.3	0.04	0.20	0.40
Lysine intake (g/d)	17.2	17.6	18.4	0.67	0.50	21.3	16.7	18.6	14.4	0.77	0.02	< 0.01	0.81
Gain:lysine	36.5	37.3	37.2	1.1	0.74	32.8	38.0	34.9	42.8	1.0	0.04	< 0.01	0.34

[1,2]Data are least squares means of 4 and 3 replicates of 17 pigs, respectively.

[3,4]Means ± standard deviations of daily ambient temperature at 13:00 were 31.9 ± 2.7℃ and 33.0 ± 1.8℃, respectively.

[5]Estimated from the final wt and ADG.

HP, high plane; MP, medium plane; LP, low plane; SEM, standard error of mean; S, sex; ADG, average daily gain; ADFI, average daily feed intake.

of days necessary to reach a 110-kg market weight was less for the HPF group vs. LPF (180.8 vs. 189.3 with SEM = 2.3), with no difference between the barrow and gilt. The ADFI and daily ME intake were greater for the barrow vs. gilt, but the gain:feed and gain:ME ratios were greater for the latter. Furthermore, the ME intake was greater for the HPF group vs. LPF, with no difference between the two groups in the gain:ME ratio. The daily lysine intake was greater for the barrow vs. gilt (19.0 vs. 16.5 g with SEM = 0.5 g) and also for the HPF vs. LPF group (19.9 vs. 15.5 g with SEM = 0.5 g), whereas the reverse was true for the gain:lysine ratio (35.4 vs. 38.8 with SEM = 0.4 for the barrow and gilt, respectively; 33.9 vs. 40.3 with SEM = 0.9 for the HPF and LPF groups, respectively).

The live weight was greater for the HPF group vs. the LPF group (113.1 ± 0.5 kg vs. 109.5 ± 0.6 kg; Table 4). The dressing percentage was greater for the group of pigs provided with the high-plane grower diet (HPG) than for the group provided with the medium-plane grower diet (MPG; 77.1 vs. 76.3% with SEM = 0.2%) as well as for the gilt vs. barrow (77.0 vs. 76.6% with SEM = 0.2%). The BFT corrected for a 112-kg live weight was greater for

the LPG group vs. HPG and MPG (23.9 vs. 21.7 and 22.4 mm, respectively, with SEM = 0.5 mm), for the barrow vs. gilt (23.6 vs. 21.8 mm with SEM = 0.4 mm), and LPF group vs. HPF (23.3 vs. 22.0 mm with SEM = 0.4 mm), respectively. These differences between the dietary groups were attributable to a significant interaction between GPN and FPN (p = 0.02), i.e. the LPF pigs had a greater corrected BFT than the HPG within the LPG pigs whereas within the HPG or MPG pigs, it was not different between the LPF and HPF pigs. Moreover, the corrected BFT was influenced by a GPN × sex × FPN interaction (p = 0.03) as follows. The corrected BFT was greater for the barrow than for the gilt within the LPG-HPF pigs (24.0 vs. 20.4 mm with SEM = 0.8 mm) whereas it did not differ between the two sexes within the HPG-HPF or MPG-HPF pigs. Further, it was greater for the barrow vs. gilt within the HPG-LPF or LPG-LPF pigs, but not within the MPG-LPF pigs.

Meat quality attributes of LM

Results for the physicochemical characteristics for fresh LM and sensory quality attributes for fresh and cooked LM are shown in

Table 4. Carcass characteristics of the finisher pigs reared on varying planes of nutrition during the grow-finish period

Item	High-plane grower				Medium-plane grower				Low-plane grower			
	Barrow		Gilt		Barrow		Gilt		Barrow		Gilt	
	HPF[1]	LPF[1]	HPF	LPF	HPF	LPF	HPF	LPF	HPF	LPF	HPF	LPF
No. of animals[2]	12	15	12	13	16	14	15	12	16	10	14	14
Live wt (kg)	114.2	109.7	110.1	110.9	115.7	110.2	113.5	108.2	112.5	108.3	112.8	109.7
	± 1.4	± 1.3	± 1.4	± 1.4	± 1.2	± 1.3	± 1.3	± 1.4	± 1.2	± 1.6	± 1.3	± 1.4
Carcass wt (kg)	87.5	84.9	85.2	85.5	88.3	83.5	87.4	82.3	86.5	82.1	87.1	84.5
	± 1.2	± 1.1	± 1.2	± 1.2	± 1.0	± 1.1	± 1.1	± 1.2	± 1.0	± 1.3	± 1.1	± 1.2
Dressing (%)	76.6	77.4	77.4	77.1	76.3	75.7	77.0	76.1	76.9	75.8	77.2	77.1
	± 0.4	± 0.4	± 0.4	± 0.4	± 0.3	± 0.4	± 0.4	± 0.4	± 0.3	± 0.4	± 0.4	± 0.4
Backfat thickness (BFT; mm)												
Measurement	21.8	22.7	22.1	19.8	24.2	22.4	21.3	21.9	24.1	26.1	20.6	23.5
	± 1.1	± 0.9	± 1.1	± 1.0	± 0.9	± 1.0	± 0.9	± 1.1	± 0.9	± 1.2	± 1.0	± 1.0
At 112 kg[3]	21.2	23.3	22.4	20.1	23.2	22.8	21.0	22.6	24.0	27.1	20.4	24.0
	± 0.9	± 0.8	± 0.9	± 0.9	± 0.8	± 0.9	± 0.8	± 0.9	± 0.8	± 1.0	± 0.8	± 0.9

Item	p-value						
	G[1]	S[1]	F	G×S	G×F	S×F	G×S×F
Live wt (kg)	0.50	0.27	< 0.01	0.20	0.19	0.17	0.37
Dressing (%)	< 0.01	0.02	0.10	0.62	0.11	0.74	0.18
BFT at 112 kg	< 0.01	0.01	0.02	0.14	0.02	0.54	0.03

[1]Data are least squares means ± standard errors of means of the indicated numbers of animals.

[2]Pigs weighing 102 kg or less at the end of the feeding trial were not slaughtered.

[3]Corrected for the indicated live weight.

HPF, high-plane finisher; LPF, low-plane finisher; G, grower; S, sex; F, finisher.v

Table 5. No two-way or three-way interaction was detected in any of the physicochemical characteristics analyzed in the present study, for which reason, only the results for GPN, FPN, and sexes with no combination of them are shown in this table. The L* value was greater for the HPG and MPG pigs than for the LPG pigs and also for the barrow than for the gilts. No difference was detected among the three GPN groups or between the two FPN groups or sexes in any of the redness value (a*), water holding capacity, drip loss, cooking loss, shear force, cohesiveness, springiness, and gumminess. The moisture and protein contents of LM also did not differ among or between the dietary groups or sexes, but the fat content was greater for the LPF group vs. HPF group.

In the sensory evaluation for fresh LM, the scores for the color, aroma, off-odor, drip, marbling, and overall acceptability were not influenced by GPN, FPN, or sex, except for a greater drip score for the barrow vs. gilt. In the off-odor score, a GPN × sex as well as FPN × sex interaction was detected. However, combinatorial results for the main factors are not shown in the table for this variable, because no difference was noted between any two means among the six means of the GPN × sex combination or among four means of the FPN × sex combination.

No main effect was detected in the sensory evaluation for cooked LM with respect to the color, aroma, flavor, juiciness, tenderness, and overall acceptability, except for a greater aroma score for the barrow vs. gilt. The juiciness score was greater for the barrow vs. gilt within the MPG pigs (7.27 vs. 6.81 with SEM = 0.11), but it did not differ between the two sexes in the HPG or LPG pigs (p = 0.01 for the GPN × sex interaction).

Discussion

The ADFI, daily ME intake, and daily lysine intake of the grower pigs of the present study were 9%–12% lower than those of the pigs with identical genetic backgrounds observed in winter in the previous study [12], with a 7% lower ADG in the former, whereas all of these variables including ADG of the finisher pigs were approximately 30% lower in the present study. Nevertheless, the ADG during the entire finisher phase was 10.5% greater for the

Table 5. Physicochemical and sensory characteristics of the *longissimus dorsi* muscle (LM) of the pigs reared on varying planes of nutrition during the grow-finish period

Item	Grower plane of nutrition (PN)					Finisher PN				Sex			
	H[1]	M[1]	L[1]	SEM	p–value	H[2]	L[2]	SEM	p–value	B[2]	G[2]	SEM	p–value
Physicochemical characteristics													
pH	5.67	5.67	5.65	0.03	0.78	5.64	5.69	0.03	0.16	5.68	5.65	0.03	0.35
CIE L*	56.1[a]	56.2[a]	52.9[b]	1.0	0.05	55.6	54.5	0.8	0.35	56.6[a]	53.5[b]	0.8	0.02
CIE a*	8.09	8.15	8.46	0.34	0.72	8.38	8.09	0.29	0.49	8.21	8.26	0.28	0.90
WHC	63.1	62.4	62.9	0.6	0.70	62.8	62.8	0.5	0.95	62.7	62.8	0.5	0.90
Drip loss (%)	7.27	7.68	9.72	0.89	0.14	8.59	7.85	0.73	0.48	7.86	8.59	0.73	0.49
Cooking loss (%)	37.7	36.9	38.3	0.6	0.27	37.5	37.8	0.5	0.62	37.8	37.4	0.5	0.55
W-B SF	5.29	5.91	5.22	0.52	0.59	5.68	5.27	0.42	0.50	5.54	5.41	0.42	0.82
Cohesiveness (%)	0.43	0.42	0.44	0.02	0.73	0.44	0.43	0.01	0.55	0.43	0.43	0.01	0.91
Springiness (mm)	1.06	1.02	1.04	0.02	0.40	1.06	1.01	0.02	0.09	1.05	1.04	0.02	0.63
Gumminess (kg)	0.55	0.55	0.63	0.04	0.27	0.58	0.56	0.03	0.68	0.60	0.55	0.03	0.33
Moisture (%)	74.5	73.9	74.0	0.2	0.11	74.1	74.2	0.2	0.62	74.2	74.1	0.2	0.86
Protein (%)	21.5	21.6	21.3	0.3	0.84	21.6	21.3	0.3	0.56	21.4	21.5	0.3	0.75
Fat (%)	1.88	2.44	1.96	0.16	0.05	1.88[b]	2.31[a]	0.13	0.03	0.34	1.95	0.13	0.14
Sensory attributes of fresh LM[3]													
Color	7.27	7.20	7.33	0.07	0.51	7.24	7.30	0.06	0.48	7.26	7.28	0.06	0.81
Aroma	7.32	7.49	7.40	0.06	0.16	7.42	7.39	0.05	0.64	7.41	7.40	0.05	0.92
Off-odor	7.46	7.38	7.44	0.06	0.63	7.37	7.49	0.05	0.10	7.35	7.42	0.05	0.92
Drip	7.24	7.24	6.91	0.13	0.15	7.02	7.24	0.11	0.17	7.29[a]	6.97[b]	0.11	0.05
Marbling	7.24	7.30	7.16	0.10	0.61	7.21	7.26	0.08	0.69	7.34	7.13	0.08	0.08
Acceptability	7.34	7.25	7.41	0.13	0.70	7.28	7.38	0.11	0.51	7.27	7.39	0.11	0.43
Sensory attributes of cooked LM[3]													
Color	7.13	7.04	7.31	0.10	0.18	7.09	7.23	0.08	0.26	7.17	7.15	0.08	0.88
Aroma	7.38	7.34	7.32	0.06	0.83	7.39	7.31	0.05	0.27	7.42[a]	7.27[b]	0.05	0.04
Flavor	7.18	7.03	7.10	0.07	0.32	7.07	7.14	0.06	0.41	7.13	7.08	0.06	0.62
Juiciness	7.05	7.04	6.91	0.07	0.35	7.04	6.97	0.06	0.41	7.04	6.97	0.06	0.41
Tenderness	7.15	7.05	6.90	0.11	0.30	6.96	7.10	0.09	0.28	6.98	7.08	0.09	0.44
Acceptability	7.11	7.05	7.02	0.07	0.66	7.06	7.06	0.06	0.94	7.05	7.08	0.06	0.69

[1,2]Data are means for 12 and 18 animals, respectively.

[3]Scored arbitrarily by 9 panelists according to a 9-ladder whole number scale such that a greater score indicates better quality.

[a,b]Means with no common superscript within a row differ ($p < 0.05$).

H, high; M, medium; L, low; B, barrow; G, gilt; WHC, water holding capacity; W-B SF, Warner-Bratzler shear force.

HPF group vs. LPF in the present study, even though the finisher-phase ADG in winter did not differ between the two dietary groups. As such, the latter diet, which was classified as a MPF in winter, was regarded as LPF in the present study. Overall, these results are consistent with those in the literature in which the negative slope of ADFI as a function of ambient temperature gets steeper with increasing body weight of the pig and the decrease of weight gain due to the high temperature can be reduced by increasing PN [7, 10, 19, 20]. On the other hand, the gain:feed ratios of the present pigs during the grower and finisher phases, respectively, were only 6% and 4% lower than those of the pigs in winter, respectively. This is also consistent with the fact that the

feed efficiency is minimally influenced by the increase of ambient temperature because the heat production of the pigs also decreases with increasing ambient temperature [10, 21].

The ADG of the present grow-finish pigs were reflective of their daily lysine intakes, which was consistent with the report of Noblet et al. [10] in which ADG of the grow-finish pigs during the hot season was commensurate with the lysine intake. It is known that when the lysine intake of the grow-finish pig is suboptimal, the efficiency of lysine utilization increases to result in an increase in the gain:lysine ratio [22, 23]. In this context, the increasing order of HPG → MPG → LPG group in the gain:lysine ratio in the grower pigs, as well as the order of HPF → LPG group in the finisher pigs,

albeit non-significant statistically, suggested that the lysine intakes of the MPG, LPG, and LPF groups were not enough for a maximal weight gain. A compensatory growth often occurs when pigs reared on a suboptimal PN during the grower phase are switched to an optimal PN during the finisher phase [23–25]. Such a compensatory growth, which was apparent in winter [12], was seemingly precluded in the present grow-finish pigs due to their reduced feed intake and growth rate under the high ambient temperature.

When the lysine intake of the growing-finishing pig is suboptimal, the rate of lean gain decreases but the fat deposition increases [4, 26]. When the pigs with an increased BFT due to the low-lysine diet during the grower phase are switched to a diet with a normal lysine content, the pigs usually exhibit a normal BFT as well as a normal lean percentage resulting from the aforementioned compensatory growth [22–25]. The reduced BFT of the HPF vs. LPF group within the LPG pigs in the present study thus suggests that BFT probably increased during the grower phase due to the LPG diet and returned to the normal level through the compensatory growth mechanism while they were fed the HPF diet. The lack of difference in BFT between the LPF and HPF groups within the HPG and MPG pigs, respectively, then suggests that the LPF diet alone was not enough to influence the BFT. However, these are speculative suggestions at the present and therefore more studies are necessary to confirm them, because the BFT and lean percentage were not measured or estimated at the end of the grower phase in the present study.

It was noteworthy that the fat content of LM was greater for the LPF group vs. HPF, which was consistent with the results of Witte et al. [27], in which the intramuscular fat content increased when the finisher pigs were fed a low-lysine diet. It also was noteworthy that the L* value and drip loss percentage were within the ranges of PSE (pale, soft, and exudative; [28]) in all groups, i.e. ≥ 50% and ≥ 5%, respectively. These variables therefore need to be closely watched in future studies, even though no carcass was judged as PSE in the present study. On the other hand, results for other physicochemical characteristics of LM, as well as those for sensory quality attributes of fresh and cooked LM, indicated that meat quality is not influenced by GPN or FPN.

Collectively, the present results indicated that HPN is necessary for the finishing pigs during the hot season with the daily high temperature exceeding 30℃ to minimize the reduced rate of weight gain and also to prevent the increase of BFT resulting from LPN. The intramuscular fat content could be increased by LPN, but this does not appear to influence the physicochemical and sensory quality attributes of pork.

Competing interests

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

Availability of data and material

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

Authors' contributions

Conceptulization: Lee CY, Park MJ, Song YM.
Data curation: Lee CY.
Formal analysis: Yang BS, Choi JS.
Methodology: Kim MH, Choi JS. Park MJ, Jin SK.
Software: Lee CY, Choi JS.
Validation: Lee CY, Jin SK.
Investigation: Yang SW, Jin SK, Lee CY.
Writing – original draft: Yang SW, Lee CY.
Writing – review & editing: Jin SK, Song YM, Lee CY.

Ethics approval and consent to participate

All experimental protocols involving animals of the present study were approved by the Institutional Animal Care and Use Committee (IACUC) of Gyeongnam National University of Science and Technology (2018-4).

ORCID

Jung-Seok Choi   https://orcid.org/0000-0001-8033-0410
Sang Keun Jin   https://orcid.org/0000-0002-8983-5607
Young-Min Song   https://orcid.org/0000-0002-4190-2997
Chul Young Lee   https://orcid.org/0000-0002-4735-1268

References

1. NRC. Nutrient requirements of swine, 11th ed. Washington, D.C., U.S.A: National Academy Press; 2012.

2. Noblet J, Van Milgen J. Energy and energy metabolism in swine. In: Chiba LI, editor. Sustainable swine nutrition. Ames, IA, USA: John Wiley & Sons, Inc.; 2013. p. 23-57.

3. Smith JW, Tokach MD, O'Quinn PR, Nelssen JL, Goodband

RD. Effects of dietary energy density and lysine:calorie ratio on growth performance and carcass characteristics of growing-finishing pigs. J Anim Sci. 1999;77:3007-15.

4. Main RG, Dritz SS, Tokach MD, Goodband RD, Nelssen JL. Determining an optimum lysine:calorie ratio for barrows and gilts in a commercial finishing facility. J Anim Sci. 2008;86:2190-207.

5. Beaulieu AD, Williams NH, Patience JF. Response to dietary digestible energy concentration in growing pigs fed cereal grain-based diets. J Anim Sci. 2009;87:965-76.

6. De La Llata M, Dritz SS, Langemeier MR, Tokach MD, Goodband RD, Nelssen JL. Economics of increasing lysine:calorie ratio and adding dietary fat for growing-finishing pigs reared in a commercial environment. J Swine Health Prod. 2001;9:215-23.

7. Stahly TS, Cromwell GL. Effect of environmental temperature and dietary fat supplementation on the performance and carcass characteristics of growing and finishing swine. J Anim Sci. 1979;49:1478-88.

8. Hyun Y, Ellis M, Riskowski G, Johnson RW. Growth performance of pigs subjected to multiple concurrent environmental stressors. J Anim Sci. 1998;76:721-27.

9. Le Bellego L, van Milgen J, Noblet J. Effect of high temperature and low-protein diets on the performance of growing-finishing pigs. J Anim Sci. 2002;80:691-701.

10. Noblet J, Le Dividich J, Van Milgen J. Thermal environment and swine nutrition. In: Lewis AJ, Southern LL, editors. Swine nutrition, 2nd ed. Boca Raton, FL, USA: CRC Press LLC; 2001. p. 519-44.

11. Lopez J, Goodband RD, Allee GL, Jesse GW, Nelssen JL, Tokach MD, et al. The effects of diets formulated on an ideal protein basis on growth performance, carcass characteristics, and thermal balance of finishing gilts housed in a hot, diurnal environment. J Anim Sci. 1994;72:367-79.

12. Yang BS, Kim MH, Choi JS, Jin SK, Park MJ, Song YM, et al. Effects of the plane of nutrition for grower pigs on their grow-finish performance and meat quality in winter. J Anim Sci Technol. 2019;61:1-9.

13. Choi JS, Yang BS, Kim MH, Lee KH, Jung HJ, Jin SK, et al. Effects of the low plane of nutrition on carcass and pork quality of finishing pigs. Ann Anim Resour Sci. 2018;29:172-82.

14. CIE. Colorimetry, 2nd ed. CIE Publication No. 15.2. Vienna: Commission Internationale de l'Eclairage; 1986.

15. Lee CY, Lee HP, Jeong JH, Baik KH, Jin SK, Lee JH, et al. Effects of restricted feeding, low-energy diet, and implantation of trenbolone acetate plus estradiol on growth, carcass traits, and circulating concentrations of insulin-like growth factor (IGF)-I and IGF-binding protein-3 in finishing barrows. J

Anim Sci. 2002;80:84-93.

16. Lee CH, Jung DY, Choi JS, Jin SK, Lee CY. Effects of the plane of nutrition on physiochemical characteristics and sensory quality traits of the muscle in finishing pigs. Korean J Food Sci Anim Resour. 2014;34:516-24.

17. Jin SK, Kim IS, Hur SJ, Hah KH, Kim BW. Effects of feeding period on carcass and objective meat quality in crossbred longissimus muscle. J Anim Sci Technol. 2004;46:811-20.

18. Park MJ, Ha DM, Shin HW, Lee SH, Kim WK, Ha SH, et al. Growth efficiency, carcass quality characteristics and profitability of 'high'-market weight pigs. J Anim Sci Technol. 2007;49:459-70.

19. Katsumata M, Kaji Y, Saitoh M. Growth and carcass fatness responses of finishing pigs to dietary fat supplementation at a high ambient temperature. Anim Sci. 1996;62:591-8.

20. Nienaber JA, Hahn GL, McDonald TP, Korthals RL. Feeding patterns and swine performance in hot environments. Trans ASAE. 1996;39:195-202.

21. Quiniou N, Noblet J, van Milgen J, Dubois S. Modelling heat production and energy balance in group-housed growing pigs exposed to low or high ambient temperatures. Br J Nutr. 2001;85:97-106.

22. Fabian J, Chiba LI, Kuhlers DL, Frobish LT, Nadarajah K, Kerth CR, et al. Degree of amino acid restrictions during the grower phase and compensatory growth in pigs selected for lean growth efficiency. J Anim Sci. 2002;80:2610-18.

23. Millet S, Langendries K, Aluwe M, De Brabander DL. Effect of amino acid level in the pig diet during growing and early finishing on growth response during the late finishing phase of lean meat type gilts. J Sci Food Agric. 2011;91:1254-8.

24. Fabian J, Chiba LI, Frobish LT, McElhenney WH, Kuhlers DL, Nadarajah K. Compensatory growth and nitrogen balance in grower-finisher pigs. J Anim Sci. 2004;82:2579-87.

25. Millet S, Aluwe M. Compensatory growth response and carcass quality after a period of lysine restriction in lean meat type barrows. Arch Anim Nutr. 2014;68:16-28.

26. De La Llata M, Dritz SS, Tokach MD, Goodband RD, Nelssen JL. Effects of increasing lysine to calorie ratio and added fat for growing-finishing pigs reared in a commercial environment: I. growth performance and carcass characteristics. Prof Anim Sci. 2007;23:417-28.

27. Witte DP, Ellis M, McKeith FK, Wilson ER. Effect of dietary lysine level and environmental temperature during the finishing phase on the intramuscular fat content of pork. J Anim Sci. 2000;78:1272-6.

28. Warner RD, Kauffman RG, Greaser ML. Muscle protein changes post mortem in relation to pork quality traits. Meat Sci. 1997;45:339-52.