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Study on the Lysine Requirement of Replacement Gilts During the Rearing Period

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Simple Summary

The standardized ileal digestible lysine (SID-Lys) requirement of DanBred replacement gilts during the rearing phase was evaluated in this study to determine whether the SID-Lys level maximizing growth performance also supports optimal reproductive performance across the first two parities. A total of 243 DanBred Landrace × Yorkshire gilts aged approximately 120 d were fed one of five SID-Lys levels in two phases. Increasing the dietary SID-Lys level improved growth performance and increased body weight and backfat thickness at entry into the breeding herd, but had no effect on the timing of puberty or the estrus rate at any stage. The best reproductive performance was obtained at a moderate SID-Lys level that did not coincide with the growth optimum. These results provide a scientific basis for the precision lysine feeding of DanBred replacement gilts during the rearing period.

Abstract

This study aimed to determine the optimal dietary standardized ileal digestible lysine (SID-Lys) supply level for DanBred replacement gilts during the rearing period. In total, 243 DanBred Landrace × Yorkshire crossbred gilts at approximately 120 days of age were randomly assigned to five dietary treatments (T1–T5), with five replicate pens per treatment (9–12 gilts per pen). Treatments were arranged in a two-phase feeding program: phase 1 (120–156 d) contained graded SID-Lys concentrations of 0.55%, 0.60%, 0.65%, 0.70%, and 0.75%, and phase 2 (157 d to puberty) contained 0.40%, 0.45%, 0.50%, 0.55%, and 0.60% SID-Lys, respectively. Initial body weight was balanced across treatments ($p > 0.05$) with homogeneous variance. Gilts were group-housed in a mechanically ventilated barn (20–25 °C; 12 h light:12 h dark photoperiod), with an allocated floor space of 1.5–2.0 m^2 per gilt. Growth performance, estrus rate, puberty and first-mating parameters, and reproductive performance over the first two parities were measured. Increasing the dietary SID-Lys level significantly increased the average daily gain of gilts in each phase and over the entire rearing period ($p < 0.01$), with significant linear and quadratic effects, and T4 showed the best growth performance. Dietary SID-Lys level had no significant effect on the estrus rate before 180, 200, or 220 d of age or on the age at puberty and at first mating ($p > 0.05$). However, body weight at puberty, body weight at first mating, and backfat thickness at first mating increased significantly with increasing SID-Lys level ($p < 0.05$). The average number of weaned piglets per sow over the first two parities was highest in T3 (23.45), significantly higher than in T1, T4, and T5 ($p = 0.021$), and the retention rates of T3 in parities 1 and 2 (95.74% and 85.11%) were both significantly higher than those of

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T1, T4, and T5 ($p < 0.05$), whereas T4, which grew fastest, had the poorest reproductive performance. In summary, growth performance and reproductive performance showed an "uncoupling" in their responses to lysine, and the dietary SID-Lys level giving the best overall reproductive outcome was 0.65% in phase 1 and 0.50% in phase 2 (T3). Future studies should evaluate gilt SID-Lys requirements under different growth rates and target body composition benchmarks, and explore interactive effects between lysine supply and body energy reserves on long-term reproductive persistence in hyperprolific sow lines.

Keywords: standardized ileal digestible lysine; growth performance; puberty; reproductive performance; retention rate

1. Introduction

The lifetime reproductive performance of sows is a key determinant of the economic sustainability of pig production systems, and nutrient supply during the rearing period of replacement gilts is the starting point that shapes body reserves and reproductive potential. Lysine is the first limiting amino acid in corn-soybean meal diets for pigs and is mainly involved in body protein synthesis and muscle tissue deposition [1]; expressing dietary supply levels as standardized ileal digestible lysine (SID-Lys) reduces the influence of differences in amino acid digestibility among ingredients on the assessment of the supply level [2]. As a benchmark, the NRC (2012) growth model [3] estimates SID-Lys requirements of approximately 0.85% and 0.72% for growing gilts at 50–75 kg and 75–100 kg, respectively, in corn-soybean meal diets; breeding-company recommendations for replacement gilt developer diets are generally lower because of restricted feeding and the need to control body composition during rearing. Studies on growing pigs and replacement gilts have shown that an insufficient SID-Lys supply limits daily gain and feed utilization efficiency and that the growth response gradually diminishes and plateaus as the supply increases; the optimal supply level is additionally influenced by genetic growth potential, energy intake, actual feed intake, and the proportions of other essential amino acids [4,5].

However, the nutritional objectives for rearing replacement gilts differ from those for commercial finisher pigs. Increasing SID-Lys or the SID-Lys-to-energy ratio is generally favorable for lean tissue growth, but the supply level that maximizes growth is not necessarily the most favorable for body fat reserves, puberty onset, or subsequent reproductive retention [6]. Studies have shown that reducing the dietary SID-Lys supply decreases the growth rate and body weight of replacement gilts, whereas the effects of different lysine-to-energy regimens on the age at puberty are not entirely consistent [7,8]; Lents et al. [9] further reported that different SID-Lys/ME ratios can modulate the growth and body composition of replacement gilts, while growth, body condition, and pubertal development may show different response patterns. This "uncoupling" between the growth response and the reproductive response suggests that determining the lysine requirement of replacement gilts solely on the basis of growth performance may bias nutrient supply during the rearing period.

Because of the inherent genetic differences among lines, the target values for nutrient requirements are not consistent. The NRC (2012) [3] estimated the lysine requirements of pigs at different growth stages using a dynamic model, whereas breeding companies propose phase-specific recommendations based on specific genetic systems and body-condition targets, and considerable differences remain between these two sources. Modern sows have undergone continuous genetic selection, and their growth rate and body composition have changed markedly [10], so their lysine requirement during the rearing period may already differ from previous recommended levels. Previous studies have shown that the

age, body weight, and backfat thickness at puberty and at first mating significantly affect the lifetime reproductive performance and retention rate of DanBred replacement gilts [11]; however, systematic studies on the optimal SID-Lys supply level for DanBred replacement gilts during the rearing period have not yet been reported. We hypothesized that the dietary SID-Lys level maximizing growth performance during rearing would not necessarily coincide with the SID-Lys level optimizing subsequent reproductive performance over the first two parities, i.e., that the growth and reproductive responses of replacement gilts to lysine supply would be uncoupled. Accordingly, this study used DanBred Landrace × Yorkshire replacement gilts and applied five SID-Lys levels in two phases in a feeding trial, aiming to investigate the effects of dietary SID-Lys level during the rearing period on growth performance, puberty onset, and reproductive performance in the first two parities, and to provide a scientific basis for the precision lysine feeding of DanBred replacement gilts.

2. Materials and Methods

2.1. Experimental Animals and Feeding Management

The experiment was conducted from August 2024 to December 2025 at a commercial pig farm in southern China. A total of 243 120-day-old DanBred replacement gilts (Landrace × Yorkshire) were selected and randomly assigned to five treatment groups (T1–T5). Gilts were reared in group housing, with five replicate pens per treatment. Each pen contained 9–12 gilts, providing 1.5–2.0 m^2 floor space per gilt. The barn was mechanically ventilated; ambient temperature was maintained at 20–25 °C, and the photoperiod was set to approximately 12 h of light daily. The overall mean initial body weight of gilts at 120 d of age was 75.7 kg, and initial body weight did not differ among treatments ($p = 0.970$).

The five graded SID-Lys levels in each phase were designed to bracket the estimated requirement range for replacement gilts of this body-weight stage, spanning from below to above the values recommended by the NRC (2012) growth model [3] and by breeding-company gilt-developer guidelines, so that both the ascending and the plateau regions of the growth response curve could be captured; phase 1 (120–156 d of age) represents the period of high lean-growth demand, whereas phase 2 (157 d of age to puberty) reflects the adaptive period during which lysine supply is reduced to promote moderate body-fat deposition before first mating. The experiment consisted of two phases: phase 1 from 120 to 156 d of age and phase 2 from 157 d of age until transfer to the breeding herd. In phase 1, the dietary SID-Lys levels of groups T1–T5 were 0.55%, 0.60%, 0.65%, 0.70%, and 0.75%, respectively, with a corresponding crude protein (CP) level of 14.0% and a uniform dietary NE of 2320 kcal/kg; the daily SID-Lys intakes were 13.75, 15.00, 16.25, 17.50, and 18.75 g/d, respectively, and the diet compositions are shown in Table 1. In phase 2, the dietary SID-Lys levels of groups T1–T5 were adjusted to 0.40%, 0.45%, 0.50%, 0.55%, and 0.60%, respectively, with CP reduced to 13.0% and dietary NE reduced to 2270 kcal/kg; the daily SID-Lys intakes were 12.00, 13.50, 15.00, 16.50, and 18.00 g/d, respectively, and the diet compositions are shown in Table 2.

From 170 d of age, gilts received daily boar exposure (15–20 min of direct contact with a mature boar) to stimulate puberty onset. Estrus was detected daily by the back-pressure test combined with observation of vulvar reddening and swelling, and gilts showing a clear standing reflex were judged to be in estrus and recorded accordingly. According to the DanBred gilt management guidelines and standard farm procedures, replacement gilts were usually mated at the second observed estrus. Artificial insemination was performed 12 h after the onset of estrus, twice daily (morning and evening). After mating, sows were moved to the gestation house, and sows returning to estrus were identified 18–24 d after mating. Pregnancy diagnosis was performed by ultrasonography 30 d after mating; to ensure accuracy, any sow diagnosed as not pregnant was re-examined one week later. Sows

returning to estrus or experiencing early pregnancy failure were removed from the gestation house, and pregnant sows were moved to the farrowing house on day 109 of gestation.

Table 1. Dietary composition and nutrient levels during 120–156 days of age (%, as-fed basis).

Items	T1	T2	T3	T4	T5
Ingredients					
Corn	28.31	27.89	27.69	27.34	27.38
Barley	20.16	20.72	21.14	21.65	21.89
Sorghum	30.00	30.00	30.00	30.00	30.00
Palm kernel meal	5.00	5.00	5.00	5.00	5.00
Soybean meal	13.33	13.12	12.79	12.53	12.11
Salt	0.56	0.56	0.56	0.56	0.56
Limestone	1.32	1.32	1.32	1.32	1.32
Monocalcium phosphate	0.78	0.78	0.78	0.78	0.78
L-Lysine(78%)	0.08	0.15	0.22	0.30	0.37
DL-Methionine(99%)			0.02	0.02	0.06
L-Threonine(98.5%)			0.03	0.04	0.08
Choline chloride (50%)	0.14	0.14	0.14	0.14	0.14
Vitamin-trace mineral premix [1]	0.32	0.32	0.32	0.32	0.32
Total	100.00	100.00	100.00	100.00	100.00
Calculated composition [2]					
NE, kcal/kg	2320	2320	2320	2320	2320
Crude protein, %	14.00	14.00	14.00	14.00	14.00
Standardized ileal digestible lysine, %	0.55	0.60	0.65	0.70	0.75
Calcium, %	0.70	0.70	0.70	0.70	0.70
Available phosphorus, %	0.28	0.28	0.28	0.28	0.28

[1] Premix supplied per kg diet: vitamin A, 8400 IU; vitamin D_3, 1680 IU; vitamin E, 70 mg; vitamin K_3, 3.4 mg; vitamin B1, 1.85 mg; vitamin B_2, 6 mg; vitamin B_6, 3 mg; vitamin B_{12}, 30 µg; D-pantothenic acid, 21 mg; nicotinic acid, 32 mg; D-biotin, 0.44 mg; folic acid, 1.7 mg; Zn ($ZnSO_4 \cdot H_2O$), 60 mg; Fe ($FeSO_4 \cdot H_2O$), 140 mg; Mn ($MnSO_4 \cdot H_2O$), 50 mg; Cu ($Cu_2(OH)_3Cl$), 22 mg; I ($Ca(IO_3)_2$), 1.5 mg; Se (Na_2SeO_3), 0.34 mg. [2] Nutrient content was calculated using the Brill Formulation Version 2.0 software, based on the 2012 version of the INRA-AFZ Feedipedia database (standard French feed ingredient database). DL-Methionine and L-threonine were co-supplemented at the higher SID-Lys levels to maintain the ideal protein ratios of methionine + cysteine and threonine relative to lysine. Feed samples were not retained, so the calculated nutrient values were not verified by chemical analysis.

2.2. Data Collection

Feed intake was recorded daily during the experiment. Gilts were weighed after overnight fasting on the first day of the experiment, at 156 d of age, on the day of first estrus, and on the day of first mating. Backfat thickness was measured at first estrus and at first mating using a Renco backfat meter (Renco Corporation, Golden Valley, MN, USA) at the P2 site (6.5 cm off the dorsal midline at the last rib). The age at estrus was recorded when a gilt showed a standing reflex, and the estrus rate was calculated for gilts reaching estrus before 180, 200, and 220 d of age.

Growth performance, including average daily gain (ADG), average daily feed intake (ADFI), and feed-to-gain ratio (F:G), was assessed in two defined rearing phases: phase 1 from 120 d to 156 d of age (fixed 36-d period), phase 2 from 157 d of age until individual puberty detection, as well as for the overall period from 120 d of age to puberty. For each sow in each of the first two parities, the total number of piglets born, the number of piglets born alive, and the number of piglets weaned per litter were recorded, and the total numbers of piglets born, born alive, and weaned per sow over the first two parities were calculated. In addition, the number of sows mated, the number of sows farrowing, and the number of

sows re-mated in each of the first two parities were recorded, and the farrowing rate and the retention rate for each of the first two parities were calculated.

Table 2. Dietary composition and nutrient levels from 157 d of age to puberty (%, as-fed basis).

Items	T1	T2	T3	T4	T5
Ingredients					
Barley	39.88	40.35	40.86	41.37	41.80
Sorghum	42.87	42.49	42.07	41.66	41.28
Palm kernel meal	5.00	5.00	5.00	5.00	5.00
Soybean meal	9.09	8.94	8.78	8.61	8.35
Salt	0.57	0.57	0.57	0.57	0.57
Limestone	1.34	1.34	1.34	1.34	1.34
Monocalcium phosphate	0.74	0.74	0.74	0.74	0.74
L-Lysine(78%)	0.05	0.11	0.18	0.25	0.32
DL-Methionine(99%)					0.12
L-Threonine(98.5%)					0.03
Choline chloride (50%)	0.14	0.14	0.14	0.14	0.14
Vitamin-trace mineral premix [1]	0.32	0.32	0.32	0.32	0.32
Total	100.00	100.00	100.00	100.00	100.00
Calculated composition [2]					
NE, kcal/kg	2270	2270	2270	2270	2270
Crude protein, %	13.00	13.00	13.00	13.00	13.00
Standardized ileal digestible lysine, %	0.40	0.45	0.50	0.55	0.60
Calcium, %	0.70	0.70	0.70	0.70	0.70
Available phosphorus, %	0.28	0.28	0.28	0.28	0.28

[1] The vitamin and trace mineral premix was the same as that in the formula shown in Table 1. [2] Nutrient content was calculated using the Brill Formulation software, based on the 2012 version of the INRA-AFZ Feedipedia database (standard French feed ingredient database). DL-Methionine and L-threonine were co-supplemented at the higher SID-Lys levels to maintain the ideal-protein ratios of methionine + cysteine and threonine relative to lysine. Feed samples were not retained, so the calculated nutrient values were not verified by chemical analysis.

2.3. Statistical Analysis

All statistical analyses were performed using SAS 9.4 software (SAS Institute Inc., Cary, NC, USA). Normality of continuous variables was evaluated by the Shapiro–Wilk test, and homogeneity of variance was also checked; data that did not meet the assumptions of parametric tests were transformed using logarithmic, square-root, reciprocal transformations, or Box–Cox transformations according to their distributional characteristics. Growth performance, puberty parameters, first-mating parameters, and cumulative reproductive indices over the first two parities were compared among SID-Lys treatments by one-way analysis of variance (ANOVA), and when the overall treatment effect was significant, Duncan's multiple range test was used for multiple comparisons among groups. Linear and quadratic regression models were fitted with the dietary SID-Lys level of each treatment as the independent variable to test the linear and quadratic responses of each index to SID-Lys level, and model fit was evaluated by the adjusted coefficient of determination and residual analysis. The estrus rate before 180, 200, and 220 d of age, as well as the farrowing rate and the retention rate in parities 1 and 2, were analyzed by the chi-square test. Continuous variables are expressed as means and standard errors, and all tests were two-tailed; $p < 0.05$ indicated a statistically significant difference, and $0.05 \leq p < 0.10$ indicated a tendency toward a difference.

3. Results

3.1. Growth Performance

As shown in Table 3, there was no significant difference in the initial body weight of replacement gilts among the five treatment groups ($p > 0.05$). For body weight at 156 d of age, T4 (104.72 kg) was significantly higher than T2 (99.00 kg) ($p = 0.032$), but the linear trend was not significant ($p > 0.05$). From the start of the experiment to 156 d of age, T4 had the highest ADFI (3011.61 g/d), although this difference did not reach significance ($p = 0.096$). The ADG of replacement gilts differed significantly among groups ($p < 0.001$), with significant linear and quadratic effects ($p < 0.05$); the ADG of T4 (1189.30 g/d) was the highest and T2 (982.69 g/d) the lowest. Meanwhile, F:G differed significantly among groups ($p = 0.001$), with a significant linear effect ($p = 0.020$); T4 (2.55) was the lowest and T2 (2.92) the highest.

From 157 d of age to the onset of puberty, F:G did not differ significantly among groups ($p > 0.05$), whereas ADG showed highly significant linear and quadratic effects ($p < 0.01$); T4 (1037.00 g/d) was significantly higher than the other groups ($p < 0.01$). ADFI differed significantly among treatment groups ($p < 0.01$), with T4 (2958.54 g/d) the highest and T1 (2779.01 g/d) the lowest, and it also showed highly significant linear and quadratic effects ($p < 0.01$). Throughout the whole feeding period, dietary SID-Lys treatment had highly significant effects on the ADG, ADFI, and F:G of replacement gilts ($p < 0.01$), and all of these indices showed highly significant linear and quadratic effects ($p < 0.01$). The ADG and ADFI of T4 were significantly higher than those of T1, T2, and T3 throughout the period ($p < 0.01$), with T2 having the lowest ADG and T1 the lowest ADFI; in terms of F:G, T4 was significantly lower than T1, T2, and T3 ($p < 0.01$), and T2 had the highest F:G.

Table 3. Effects of dietary SID-Lys levels on growth performance of replacement gilts.

Items	T1	T2	T3	T4	T5	SEM	*p*-Value		
							Treatment	Linear	Quadratic
No. of pens, n	5	5	5	5	5				
Initial body weight, kg	75.98	75.41	75.61	76.17	75.20	0.49	0.970	0.831	0.971
Body weight at 156 d of age, kg	100.73 ^{ab}	99.00 ^{b}	102.45 ^{ab}	104.72 ^{a}	100.96 ^{ab}	0.60	0.032	0.135	0.182
Body weight at puberty, kg	132.05 ^{ab}	128.80 ^{b}	132.99 ^{ab}	137.87 ^{a}	138.79 ^{a}	1.08	0.018	0.003	0.008
120–156 d of age									
ADG, g/d	1031.25 ^{cd}	982.69 ^{d}	1118.03 ^{ab}	1189.30 ^{a}	1073.01 ^{bc}	13.37	<0.001	0.002	0.001
ADFI, g/d	2809.68	2838.94	2909.53	3011.61	2854.48	25.88	0.096	0.137	0.093
F:G	2.75 ^{b}	2.92 ^{a}	2.70 ^{bc}	2.55 ^{c}	2.71 ^{bc}	0.03	0.001	0.020	0.064
157 days of age to puberty									
ADG, g/d	845.15 ^{b}	845.61 ^{b}	863.16 ^{b}	1037.00 ^{a}	905.99 ^{b}	15.80	<0.001	0.004	0.011
ADFI, g/d	2779.01 ^{d}	2859.88 ^{bc}	2823.53 ^{cd}	2958.54 ^{a}	2907.46 ^{ab}	12.04	<0.001	<0.001	<0.001
F:G	3.47	3.53	3.50	3.09	3.46	0.07	0.179	0.301	0.536
120 days of age to puberty (overall period)									
ADG, g/d	905.99 ^{bc}	885.23 ^{c}	969.20 ^{b}	1076.52 ^{a}	972.53 ^{b}	11.19	<0.001	< 0.001	<0.001
ADFI, g/d	2796.14 ^{b}	2840.39 ^{b}	2862.07 ^{b}	2987.77 ^{a}	2897.12 ^{ab}	15.47	0.001	0.001	0.002
F:G	3.15 ^{ab}	3.25 ^{a}	3.01 ^{bc}	2.84 ^{c}	3.03 ^{b}	0.03	<0.001	0.001	0.003

Note: Values within the same row with the same or no superscript letters indicate no significant difference ($p > 0.05$), while different superscript letters indicate significant difference ($p < 0.05$). SEM stands for the standard error of the mean of the overall data.

3.2. Estrus Rate

As shown in Table 4, the estrus rate before 180 d of age ranged from 23.40% (T5) to 41.30% (T2), being highest in T2 and lowest in T5; before 200 d of age it ranged from 48.94% (T5) to 65.38% (T4), being highest in T4 and lowest in T5; and before 220 d of age it ranged from 75.51% (T1) to 91.84% (T3), being highest in T3 and lowest in T1. Although the proportion of gilts expressing estrus by 220 d of age showed a numerical increase with

increasing dietary SID-Lys, the difference among treatments was not statistically significant ($p > 0.05$).

Table 4. Effects of different SID-Lys levels on the estrus rate of replacement gilts.

Items	T1	T2	T3	T4	T5	*p*-Value
No. of gilts, n	49	46	49	52	47	
No. of gilts that exhibited estrus before 180 d of age, n	19	19	19	20	11	
No. of gilts that exhibited estrus before 200 d of age, n	29	25	30	34	23	
No. of gilts that exhibited estrus before 220 d of age, n	37	37	45	45	40	
Estrus rate before 180 d of age, %	38.78	41.30	38.78	38.46	23.40	0.374
Estrus rate pre-200 d of age, %	59.18	54.35	61.22	65.38	48.94	0.519
Estrus rate pre-220 d of age, %	75.51	80.43	91.84	86.54	85.11	0.233

3.3. Puberty Traits

As shown in Table 5, dietary lysine level had a significant effect on the body weight at puberty of replacement gilts ($p < 0.05$); with respect to the dose effect, both the linear effect ($p = 0.003$) and the quadratic effect ($p = 0.008$) were highly significant. T4 and T5 (137.87 kg and 138.79 kg) were significantly higher than T2 (128.80 kg) ($p = 0.018$), while T1 and T3 were intermediate. In addition, dietary lysine level had no significant effect on the age at puberty or the backfat thickness at puberty among groups ($p > 0.05$); the age at puberty ranged from 190.96 d (T4) to 197.52 d (T5), and the backfat thickness at puberty ranged from 12.65 mm (T3) to 13.39 mm (T4).

Table 5. Effects of different SID-Lys levels on the puberty traits of replacement gilts.

First Estrus Traits	T1	T2	T3	T4	T5	SEM	*p*-Value		
							Treatment	Linear	Quadratic
No. of gilts, n	49	46	49	52	47				
Age at first estrus, d	195.17	193.96	191.57	190.96	197.52	1.43	0.587	0.901	0.343
Backfat thickness at first estrus, mm	12.69	12.76	12.65	13.39	13.15	0.12	0.158	0.053	0.150

Note: SEM stands for the standard error of the mean of the overall data.

3.4. First-Mating Traits

As shown in Table 6, dietary lysine level had significant effects on the first-mating parameters of replacement gilts. According to the production management requirements of the farm, the age at first mating was management-controlled (≥220 d); as expected, no treatment effect was detected ($p > 0.05$). The body weight at first mating differed significantly among groups ($p < 0.05$), with T4 (160.44 kg) significantly higher than T1 and T2 (151.09 kg and 151.15 kg) ($p = 0.010$), while T3 and T5 were intermediate; it also showed highly significant linear and quadratic effects ($p < 0.01$). The backfat thickness at first mating differed significantly among groups ($p < 0.01$), with T4 (15.90 mm) significantly higher than all the other groups ($p = 0.002$) and no significant differences among T1, T2, T3, and T5 ($p > 0.05$); it showed significant linear and quadratic effects ($p < 0.05$).

Table 6. Effects of different SID-Lys levels on the first mating traits of replacement gilts.

First Mating Traits	T1	T2	T3	T4	T5	SEM	*p*-Value		
							Treatment	Linear	Quadratic
No. of gilts, n	45	43	47	49	45				
Age at first mating, d	225.98	227.91	225.81	226.84	224.80	0.10	0.930	0.676	0.806
Body weight at first mating, kg	151.09 ^{b}	151.15 ^{b}	155.59 ^{ab}	160.44 ^{a}	156.18 ^{ab}	0.99	0.010	0.004	0.010
Backfat thickness at first mating, mm	14.53 ^{b}	14.74 ^{b}	14.98 ^{b}	15.90 ^{a}	14.87 ^{b}	0.12	0.002	0.026	0.015

Note: Values within the same row with the same or no superscript letters indicate no significant difference ($p > 0.05$), while different superscript letters indicate significant difference ($p < 0.05$). SEM stands for the standard error of the mean of the overall data.

3.5. Reproductive Performance, Farrowing Rate, and Retention Rate in the First Two Parities

As shown in Table 7, dietary lysine level had a significant effect on the average number of weaned piglets per sow over the first two parities of replacement gilts ($p < 0.05$), with T3 (23.45) significantly higher than T1, T4, and T5 (19.00, 16.92, and 18.16, respectively) ($p = 0.021$), while T2 (20.63) was intermediate; however, the linear and quadratic effects were not significant ($p > 0.05$). In addition, the average total number of piglets born per sow over the first two parities ranged from 19.41 (T4) to 25.91 (T3), with the difference among groups approaching significance ($p = 0.056$), and the average number of piglets born alive per sow over the first two parities ranged from 18.98 (T4) to 24.98 (T3), with the difference among groups approaching significance ($p = 0.059$).

As shown in Table 8, dietary lysine level had no significant effect on the farrowing rate in parities 1 and 2 of replacement gilts ($p > 0.05$); the farrowing rate in parity 1 ranged from 75.51% (T4) to 95.74% (T3), and that in parity 2 ranged from 88.24% (T5) to 93.94% (T1). By contrast, dietary lysine level had a significant effect on the retention rate in parities 1 and 2 ($p < 0.05$); the retention rate of T3 in parity 1 (95.74%) was significantly higher than those of T1, T4, and T5 ($p = 0.020$), while T2 (83.72%) was intermediate, and the retention rate of T3 in parity 2 (85.11%) was significantly higher than those of T1, T4, and T5 ($p = 0.027$), while T2 (74.42%) was intermediate.

Table 7. Effects of different SID-Lys levels on the reproductive performance of replacement gilts during the first two parities.

Treatment	T1	T2	T3	T4	T5	SEM	*p*-Value		
							Treatment	Linear	Quadratic
No. of gilts, n	45	43	47	49	45				
TNB from first two parities per sow, piglets	22.00	24.91	25.91	19.41	21.29	0.80	0.056	0.214	0.171
NBA from first two parities per sow, piglets	20.73	23.81	24.98	18.98	20.09	0.77	0.059	0.255	0.122
NW from first two parities per sow, piglets	19.00 ^{b}	20.63 ^{ab}	23.45 ^{a}	16.92 ^{b}	18.16 ^{b}	0.68	0.021	0.251	0.107

Note: TNB = total number of piglets born; NBA = number of born alive; NW = number of weaned piglets. Values within the same row with the same or no superscript letters indicate no significant difference ($p > 0.05$), while different superscript letters indicate significant difference ($p < 0.05$). SEM stands for the standard error of the mean of the overall data.

Table 8. Effects of different SID-Lys levels on the farrowing rate and retention rate of replacement gilts.

Treatment	T1	T2	T3	T4	T5	*p*-Value
No. of gilts mated for the first time, n	45	43	47	49	45	
No. of primiparous farrowings, n	36	37	45	37	35	
No. of post-weaning matings for primiparous sows, n	33	36	45	35	34	
No. of second farrowings, n	31	32	42	31	30	
No. of post-weaning matings for parity 2 sows, n	27	32	40	29	28	
Farrowing rate at parity 1, %	80.00	86.05	95.74	75.51	77.78	0.067
Farrowing rate at parity 2, %	93.94	88.89	93.33	88.57	88.24	0.852
First-parity sow retention rate, %	73.33 ^{b}	83.72 ^{ab}	95.74 ^{a}	71.43 ^{b}	75.56 ^{b}	0.020
Second-parity sow retention rate, %	60.00 ^{b}	74.42 ^{ab}	85.11 ^{a}	59.18 ^{b}	62.22 ^{b}	0.027

Values within the same row with the same or no superscript letters indicate no significant difference ($p > 0.05$), while different superscript letters indicate significant difference ($p < 0.05$).

4. Discussion

4.1. Effects of Different Lysine Levels on Growth Performance of Replacement Gilts During the Rearing Period

As the first limiting amino acid for pigs, lysine is a key substrate for skeletal muscle protein synthesis and can accelerate growth by activating the mTORC1 signaling pathway, promoting the phosphorylation of S6K1/4E-BP1, and initiating muscle protein synthesis [12–14]. In this study, increasing the dietary lysine level significantly increased the ADG of replacement gilts in both phases and over the whole rearing period, with significant linear and quadratic effects, while F:G decreased accordingly; this is consistent with the report of Supakorn et al. [15] that increasing the lysine level improves the growth efficiency of replacement gilts and confirms that lysine promotes body protein deposition through the dual actions of substrate supply and signaling activation. In a study of the lysine requirement of replacement gilts, Shelton et al. [16] found that increasing dietary lysine level reduced F:G for gilts heavier than 84 kg, which is consistent with the results of the 120–156 d of age phase in this study. Notably, the F:G response to lysine showed a clear phase-dependent difference: from 156 d of age to puberty, F:G no longer differed among groups as the lysine level changed. This phenomenon may reflect a shift in the focus of growth and development of replacement gilts: once gilts reach a certain body weight at 156 d of age, their tissue deposition gradually shifts from being dominated by skeletal muscle protein deposition to being dominated by body fat deposition, at which point feed conversion efficiency is regulated more by energy intake than by amino acid supply and the limiting role of lysine is correspondingly weakened. This inference is consistent with the phase-specific nutritional regulation principle of "reducing lysine and promoting moderate body fat deposition" during the adaptation period of replacement gilts [17], and also suggests that simply increasing lysine in the later rearing period no longer improves feed utilization efficiency. In this trial, the group with the best ADG and F:G was T4 rather than T5, which had the highest lysine level, and the feed intake of T4 was relatively high throughout the experimental period. This may be because feed intake in T4 was not effectively controlled during the trial, so its outstanding growth performance was partly due to high feed intake rather than being driven solely by the lysine level. Of note, feed intake was not a pre-assigned experimental factor in this feeding trial; hence, the observed differences in average daily feed intake among treatments were incidental.

4.2. Effects of Different Lysine Levels on Puberty Onset of Replacement Gilts During the Rearing Period

Puberty onset in replacement gilts is precisely regulated by the hypothalamic–pituitary–gonadal (HPG) axis and depends on activation of the Kisspeptin/GPR54 system, whose activity is in turn regulated by leptin secreted by adipose tissue, with circulating leptin levels varying mainly with dietary energy intake and body fat reserves [18–20]. Within this mechanistic framework, energy is generally regarded as the key metabolic signal regulating the timing of puberty, whereas the roles and mechanisms by which amino acid nutrients affect puberty onset have been less frequently studied and remain unclear. In this study, increasing the dietary lysine level had no significant effect on the age at puberty or at first mating, the backfat thickness at puberty, or the estrus rate at 180, 200, or 220 d of age in replacement gilts, with the age at puberty concentrated between 191 and 198 d and the backfat thickness at puberty concentrated between 12.7 and 13.4 mm in all groups. Calderón Díaz et al. [8] reported that when dietary SID-Lys was increased from 0.64% to 0.77% and 0.91%, the age at puberty of replacement gilts was shortened by 6 d and 10 d, respectively, which is inconsistent with the results of this study. This discrepancy may arise from differences between the two studies in feeding management, line, and the range of the lysine gradient, since feeding management itself (e.g., the boar exposure protocol and group-housing density) has an important influence on the age at puberty and may mask or alter the effect of lysine.

Although lysine did not change the timing of puberty and first mating, its regulatory effect on body condition development was clear: with increasing lysine level, the body weight at puberty, the body weight at first mating, and the backfat thickness at first mating all increased significantly and showed significant linear and quadratic effects, and the body weights at puberty and at first mating of the high-lysine groups (T4 and T5) were significantly higher than those of the low-lysine group (T2). This indicates that, under conditions in which the timing of puberty is relatively fixed by energy and management constraints, increasing lysine mainly increases the body condition reserves of gilts when they enter the breeding herd by promoting body protein and body fat deposition. Adequate body condition reserves are potentially important for alleviating excessive weight loss during the first lactation and reducing the risk of second-litter syndrome, which is an important manifestation of the nutritional value of lysine. [21,22] The estrus rate of the high-lysine group (T5) was numerically lower, which may be related to imbalanced nutrient partitioning and metabolic stress. Excessive lysine continuously activates the mTORC1 pathway [12], causing nutrients to be preferentially used for skeletal muscle deposition and reducing body fat reserves, which leads to insufficient leptin secretion and failure to initiate estrus; high lysine also disrupts amino acid balance and induces oxidative stress [23,24], and the accumulation of free radicals damages granulosa cells and inhibits follicular development [25], while inhibiting the HPG axis and gonadotropin secretion, thereby reducing the estrus rate.

4.3. Effects of Different Lysine Levels on the Reproductive Performance of Replacement Gilts During the Rearing Period

In this study, the regulation of reproductive performance by lysine level was not consistent with its regulation of growth performance, and the two showed a clear "uncoupling": growth performance improved continuously with increasing lysine level, but the optimum for reproductive performance did not occur in T5, which grew fastest, but rather in T3, at a moderate lysine level. The T3 group had the best farrowing rate and retention rate and also the largest number of piglets born over the first two parities; its corresponding mating parameters were "age at first mating 225.81 d, body weight at first mating 155.59 kg, and backfat thickness at first mating 14.98 mm", which were close to the optimal mating param-

eters for DanBred replacement gilts proposed by Tan [26]: "age at first mating 210–229 d, body weight at first mating 140–149.9 kg, and backfat thickness at first mating 15–16 mm". Notably, T4, which grew fastest and had the highest body weight at first mating, had the poorest reproductive performance: its farrowing rate in parity 1 was only 75.51%, its retention rates in parities 1 and 2 were as low as 71.43% and 59.18%, respectively, and its average number of weaned piglets per sow over the first two parities was only 16.92, all of which were the lowest among the groups. This supports the argument of Thitachot et al. [27] that excessive body weight at mating reduces the reproductive performance of replacement gilts; however, it should be noted that, in addition to body weight, the reproductive performance of replacement gilts is also affected by pen, feed intake, and other factors, and whether the reduction in reproductive performance is caused by mating body weight alone requires further verification. The first-mating parameters of T3 and T5 were relatively similar, yet their reproductive performance differed considerably, indicating that, in addition to regulating reproductive performance through the body condition of replacement gilts, lysine may also affect reproductive performance through other direct or indirect mechanisms, such as amino acid balance, oxidative stress status, reproductive hormones, or oocyte quality. This observation provides an important direction for subsequent in-depth analysis of the molecular mechanisms by which lysine regulates reproductive performance.

5. Conclusions

Among the SID-Lys concentrations tested in this study, the DanBred replacement gilts showed the best growth performance in T4 (0.70% in phase 1 and 0.55% in phase 2), whereas the best reproductive performance was obtained in T3 (0.65% in phase 1 and 0.50% in phase 2), at a moderate lysine level. When different production objectives are pursued, the dietary SID-Lys concentration should therefore be adjusted accordingly.

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