Effects of dietary lysine levels on production performance, milk composition and plasma metabolites of the high-producing lactating SOWS

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Abstract

Background

Modern genotype sows require better nutrition because of larger body size and higher reproductive performance. Especially primiparous sows not only meet the needs of lactation, but also meet the needs of their own growth and development. The aim of the study was to evaluate the effect of dietary lysine over two consecutive lactations on lactation and subsequent reproductive performance in primiparous sows.

Results

A total of 160 primiparous Yorkshire sows were randomly allotted to one of four experimental lactation diets. Lactation diets were formulated to contain 0.84, 0.94, 1.04, and 1.14% SID Lys and balanced in Met, Thr, Trp and Val. There were no dietary effects on sows body weight and backfat change and feed intake of sows during lactation. However, WEI ($P = 0.07$) tended to be a quadratic effect by increasing dietary Lys level. Compared with the primiparous, sows had greater body weight ($P < 0.01$) and backfat thickness ($P < 0.01$) of sows at farrowing and at weaning, and weight loss ($P = 0.01$) during the second lactation period. Higher Lys level during lactation increased survival rate of piglets ($P = 0.03$), weight of piglets ($P = 0.04$), and weight gain of piglets at weaning ($P = 0.05$). Dietary Lys level did not affect colostrum compositions. However, fat ($P = 0.04$), protein ($P = 0.03$), solid not fat ($P = 0.03$), total solids content ($P = 0.04$), and moisture ($P = 0.04$) in milk increased linearly with increasing dietary levels of Lys. Likewise, PUN level was increased ($P = 0.04$). There were significant linear increases in plasma Lys ($P = 0.02$), Met ($P = 0.05$), and Val ($P = 0.04$) levels as dietary Lys level increased at weaning. Furthermore, there were significant linear increases in milk Asp, Glu, His, Ile, Leu, Lys, Met, Phe, Pro, Ser, Thr, Trp and Val levels as dietary lysine level increased ($P < 0.05$) at 21 d of lactation.

Conclusions

These results indicated that primiparous sows need higher dietary lysine levels than multiparous sow. Moreover, impacts of dietary amino acids on reproductive performance could be mediated through milk compositions change and increasing amino acid concentration.

Introduction

The modern sow has been selected for large litter size and milk production. In addition, balanced nutrition, more standardized management and effective disease control were widely used in sow production [1, 2]. Efficiency of reproduction significantly increased in the breeding herd [3]. However, sows need more nutrient levels to meet their lactation needs with a high litter size.

Compared with multiparous sow, primiparous sow not only meet the needs of lactation, but also meet the needs of their own growth and development [4]. Kim et al. (1999) reported that the weight of nursed individual mammary glands increases 50% during the 5–21 d lactation of primiparous sow [5]. Sow lactation feed intake often is not enough during lactation to meet the sow's energy and nutrient needs for maintenance and milk production, especially for parity 1 and 2 sows [6]. Research has shown that if these first and second parity sows mobilize more than 15% of their protein mass during lactation, thus reducing subsequent reproductive efficiency and litter weaning weight [7]. Therefore, lactation nutrition level is more important for primiparous sow. This not only affected the lactation performance and the growth performance of piglets, but also affected the growth and development of sows, and further affected the litter number and life span of sow. Therefore, ensuring nutrient intake for first-time sows will increase the productivity of the entire breeding population.

Sows can achieve and maintain high levels of milk production throughout her productive life if given adequate levels of energy and nutrients. The most critical nutrients for maintaining optimum lifetime milk productivity are energy and amino acids [8]. Lysine has been considered the first-limiting amino acid in corn-soybean meal diets for sows in lactation [9]. An adequate supply of lysine during lactation allowed sows to maximize milk production and subsequent reproductive performance [10]. Extensive studies have estimated total lysine requirements of sows during lactation between 37 g/d and 58 g/d [11–15]. Recent research showed that total lysine intakes of 70 g/day or 62 grams of SID lysine/day to optimize reproductive and milk production performance of sows [8]. Moreover, gilts eat 10 to 15% less than sows the percent SID lysine in the lactation must increase compared to a mature sow herd [8].

Increased supply of lysine in lactation could allow gilts to consume adequate amino acids to maximize reproductive performance and ensure body development. Therefore, the objective of this experiment was to evaluate the effect of dietary lysine levels for lactating primiparous sows on multiple reproductive cycles including piglet's performance, milk composition and nitrogen emissions.

Methods

Animals, dietary treatments, and Housing

A total of 160 primiparous Yorkshire sows were randomly allocated into four groups (40 sows each group). On d 110 of pregnancy, they were moved to the farrowing accommodation where they were housed in single farrowing pens. Four experimental diets containing different SID lysine levels of 0.84%, 0.94%, 1.04%, and 1.14% were provided to the gilts during lactation (Table 1). Methionine, threonine, tryptophan and valine were used to maintain ratios to lysine that were equal to those of the 0.84% Lys diet. Litter size was adjusted to 12 to 14 pigs per litter by 2 d after farrowing. On the day of farrowing, the sows were fed 1.5 kg, which was then successively increased (3 kg/d on d 1 and 2 of lactation; 4.5 kg/d on d 3 and 4 of lactation; ad libitum consumption from d 5 of lactation to weaning). Sows were fed two times daily (at 0900 and 1600 h.) and allowed ad libitum access to water from parturition until weaning. Sows were weighed and backfat were determined within 24 h after farrowing and at weaning. All sows were fed with the same diet from weaning until the second insemination (day 0 of gestation), and then fed with the same gestation diets (3,000 kcal of ME/kg, SID Lys 0.70%) in individual stalls until farrowing. During the second reproductive cycle, repeat the treatment of the first reproductive cycle.

Table 1
Ingredients and nutrient compositions of the experimental diets

Item	Lys 0.84%	Lys 0.94%	Lys 1.04%	Lys 1.14%
Feedstuff, %				
Corn	60.29	60.55	60.86	61.18
Soybean meal	17.45	16.87	16.16	15.44
DDGS	5.00	5.00	5.00	5.00
Extruded-soybean	5.00	5.00	5.00	5.00
wheat bran	3.00	3.00	3.00	3.00
Fish meal	2.50	2.50	2.50	2.50
Soybean oil	1.37	1.37	1.37	1.37
Glucose	1.50	1.50	1.50	1.50
Yeast cell wall	0.02	0.02	0.02	0.02
Limestone	0.95	0.96	0.96	0.96
Calcium phosphate (monocalcium)	1.25	1.25	1.26	1.26
Sodium chloride	0.47	0.47	0.47	0.47
Choline chloride	0.10	0.10	0.10	0.10
98% Lysine	0.07	0.22	0.37	0.52
DL-Methionine	0.01	0.04	0.08	0.12
L-Threonine	0.00	0.03	0.10	0.18
Valine	0.00	0.09	0.19	0.30
Tryptophan	0.00	0.01	0.04	0.06
Phytas	0.02	0.02	0.02	0.02
Premix ^a	1.00	1.00	1.00	1.00
Total %	100.00	100.00	100.00	100.00
Composition (calculated) ^b				
NE, kcal/kg	2433	2438	2445	2451
CP, %	18.00	18.00	18.00	18.00
SID Lys, %	0.85	0.95	1.05	1.14
SID Met, %	0.27	0.30	0.34	0.37
SID Thr, %	0.57	0.59	0.65	0.72
SID Trp, %	0.16	0.19	0.22	0.25
SID Val, %	0.71	0.75	0.78	0.82
CF, %	3.29	3.27	3.24	3.20
EE,%	5.12	5.12	5.12	5.12
NDF, %	11.68	11.64	11.58	11.53
Ca, %	0.85	0.85	0.85	0.85
Available phosphorus, %	0.43	0.43	0.43	0.43
^a Provided per kilogram of the diet: Cu 30 mg; Fe 160 mg; Zn 150 mg; Mn 50 mg; I 0.53 mg; Se 0.53 mg; Co 0.75 mg; Cr 0.22 mg; vitamin A 1.271 × 10 ⁴ U; vitamin D3 2853 U; vitamin E 180 mg; vitamin K3 3.85 mg; vitamin B1 1.6 mg; vitamin B2 5.75 mg; vitamin B6 2.88 mg; vitamin B12 0.02 mg; nicotinamide 32 mg; pantothenic acid 20 mg; folic acid 3.2 mg; biotin 0.44 mg; vitamin C 450 mg; choline 1800 mg.				
^b Calculated chemical concentrations using values for feed ingredients from National Research Council (2012)				

Data collection

Body weight and backfat thickness of sows were measured at 24 h postpartum and 21 d of lactation. An ultrasound device (Lean-meter, Renco Corp., Minneapolis, US) was used for measuring backfat thickness at P₂ position. The numbers of total born, born alive, stillborn and mummified piglets were recorded within 24 h postpartum and the number of pigs was recorded after cross-fostering and at 21 d of lactation. Lactation feed intake was recorded weekly. Piglet weight was recorded at 24 h postpartum, after cross-fostering, at 7 d, 14 d and 21 d of lactation. Litter weight was calculated by summing the individual piglet weights. Weaning to estrus interval (WEI) was determined by monitoring for estrus after weaning 7 d.

Sample collection and analysis

Blood samples were randomly taken from 16 sows immediately at parturition day and 21 d of lactation. Blood samples of 10 mL were collected from sows through ear vein. Then blood samples were centrifuged at 3,000 g at 4 °C for 15 min (Eppendorf centrifuge 5810R, Hamburg, Germany) to separate plasma. Colostrum and milk of 30 mL were collected from anterior, middle, and posterior teats from one side of the sow using a 50-mL centrifuge tube at 24 h and 14 d postpartum. All samples were stored at - 20 °C until analysis.

The milk composition was determined by near-infrared reflectance spectroscopy with a Foss Milkoscan FT+ (CombiFT + 200, Denmark). Before analysis, 5 mL thawed fresh milk per sample was aliquoted into a 50-mL centrifuge tube (sterilized), and 20 mL distilled water was added to dilute the sample [16]. Plasma urea nitrogen (PUN) level was analyzed using a commercial kit (Nanjing Jiancheng Bioengineering Institute, Nanjing, China), according to the manufacturer's instructions. The amino acid contents in colostrum, milk, plasma and diets were determined by ion-exchange chromatography (Amino Acid Analyzer L-8900, Hitachi, Tokyo, Japan) with post-column derivatization with ninhydrin.

Calculation and statistical analyses

Calculation and statistical analyses were conducted using SAS software (SAS 9.4, Inst, Inc., Cary, NC) with the individual sow as the experimental unit. PROC MIXED procedure was used in the analyses. Dietary treatment, reproductive cycle, the interaction between dietary treatment and reproductive cycle were specified as fixed effects. Farrowing room was as a random effect. In the mixed model, the response variables were related measurements, including litter size, litter weight of born alive and weaning, sow daily feed intake during lactation, WEI, colostrum and milk compositions and amino acids levels, PUN and plasma amino acids levels. Regression analyses were performed to evaluate the linear and quadratic effects of dietary treatment and reproductive cycle. Multiple comparisons were made when the ANOVA indicated significant differences. Tukey's test was used in multiple comparisons of means to adjust the *P*-values when using a mixed model procedure for data analysis. Duncan's test was used for One-way ANOVA. Repeated measures analysis of variance using the MIXED procedure of SAS was used to examine the responses of piglet performance, sow body weight, backfat, lactation feed intake, data of milk and plasma parameters. Data are presented as means and SEM. Statistical significance was declared at *P* < 0.05 were indicated as significant difference, and tendencies were declared at 0.05 < *P* < 0.10.

Results

Sow performance

Body weight and backfat thickness of sows at farrowing and at weaning did not differ among dietary treatments (Table 2). Weight loss and backfat thickness loss during lactation also did not differ. Moreover, the dietary lysine levels did not affect feed intake of sows during lactation. However, WEI (*P* = 0.07) tended to be a quadratic effect by increasing dietary lysine level. Compared with the primiparous, sows had greater body weight (BW) (*P* < 0.01) and backfat thickness (*P* < 0.01) of sows at farrowing and at weaning, and weight loss (*P* = 0.01) during the second lactation period. Feed intake of the second lactation period significantly increased (*P* < 0.01). There was no interaction between dietary treatment and reproduction cycle on performance of sow.

Table 2
Effects of different levels of lysine in lactation diets on performance of sows.

Item	First reproductive cycle				Second reproductive cycle				<i>P-value</i>					
	0.84%	0.94%	1.04%	1.14%	0.84%	0.94%	1.04%	1.14%	SEM	L	Q	Diet	Cycle	Diet × Cycle
No. of sows	32	34	31	37	32	34	31	37						
Sow BW, kg														
Parturition	178.51	178.82	180.20	181.52	233.31	236.81	228.73	230.21	4.70	0.56	0.47	0.87	< 0.01	0.19
Weaning	177.86	181.31	180.59	179.91	227.75	230.237	229.90	225.64	4.38	0.33	0.38	0.80	< 0.01	0.78
Loss	-0.65	2.49	0.38	-1.61	-5.56	-6.58	1.16	-4.58	3.26	0.75	0.12	0.37	0.03	0.28
Sow backfat thickness, mm														
Parturition	13.76	13.78	14.35	13.61	15.06	15.44	15.29	14.74	0.42	0.62	0.57	0.18	< 0.01	0.59
Weaning	12.70	12.81	13.32	12.24	13.94	14.08	14.26	14.02	0.42	0.55	0.63	0.24	< 0.01	0.42
Loss	-1.06	-0.97	-1.03	-1.37	-1.46	-1.37	-1.14	-0.76	0.41	0.37	0.46	0.96	0.80	0.31
ADFI, kg	5.30	5.40	5.38	5.37	6.17	6.16	6.29	6.31	0.12	0.62	0.77	0.89	< 0.01	0.33
WEI, d	7.90	6.80	7.67	7.22	6.74	5.11	4.90	5.61	0.45	0.66	0.07	0.78	0.09	0.78

Piglet performance

The effects of dietary lysine levels in lactation diet on piglet growth performance during lactation are shown in Table 3. No significant differences were found in litter size as well as litter and piglet weight at birth and after cross-fostering. Linear increase on survival rate of piglets ($P=0.03$), weight of piglet ($P=0.04$) at 21 d of lactation, and weight gain of piglet ($P=0.05$). Compared with the first lactation period, sows had greater litter size ($P<0.01$), litter ($P<0.01$) and piglet weight ($P<0.01$) at birth and at weaning, and weight gain of piglet ($P<0.01$) in the second lactation period. The significant diet × cycle interactions for survival rate of piglets ($P=0.03$) and weight of piglet ($P=0.04$) at 21 d of lactation.

Table 3
Effects of different levels of lysine in lactation diets on growth performance of piglets

Item ^a	First reproductive cycle				Second reproductive cycle				<i>P-value</i> ^b					
	0.84%	0.94%	1.04%	1.14%	0.84%	0.94%	1.04%	1.14%	SEM	L	Q	Diet	Cycle	Diet × Cycle
No. of sows	32	34	31	37	32	34	31	37						
Litter size, number/litter														
Total born	13.59	13.56	13.58	13.71	15.09	16.19	15.51	16.44	0.56	0.44	0.37	0.47	< 0.01	0.36
Born alive	11.97	12.08	12.19	12.66	14.28	15.25	14.39	15.14	0.60	0.25	0.51	0.50	< 0.01	0.77
After cross-foster	13.53	13.86	13.71	13.26	12.80	12.83	13.09	12.79	0.29	0.78	0.66	0.30	< 0.01	0.64
Pigs weaned	11.09	11.11	11.03	11.45	11.56	12.08	12.10	11.91	0.23	0.53	0.59	0.97	< 0.01	0.10
Survival rate of piglets ^c , %	82.72 ^d	80.90 ^d	81.13 ^d	86.72 ^c	90.61 ^b	94.10 ^a	93.03 ^a	93.18 ^a	2.15	0.03	0.70	0.04	< 0.01	0.03
Litter weight (kg)														
At birth	16.91	16.77	16.48	17.06	20.68	20.76	20.60	20.38	0.45	0.64	0.70	0.66	< 0.01	0.31
After cross-foster	17.26	16.68	16.69	16.80	16.92	16.59	16.41	16.10	0.57	0.73	0.81	0.46	0.18	0.77
At day 21	55.52 ^d	56.01 ^{cd}	55.65 ^d	58.80 ^c	65.38 ^b	70.63 ^a	71.69 ^a	69.92 ^a	2.16	0.77	0.79	0.04	< 0.01	0.04
Piglet mean BW (kg)														
At birth	1.29	1.25	1.24	1.25	1.32	1.32	1.31	1.40	0.05	0.65	0.84	0.39	< 0.01	0.59
After cross-foster	1.29	1.21	1.23	1.27	1.32	1.29	1.28	1.34	0.04	0.46	0.62	0.55	0.08	0.94
At day 21	5.00	5.01	5.03	5.15	5.68	5.85	5.92	5.88	0.15	0.04	0.25	0.05	< 0.01	0.11
Piglet ADG (kg/d)	179.06	177.36	181.20	185.10	208.44	217.43	220.65	215.95	7.56	0.05	0.82	0.03	< 0.01	0.44
a The sow lactation diet contains 0.84%, 0.94%, 1.04%, 1.14% lysine, respectively.														
b No interactions were observed between dietary treatment (diet) and reproductive cycle (cycle) in terms of litter performance except litter weight on day 21 of lactation and piglet ADG during third week of lactation; There were interactions between dietary treatment (diet) and reproductive cycle (cycle) on litter weight on day 21 of lactation and piglet ADG during third week of lactation ($P < 0.05$). Linear (<i>L</i>) and quadratic (<i>Q</i>) effects of lysine levels were contrasted.														
c The pre-weaning survival rate (%) = (number of piglets weaned/number of piglets after cross-foster) × 100.														

Colostrum and milk compositions and PUN

Dietary lysine levels in lactation did not affect colostrum compositions (Table 4). No difference was observed in the lactose of milk. However, fat ($P = 0.04$), protein ($P = 0.03$), solid not fat ($P = 0.03$), total solids content ($P = 0.04$), and moisture ($P = 0.04$) in milk increased linearly with increasing dietary levels of lysine. In addition, different reproductive cycles did not affect colostrum and milk composition. PUN level was linearly increased at 21 d of lactation by increasing dietary Lys levels (Table 5). There was no interaction between dietary treatment and reproduction cycle on colostrum and milk compositions and PUN of sow.

Table 4
Effects of different levels of lysine in lactation diets on composition of colostrum and milk

Item	First reproductive cycle				Second reproductive cycle				<i>P-value</i>					
	0.84%	0.94%	1.04%	1.14%	0.84%	0.94%	1.04%	1.14%	SEM	L	Q	Diet	Cycle	Diet × Cycle
No. of sows	16	16	16	16	16	16	16	16						
Colostrum														
Fat, %	4.92	5.05	5.09	5.06	4.99	5.01	5.12	5.09	0.11	0.42	0.34	0.42	0.35	0.48
Lactose, %	3.51	3.64	3.50	3.55	3.55	3.68	3.65	3.69	0.12	0.35	0.36	0.65	0.56	0.22
Protein, %	13.36	13.63	13.58	13.51	13.54	13.60	13.65	13.63	0.09	0.29	0.41	0.24	0.64	0.30
Solid not fat, %	20.30	20.55	20.85	20.56	20.43	20.66	20.61	20.59	0.21	0.23	0.62	0.20	0.51	0.28
Total solids content, %	25.98	26.66	26.84	26.25	26.17	25.50	25.85	25.68	0.71	0.35	0.52	0.27	0.38	0.46
Moisture, %	74.02	73.34	73.16	73.75	73.84	74.50	74.15	74.32	0.71	0.35	0.52	0.26	0.35	0.50
Milk														
Fat, %	7.19	7.52	7.87	7.83	7.07	7.39	7.51	7.88	0.13	0.04	0.25	0.03	0.32	0.54
Lactose, %	6.60	6.65	6.66	6.80	6.58	6.53	6.74	6.75	0.11	0.15	0.32	0.27	0.35	0.56
Protein, %	5.76	6.20	6.63	6.85	5.62	6.18	6.62	6.67	0.18	0.03	0.42	0.03	0.27	0.42
Solid not fat, %	14.62	14.80	15.06	15.61	14.67	14.63	14.91	15.42	0.15	0.03	0.36	0.03	0.35	0.76
Total solids content, %	19.48	20.35	20.78	21.37	19.17	20.01	20.42	21.16	0.21	0.04	0.47	0.04	0.65	0.37
Moisture, %	80.52	79.65	79.22	78.63	80.83	79.99	79.58	78.84	0.21	0.04	0.47	0.05	0.45	0.38

Table 5
Effects of different levels of lysine in lactation diets on plasma urea nitrogen (PUN) of sows

Item	First reproductive cycle				Second reproductive cycle				<i>P-value</i>					
	0.84%	0.94%	1.04%	1.14%	0.84%	0.94%	1.04%	1.14%	SEM	L	Q	Diet	Cycle	Diet × Cycle
No. of sows	16	16	16	16	16	16	16	16						
Parturition	3.72	3.74	3.92	3.89	3.60	3.69	3.80	3.86	0.18	0.32	0.25	0.65	0.21	0.23
Weaning	5.21	5.36	5.71	5.81	5.13	5.35	5.59	5.83	0.21	0.04	0.37	0.05	0.42	0.36

Plasma amino acid concentrations

Effect of dietary lysine content on plasma-free amino acid concentrations of sows at farrowing and at weaning were shown in Tables 6 and 7, respectively. Concentrations of free amino acids in plasma did not differ between dietary lysine levels at farrowing. There were significant linear increases in plasma Lys ($P=0.02$), Met ($P=0.05$), and Val ($P=0.04$) levels as dietary lysine content increased at 21 d of lactation. Compared with the first lactation period, plasma Ala ($P=0.02$), His ($P=0.04$), Pro ($P=0.04$), Ser ($P<0.01$) and Thr ($P<0.01$) levels were lower at farrowing in the second lactation. At 21 d of lactation, plasma Ala (<0.01), Pro (<0.01), Ser ($P<0.01$), Thr ($P<0.01$) and Val ($P<0.01$) levels were also reduced at farrowing in the second lactation. In addition, concentrations of His tended to decrease ($P=0.04$) at farrowing in the second lactation. There was no interaction between dietary treatment and reproduction cycle on plasma amino acid levels at farrowing and at 21 d of lactation of sows.

Table 6
Effects of different levels of lysine in lactation diets on plasma (0 d) amino acid concentrations of sows

Item	First reproductive cycle				Second reproductive cycle				<i>P-value</i>					
	0.84%	0.94%	1.04%	1.14%	0.84%	0.94%	1.04%	1.14%	SEM	L	Q	Diet	Cycle	Diet x Cycle
No. of sows	16	16	16	16	16	16	16	16						
Ala	693.18	660.24	692.33	649.66	468.82	480.40	538.74	464.04	32.26	0.58	0.48	0.45	0.02	0.65
Arg	163.05	164.90	184.06	182.57	160.44	158.97	166.38	175.26	13.42	0.29	0.42	0.24	0.54	0.38
Asp	23.36	17.72	21.43	18.56	13.89	14.77	12.88	17.67	1.64	0.35	0.21	0.42	0.52	0.78
Glu	344.08	307.51	376.14	290.30	272.41	348.25	326.52	333.57	23.65	0.15	0.23	0.35	0.32	0.38
Gly	639.31	692.73	607.37	698.17	671.77	608.38	679.19	650.06	36.72	0.65	0.52	0.56	0.43	0.67
His	172.28	149.27	160.88	161.34	134.92	132.27	122.41	133.53	4.36	0.31	0.63	0.43	0.04	0.56
Ile	133.00	138.34	125.70	138.88	126.68	131.90	134.10	131.88	8.21	0.68	0.51	0.78	0.45	0.94
Leu	254.22	240.67	235.40	246.51	218.51	265.16	239.59	230.09	13.26	0.62	0.42	0.21	0.32	0.43
Lys	275.80	265.50	276.21	263.17	270.11	276.71	269.48	265.13	22.14	0.36	0.26	0.34	0.56	0.67
Met	54.72	56.64	54.98	52.59	52.03	52.37	54.42	58.01	1.62	0.25	0.36	0.68	0.62	0.87
Phe	101.61	107.18	106.23	102.84	100.62	108.88	99.36	101.52	5.42	0.42	0.51	0.75	0.58	0.88
Pro	411.09	338.86	359.44	396.93	305.57	284.70	266.47	283.19	25.48	0.62	0.33	0.23	0.04	0.76
Ser	225.24	205.56	217.27	217.87	169.39	178.31	148.44	168.76	10.56	0.23	0.36	0.32	< 0.01	0.43
Thr	607.25	605.41	579.58	661.74	422.63	461.70	492.40	488.55	34.74	0.41	0.26	0.27	< 0.01	0.22
Trp	112.46	124.07	114.64	134.14	114.47	119.88	125.67	115.86	7.02	0.51	0.36	0.32	0.46	0.76
Val	358.23	381.66	377.92	401.81	383.39	361.64	366.91	344.63	26.28	0.62	0.37	0.21	0.32	0.68

Table 7
Effects of different levels of lysine in lactation diets on plasma (21 d) amino acid concentrations of sows

Item	First reproductive cycle				Second reproductive cycle				<i>P-value</i>					
	0.84%	0.94%	1.04%	1.14%	0.84%	0.94%	1.04%	1.14%	SEM	L	Q	Diet	Cycle	Diet × Cycle
No. of sows	16	16	16	16	16	16	16	16						
Ala	515.12	604.65	562.33	480.22	456.22	504.41	464.10	468.75	18.26	0.15	0.45	0.05	< 0.01	0.40
Arg	187.20	169.83	178.66	162.59	175.74	184.75	176.29	200.11	13.28	0.22	0.36	0.97	0.41	0.49
Asp	23.03	22.96	23.14	19.78	20.516	22.05	20.21	23.34	1.34	0.21	0.36	0.96	0.61	0.33
Glu	312.76	332.39	341.29	339.01	277.25	320.98	352.12	371.88	21.62	0.12	0.35	0.10	0.96	0.66
Gly	807.41	797.99	726.21	786.51	707.86	775.48	716.24	756.64	23.20	0.22	0.25	0.49	0.21	0.71
His	154.43	153.35	155.47	147.38	149.19	147.32	138.28	149.02	3.42	0.52	0.30	0.65	0.06	0.41
Ile	130.37	109.50	150.16	110.08	131.64	126.77	135.82	140.58	6.24	0.26	0.32	0.19	0.23	0.16
Leu	246.58	211.08	283.11	216.57	245.53	250.16	249.63	265.58	11.56	0.56	0.72	0.35	0.29	0.10
Lys	176.25	221.14	330.50	280.52	234.54	256.21	283.12	293.59	18.70	0.02	0.28	0.01	0.20	0.14
Met	45.86	50.59	69.72	65.05	46.30	55.15	67.02	70.09	3.64	0.05	0.41	0.04	0.17	0.25
Phe	107.67	92.81	119.88	94.49	107.25	96.37	107.40	100.30	4.25	0.24	0.35	0.02	0.73	0.60
Pro	364.27	348.58	456.93	324.79	294.11	307.12	273.70	335.94	23.48	0.18	0.38	0.67	< 0.01	0.22
Ser	221.53	200.62	232.16	192.86	177.63	190.37	186.04	189.04	7.62	0.63	0.58	0.56	< 0.01	0.22
Thr	519.10	448.18	540.36	524.11	380.59	400.64	382.39	381.10	23.21	0.48	0.27	0.69	< 0.01	0.23
Trp	147.85	115.17	143.46	124.10	131.34	118.01	114.07	121.31	6.68	0.48	0.32	0.18	0.29	0.56
Val	284.73	302.14	450.98	401.63	303.34	305.69	361.75	340.53	18.42	0.04	0.26	0.04	< .0.01	0.11

Colostrum and milk amino acid concentrations

Effect of dietary lysine content on colostrum and milk free amino acid concentrations of sows were shown in Tables 8 and 9, respectively. The concentrations of amino acid in the colostrum were not influenced by the dietary lysine level, except for lysine ($P=0.05$). Compared with the primiparous, prolines in the colostrum were lower ($P=0.05$) at the second lactation. There were significant linear increases in milk Asp, Glu, His, Ile, Leu, Lys, Met, Phe, Pro, Ser, Thr, Trp and Val levels as dietary Lys content increased ($P<0.05$) at 21 d of lactation. Ala and Arg in milk from sows in the 0.94%, 1.04% and 1.14% lysine group were higher ($P<0.05$) than those in the 0.84% Lys group. There was no interaction between dietary treatment and reproduction cycle on colostrum and milk amino acid concentrations of sow.

Table 8
Effects of different levels of lysine in lactation diets on colostrum amino acid concentrations of sows

Item	First reproductive cycle				Second reproductive cycle				<i>P-value</i>					
	0.84%	0.94%	1.04%	1.14%	0.84%	0.94%	1.04%	1.14%	SEM	L	Q	Diet	Cycle	Diet x Cycle
No. of sows	16	16	16	16	16	16	16	16						
Ala	103.54	95.94	135.03	130.94	75.36	131.73	126.44	116.45	16.70	0.20	0.39	0.12	0.41	0.42
Arg	50.18	53.73	64.94	68.06	47.34	70.24	50.52	54.31	12.03	0.25	0.72	0.35	0.45	0.36
Asp	39.17	36.10	38.08	40.41	38.39	43.14	34.72	38.09	2.56	0.56	0.35	0.65	0.21	0.43
Glu	245.17	235.49	324.96	205.63	170.73	306.50	303.49	190.78	30.52	0.28	0.21	0.16	0.26	0.61
Gly	123.69	101.39	179.24	107.98	77.89	139.45	168.29	100.70	25.22	0.23	0.36	0.14	0.34	0.51
His	35.33	53.14	90.46	106.92	67.12	55.40	75.03	103.09	12.02	0.32	0.40	0.45	0.82	0.37
Ile	9.78	9.57	12.39	15.51	9.83	11.94	9.55	16.87	1.24	0.10	0.38	0.34	0.36	0.26
Leu	148.07	129.34	179.90	200.80	202.01	146.37	168.27	157.94	26.64	0.15	0.26	0.45	0.49	0.65
Lys	49.26	55.69	58.24	100.00	47.19	71.54	43.94	102.34	5.86	0.52	0.34	0.05	0.42	0.25
Met	7.42	10.22	10.22	16.64	7.69	12.64	7.27	23.46	3.56	0.11	0.20	0.14	0.17	0.25
Phe	28.27	36.40	39.31	33.36	30.14	47.75	44.51	32.28	2.35	0.15	0.29	0.22	0.43	0.54
Pro	61.30	88.37	81.72	96.71	104.00	94.96	131.31	198.64	14.68	0.26	0.29	0.25	0.05	0.48
Ser	76.84	69.81	101.30	126.07	86.64	90.53	78.57	111.21	4.26	0.12	0.32	0.35	0.35	0.34
Thr	62.33	61.88	70.10	69.03	63.55	64.13	66.51	60.19	2.75	0.63	0.28	0.49	0.32	0.31
Trp	36.15	43.42	40.13	51.88	81.59	46.51	54.80	45.02	7.45	0.25	0.42	0.14	0.29	0.66
Val	67.30	72.12	74.21	83.90	84.91	66.39	76.65	85.38	9.24	0.13	0.25	0.13	0.31	0.19

Table 9
Effects of different levels of lysine in lactation diets on milk amino acid concentrations of sows

Item	First reproductive cycle				Second reproductive cycle				<i>P-value</i>					
	0.84%	0.94%	1.04%	1.14%	0.84%	0.94%	1.04%	1.14%	SEM	L	Q	Diet	Cycle	Diet × Cycle
No. of sows	16	16	16	16	16	16	16	16						
Ala	210.39	316.99	272.92	399.98	223.18	371.00	304.33	362.19	21.68	0.14	0.15	0.05	0.24	0.32
Arg	57.96	121.74	135.96	84.84	81.69	132.18	133.91	128.78	8.06	0.25	0.09	0.04	0.62	0.73
Asp	336.56	305.43	381.16	464.02	337.72	370.18	444.49	496.98	25.66	0.04	0.28	0.05	0.34	0.28
Glu	604.31	674.05	615.07	711.53	587.09	718.22	735.33	767.33	16.62	0.05	0.39	0.04	0.37	0.28
Gly	156.60	248.86	199.18	230.77	172.33	220.34	234.12	214.73	19.62	0.15	0.28	0.10	0.18	0.32
His	36.04	47.73	47.04	42.23	44.78	52.02	48.75	43.92	3.04	0.34	0.61	0.20	0.67	0.75
Ile	10.89	11.35	14.29	19.31	13.64	13.40	14.40	26.30	1.48	0.01	0.62	0.02	0.43	0.56
Leu	31.65	42.31	56.73	64.42	41.73	45.67	56.38	64.94	4.64	0.01	0.38	0.03	0.45	0.56
Lys	50.64	78.68	108.05	173.64	70.96	86.50	105.68	133.25	7.42	0.03	0.34	0.03	0.56	0.43
Met	9.40	18.43	27.00	69.43	13.86	19.29	25.94	41.27	2.26	0.02	0.56	0.04	0.32	0.38
Phe	18.59	29.10	43.07	91.86	28.03	30.31	43.11	62.41	5.08	0.01	0.52	0.03	0.43	0.45
Pro	45.60	49.01	82.72	132.72	55.61	58.40	73.96	85.99	4.28	0.04	0.40	0.03	0.34	0.65
Ser	101.67	146.46	165.50	149.47	116.47	166.58	174.36	170.43	8.94	0.02	0.46	< 0.01	0.80	0.78
Thr	199.96	223.28	174.30	283.07	128.57	250.11	253.95	288.50	18.76	0.01	0.35	< 0.01	0.87	0.19
Trp	22.57	37.24	57.98	91.51	32.48	42.34	55.74	70.79	4.26	0.02	0.40	0.04	0.16	0.34
Val	22.22	33.15	42.36	56.70	28.79	38.95	43.07	54.46	4.05	0.02	0.37	0.04	0.53	0.46

Discussion

In the present study, lysine level in the lactation diet did not affect sow lactation body weight, backfat changes and feed intake. Some studies support most of these findings. Sow average daily feed intake (ADFI), backfat changes, and litter size at weaning were not affected by increases in lysine from 0.80 to 1.06% [17]. Yang et al. (2009) reported that increasing in lysine from 1.02 to 1.34% did not affect body weight change, backfat change, feed intake and lysine intake during lactation of primiparous sow [4]. Touchette et al. (1998) reported that lysine intake during lactation decreased quadratically weight loss and loin eye area loss, while did not affect number of pigs weaned, litter growth rate, sow backfat loss, or WEI of primiparous sows [15]. Our study show that 0.94 and 1.04% lysine diets reduced WEI. Richert et al. (1996) reported that increasing lysine in lactation results in reduced BW loss during lactation [18]. Parity had a significant effect on sow body weight, backfat thickness and feed intake during lactation. It seemed that the requirements of the still growing primiparous sows were greater than those of the multiparous sows during this period.

Our study demonstrates that increasing dietary lysine increased survival rate of piglets, weight of piglet and weight gain of piglet at 21 d of lactation. These findings were in agreement with the results reported by Chen (1978) who evaluated the levels of lysine during gestation [19]. An addition of more than this synthetic amino acid could increase preweaning mortality and decrease the number of piglets weaned [19]. Similar findings on good litter performance nursed by sows fed higher lysine diets were reported [20, 21, 22]. The piglet weaning weight of the present study were similar to those observed by Santos et al. (2006) who reported no improvement on litter performance with greater Lys intake [23]. However, previous studies reported that sows fed 0.67%, 0.86%, 1.06% or 1.25% of apparent digestible lysine diet during a 17-d lactation did not find any difference on litter performance [15]. In the present study, the number of pigs born and weaned was similar for primiparous and multiparous sows, but greater litter weight at weaning and growth rate were observed in litters nursed by multiparous sows than primiparous sows. Yang et al. (2009) have also indicated that modern genotype multiparous sows have greater reproductive performance at born and at weaning than primiparous sows [4]. However, in our previous research, Lys levels (0.95% and 1.10%) over two consecutive lactations did not affect average weight at weaning, litter weight at weaning, little weight gain, and litter growth rate in multiparous sows [24]. This could be the probable reason for lysine intake levels meet

lactation requirements in multiparous sows. Therefore, this indicates that modern genotype sows need more nutrients for lactation, especially less than 3 parities of sows.

Providing sows with sufficient amounts of nutrients during lactation is crucial for optimal performances from the lactating sows and consequently the health and growth of the newborn piglets [25]. While insufficient nutrient intake caused body composition loss for maintain milk production [26]. Furthermore, excessive mobilization of body tissues results in low milk production, delayed return to estrus postweaning [27]. In the present study, the clear effect of dietary lysine levels in increasing milk contents of fat, protein, total solids and solid not fat agrees with the previous observations [4, 19]. This could be a key reason for piglets have better lactation performance due to difference in the sow milk composition with lysine levels increasing during lactation. concentrations reflected protein (amino acids) mobilization in lactating sows [28]. As dietary concentration of the Lys increases, muscle tissue loss decreases, and PUN concentration is increased [20, 29]. In our study, sows fed high-lysine diets had higher PUN concentration at d 21 of lactation. Similar findings on PUN concentration by sows fed higher lysine diets [4, 17]. Dietary concentration of the lysine increases, muscle tissue loss decreases and, PUN concentration is increase [4]. Furthermore, greater PUN may indicate less protein utilization, excess N, or more transamination or deamination [30]. Thus, PUN concentration may be increased if sows more protein or amino acids than the requirement.

The relationship between the amino acid adequacy of a diet and the plasma amino acid levels is well documented [18, 31]. Further dietary additions of this amino acid result in rapid accumulation in blood plasma of animals [32]. In our study, evaluated the first and second parity sows fed different lysine levels, keeping the ideal amino acids ratios constant by adding Met, Thr, Val, and Trp increased plasma amino acid levels by measured. In addition, the milk amino acid change was similar for plasma amino acid levels. This further suggests that good litter performance nursed and subsequent reproductive performance by sows fed higher amino acid diets over two consecutive lactations in primiparous sows.

Conclusion

Although increasing lysine (balance the other amino acids) levels for lactating sows was no difference in sow body conditions and performance of piglets at birth. However, increasing dietary lysine levels in lactation was beneficial for survival rate of piglets, litter weight, piglet weight and ADG at weaning. Moreover, milk compositions were changed, increasing amino acid concentration by dietary lysine levels which is an important reason for the performance improvement of piglets. Therefore, when implementing strategies for improving reproductive efficiency, higher dietary amino acids levels during lactation must be considered, especially for primiparous sows.

Abbreviations

ADFI: average daily feed intake; ADG: Average daily gain; Ala: alanine; Arg: arginine; Asp: aspartate; BW: Body weight; Glu: glutamate; Gly: Glycine; His: histidine; Ile: Isoleucine; Leu: Leucine; Lys: lysine; Met: Methionine; NRC: National Research Council; Phe: Phenylalanine; Pro: proline; PUN: Plasma urea nitrogen; WEI: Weaning to estrus interval; Ser: Serine; SID: Standardized ileal digestible; Thr: Threonine; Trp: Tryptophan; Val: Valine.

Declarations

Acknowledgments

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Authors' contributions

PJ, LB and WHK conceptualized and designed the study, XX provided field test guidance, ZYF XM and WC acquired the data, PJ, LB, ZYF and WC analyzed and interpreted the data, LB, ZYF and PJ drafted and revised the article. All authors critically reviewed the manuscript for intellectual content and gave final approval for the version to be published.

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Availability of data and materials

The datasets analyzed are not publicly available due to ownership by the funding partners but are available from the corresponding author upon reasonable request.

Ethics approval

The experiment was carried out according to Chinese guidelines for animal welfare and the National Institutes of Health guide for the care and use of laboratory animals. All procedures related to animal feeding and sample collections were approved by the Huazhong Agricultural University Animal Care and Use Committee.

Consent for publication

All authors approved the final manuscript.

Competing interests

The authors declare that they have no competing interests

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