A Dissertation
for the Degree of Doctor of Philosophy

Effects of Dietary Arginine, Lysine, and Energy Levels on Physiological Responses and Reproductive Performance in Sows and Growth of Their Progeny

사료내 아지닌, 라이신, 에너지 수준이 모돈의 생리학적 반응과 번식성적 및 자돈의 성장에 미치는 영향

February, 2018

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이 논문을 농학박사 학위논문으로 제출함

2018 년 2 월

서울대학교 대학원 농생명공학부

홍 진 수

홍진수의 농학박사 학위논문을 인준함

2018 년 2 월

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Overall Summary

Effects of Dietary Arginine, Lysine, and Energy Levels on Physiological Responses and Reproductive Performance in Sows and Growth of Their Progeny

Hyper-prolific sows had some advantages of having high number of piglets and high lactating ability for their litters. Although hyper-prolific sows had high number of piglets born alive, some problems were reported such as severe body weight or backfat loss, low piglet birth weight, low piglet uniformity, and low body weight of weaning pigs. In order to resolve these disadvantages, some researchers have focused on high efficiency of protein or amino acid utilization for nutrition of hyper-prolific sows, considering limited feed allowance for energy restriction (Kim et al., 2009; Zhang et al., 2011; Moehn and Ball, 2013). Supplementation of adequate amino acids amount to lactating sows not only maximizes milk yield for piglets but also retains maternal body component reservoir for the consecutive parities (NRC, 1998; Kim and Easter, 2003). To improve reproductive performance and longevity for modern hyper-prolific sows, three experiments were conducted 1) to compare the effects of arginine supplementation and increased feeding levels on reproductive performance and piglet uniformity in late gestating sows, 2) to evaluate the effects of dietary energy and lysine levels on physiological responses, reproductive performance, blood profiles, and milk composition in primiparous sows, and 3) to investigate the effects of dietary energy and lysine levels on physiological responses, reproductive performance, piglet uniformity, and longevity in sows during 1 to 3 parities.

Experiment I. Effects of Arginine Levels Compared with Increased Feeding on Reproductive Performance and Piglet Uniformity in Late-Gestating Sows

This study was conducted to evaluate the effects of arginine levels compared with increased feeding on reproductive performance and piglet uniformity in late-gestating sows. In the first trial, a total of 40 F1 multiparous sows (Yorkshire × Landrace), body weight 246.1 kg; avg. parity 5.1, were allotted to one of four treatments in a completely randomized design (CRD). Dietary treatments were divided by the supplementation level of arginine during late-gestation period; 1) CON : corn-SBM based diet + L-Arg 0% (Arg 0.72%), 2) Arg10 : basal diet + L-Arg 0.28% (Arg 1.0%), 3) Arg15 : basal diet + L-Arg 0.79% (Arg 1.5%), and 4) Arg20 : basal diet + L-Arg 1.35% (Arg 2.0%). Same lactation diet was provided *ad libitum* during lactation period regardless of dietary treatments. There were no significant differences in body weight and backfat thickness of sows during gestation and lactation. In addition, dietary arginine levels had no significant differences in the number of total born, stillbirth, total born, and piglet growth during lactation. Increasing arginine levels improved total litter weight (Linear, P=0.08) and alive litter wieght (Quadratic, P=0.07). However, additional arginine effect did not show the piglet uniformity in piglet birth weight and piglet weight at day 21 of lactation. Although there was no significant difference in blood profiles in gestating sows, blood urea nitrogen of lactating sows was increased as dietary arginine level increased (Linear, $P<0.05$). Additional arginine supplementation had no influence on composition of colostrum and milk (21d). In conclusion, L-arginine at 1.0% in late gestation improved total litter weight and alive litter weigth at farrowing. In the second trial, a total of 44 F1 multiparous sows (Yorkshire × Landrace), body weight 229.5 kg; avg. parity 4.8, were allotted to one of four treatments in a completely randomized design (CRD). Dietary treatments were CON (Arg 0.72%), Arg10 (Arg 1.0%), Arg15 (Arg 1.5%) and sows were fed at 2.4 kg/d experimental diet, and increased feeding treatment was provided at 3.0kg/d

CON diet. Same lactation diet was provided *ad libitum* during lactation regardless of dietary treatments. There were no significant differences in change of body weight and backfat thickness of sows and lactation feed intake among dietary treatments. Also, additional dietary arginine levels had no significant influences on reproductive performance and growth of their progeny compared with increased feeding treatment. However, increasing arginine levels improved litter weight at 3 week and litter weight gain, respectively (Linear, P=0.06, P=0.05). Additional arginine intake during late gestation had no significant effects on piglet uniformity and blood profiles compared with those of increased feeding treatment. Consequently, dietary arginine up to 1.5% in late-gestation diet improved total litter weight and alive litter weight at farrowing, but it did not affect piglet uniformity at birth and piglet growth. Moreover, dietary arginine at 1.5% in late-gestation had an equivalent effect with increased feeding on piglet birth weight and their uniformity.

Key words: Arginine, Increased feeding, Late gestating sow, Piglet uniformity, Reproductive performance.

Experiment II. Effects of Dietary Energy and Lysine Levels on Physiological Responses, Reproductive Performance, Blood Profiles, and Milk Composition in Primiparous Sows

This study was conducted to evaluate the effects of dietary energy and lysine levels on physiological responses, reproductive performance, blood profiles, and milk composition in primiparous sows. A total of 48 gilts (F1, Yorkshire × Landrace), initial BW of 168.1 ± 9.71 kg on 35 day of gestation, were allotted to one of eight treatments with a 2 × 4 factorial arrangement. The first factor was energy level in diet (3,265 or 3,365 kcal of ME/kg), and the second factor was total lysine level in diet (gestation 0.55, 0.65, 0.75 or 0.85%, lactation 0.70, 0.85, 1.00 or 1.15%). All sows were fed 2.0 kg/d of experimental diet in gestation and lactation diet was provided *ad libitum* during lactation. High-energy treatment group showed a greater body weight gain and backfat thickness in gestation period (Energy, P=0.07, P=0.09, respectively). In lactation period, high-energy treatment group had higher body weight at day 21 of lactation (Energy, P=0.09) and lower body weight loss (Energy, P=0.05). Backfat thickness was higher in high-energy treatment group at 24hrs postpartum and day 21 of lactation (Energy, P=0.04, P=0.07, respectively). Weaning to esturs interval was shortened in Lys 0.55/0.70 and Lys 0.75/1.00 (Lysine, P=0.03). In reproductive performance, dietary energy and lysine levels did not affect the number of total born and born alive, total litter weight, alive litter weight, litter weight gain, and piglet uniformity. Sows fed high-energy treatment diet had a tendency of greater piglet weight at 21 day and piglet weight gain (Energy, P=0.08, P=0.08, respectively). Blood urea nitrogen was greater in high-energy treatment group (Energy, P=0.08) and showed the lysine effect (Lysine, P=0.09) in day 110 of gestation. In lactating sows, blood urea nitrogen showed a quadratic decrease in Lys 0.75/1.00 treatment at 24hrs postpartum and day 21 of lactation (Quadratic, P=0.02, P<0.01, respectively). In composition of colostrum, high energy treatment group had greater casein, protein, total solid, solid not fat, and free fatty acid than those of

low-energy treatment group (P=0.03, P=0.03, P=0.03, P=0.03, and P<0.01, respectively). Also, free fatty acid in colostrum was higher in Lys 0.75/1.0 and Lys 0.85/1.15 treatment groups (Lysine, P<0.01). Sows fed high-energy treatment diet had a tendency of increased body protein mass at day 21 of lactation (Energy, P=0.05). In addition, body fat mass of sows fed a high-energy treatment diet tended to increase in whole gestation period and day 21 of lactation (Energy, P=0.06, P=0.08, respectively) and showed a lower body fat loss during lactation (Energy, P=0.09). Consequently, total lysine at 0.75% for gestation and at 1.00% for lactation with 3,365 kcal of ME/kg resulted in improving reproductive performance for primiparous sows and growth of their progeny.

Key words: Energy, Lysine, Physiological response, Primiparous sows, Reproductive performance

Experiment III. Effects of Dietary Energy and Lysine Levels on Physiological Responses, Reproductive Performance, Piglet Uniformity, and Longevity in Sows during 1 to 3 parities

This study was conducted to evaluate the effects of dietary energy and lysine levels on physiological responses, reproductive performance, piglet uniformity, and longevity in sows during 1 to 3 consecutive parities. A total of 48 F1 gilts (Yorkshire × Landrace) were allocated to one of eight dietary treatments in a completely randomized design (CRD) during the first to third consecutive parities. Experimental diets were composed with different energy level (3,265 or 3,365 kcal of ME/kg) and total lysine level (gestation 0.55, 0.65, 0.75 or 0.85%, and lactation 0.70, 0.85, 1.00 or 1.15%). Third parity sows fed high energy diet had greater body weight at day 110 of gestation, 24hrs postpartum, and huge body weight loss (Energy, $P=0.01$, $P=0.02$, and $P<0.01$, resepectively). Increasing dietary energy level induced a thicker backfat thickness of sows at day 35 of gestation and day 110 of gestation at pairty 2 (Energy, $P=0.01$, $P<0.01$, respectively) and at parity 3 (Energy, $P<0.01$, $P<0.01$, respectively). In addition, high-energy treatment group showed a greater backfat thickness of 24hrs postpartum in parities 1, 2, and 3 (Energy, $P=0.04$, $P<0.01$, and $P<0.01$, respectively) and the end of lactation at parity 3 (Energy, $P=0.01$). High-energy treatment group had a greater protein mass in gestation at parity 2 or 3 and in lactation at parity 3 (Energy, $P<0.01$, $P<0.01$, and $P<0.01$, respectively). Sows fed high-energy treatment diet had a greater fat mass in gestation period at parities 2 and 3 (Energy, $P<0.05$, $P<0.01$), and in 24hrs postpartum at parities 2 and 3 (Energy, $P<0.01$, $P<0.01$). Although there were no significant effects of energy and lysine levels on reproductive performance such as total born, born alive, total litter weight, and alive litter weight, Lys 0.55/0.70 with 3,265 kcal of ME/kg treatment group showed higher performance among treatments. Although piglet weight at 3 week and piglet weight gain at the first parity were higher in 3,365 kcal of ME/kg treatment group (Energy, $P=0.08$, $P=0.08$),

interaction responses were observed in final piglet weight and piglet weight gain at the third parity (Interaction, P=0.02, P=0.04). Low-energy treatment group at the second parity had a tendency of decreasing a standard deviation of piglet birth weight (Energy, P=0.06). Moreover, Lys 0.75/1.00% and Lys 0.65/0.85% treatments showed lower standard deviation of piglet birth weight at the second parity (Lysine, P=0.03). Lactation feed intake at parity 3 tended to increase in 3,265 kcal of ME/kg (Energy, P=0.07) treatment group. Considering the number of sow removal as pairty, 3,265 kcal of ME/kg treatment group showed high culling rate in the end of parity 1, and 3,365 kcal of ME/kg group showed high culling rate in the end of parities 2 and 3. Lys 0.55/0.70% with 3,265 kcal of ME/kg group did not have any culled sow and observed greater longevity than other treatment groups. Consequently, total lysine at 0.55 % in gestation diet and at 0.75% in lactation diet with 3,265 kcal of ME/kg resulted in better reproductive performance and longevity in sows at parities 2 and 3.

Key words: Sow, Energy, Longevity, Lysine, Reproductive performance.

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Chapter II. Review of Literature

List of Abbreviation

AA	:	Amino acid
ADG	:	Average daily gain
ADFI	:	Average daily feed intake
ARG	:	Arginine
BUN	:	Blood urea nitrogen
BF	:	Backfat
BW	:	Body weight
CP	:	Crude protein
CRD	:	Completely randomized design
CV	:	Coefficient of variation
EBW	:	Empty body weight
EE	:	Ether extract
FFA	:	Free fatty acid
FCR	:	Feed conversion ratio
GnRH	:	Gonadotropin releasing hormone
HDL	:	High-density lipoprotein
LDL	:	Low-density lipoprotein
LH	:	Luteal hormone
LW	:	Litter weight
ME	:	Metabolizable energy
NO	:	Nitric oxide
NRC	:	National Research Council
PW	:	Piglet weight
SAS	:	Statistical Analysis System
SBM	:	Soybean meal
SD	:	Standard deviation
WEI	:	Weaning to estrus interval

Chapter I. General Introduction

As hyper-prolific sows were induced to domestic swine farm recently, the upper ten percentage of Korean swine farms had weaned 25.3 pigs per sow per year and marketed 23.8 pigs per sows per year (HFMS, 2017). Further improvement being proceed, the threshold of 30 pigs per sow per year becomes an accomplishable goal for Korean swine farm. Unfortunately, low thirty percentage of Korean swine farm had weaned 18.8 pigs per sow per year and marketed 14.1 pigs per sow per year (HFMS, 2017). The reason for this difference is that they do not have the accurate understanding of hyper-prolific sows and apply the wrong feeding scheme or breeding management for hyper-prolific sows.

Hyper-prolific sows has some advantages of high number of piglets and high lactating ability for their litters. In other side, because of high number of piglets, severe body weight or backfat loss, low piglet birth weight, low piglet uniformity, and low body weight of weaning pig were easily observed in hyper-prolific sows. In order to overcome these disadvantages, precise nutrient evaluation is needed to hyper-prolific sows.

In the breeding sow, energy is required for growth, maintenance, pregnancy and lactation. Energy utilization of gestating sows was mainly recovered their body deposition and was divided into mammary, water, placenta, fetus, and uterus as the pregnancy progressed. NRC (2012) suggested that energy requirement of gilts or multi-parous sows was higher in late-gestation period than early and middle gestation period. Also, protein is used for maintenance, growth, pregnany and lactation of sows and protein depositions of mammary, uterus, placenta, and fetus were increased gradually during gestation (Patience, 1996). As hyper-prolific sows produce more piglets and have higher necessity of milk for piglets, hyper-prolific sows needed higher protein or amino acid supply rather than ordinary sows.

High energy intake resulted in increased body weight (Van den Brand et al., 2000) and maternal deposition (Dourmad et al., 1999) of sows and improved piglet birth weight (Coffey et al., 1994) or not (Eckhardt et al., 2013). It caused

impaired body condition to reproductive problems such as absence of pregnancy and abortions (Young et al., 1990). High energy intake during gestation could reduce insulin sensitivity and glucose tolerance (Weldon et al., 1994), it may be a risk factor for preweaning survival (van den Peet-Schwering et al., 2004; Averette Gatlin et al., 2002). Therefore, some researchers focused on high efficiency of protein or amino acid utilization for hyper-prolific sows considering limited feed allowance for energy restriction (Kim et al., 2009; Zhang et al., 2011; Moehn and Ball, 2013)

High producing sows were focused on the growth pattern of fetuses (McPherson et al., 2004), mammary glands (Ji et al., 2006), and maternal tissues (Ji et al., 2005). Lysine requirements for maternal, fetal, and mammary tissue gains distinctly differ in gestating sows, which are 5.57 and 8.78 g/d for d 0 to 60 and d 60 to 114 of gestation, respectively, combining the lysine needs for tissue gain and maintenance (Kim et al., 2009). Kim et al. (2009) suggested that primiparous sows, when fed a diet with ideally balanced amino acid, could conserve dietary amino acid for maternal tissue gain and for reducing fetal weight variation.

Importance of amino acid in lactation and mammary gland function of sows increased (Kim and Wu, 2008). In lactating sows, maternal tissue mobilization like body protein and fat contributes to the amino acids needs for milk production and mammary tissue growth (Trottier and Johnston, 2001; Kim and Easter, 2003). Especially, the plasma amino acid profiles of sow (Wu et al., 1999) differ markedly from the amino acid patterns taken up by mammary glands or those in milk of the sow (Trottier et al., 1997). It demonstrated that different rates of amino acid transport and transformation in mammary tissue (O'Quinn et al., 2002), inadequate supplementation of amino acid to lactating sows resulted in excessive mobilization of maternal protein and reproductive failure for the following reproductive cycle (Jones and Stahly, 1999). Thus, supplementation of adequate amino acid to lactating sows not only maximizes milk yield for piglets but also retain maternal body component reservoir for the consequtive parities (NRC, 1998).

To improve sow productivity and longevity, three experiments were

conducted 1) to compare the effects of arginine supplementation levels and increased feeding on reproductive performance and piglet uniformity in late gestating sows, 2) to evaluate the effects of dietary energy and lysine levels on physiological responses, reproductive performance, blood profiles, and milk composition in primiparous sows, and 3) to investigate the effects of dietary energy and lysine levels on physiological responses, reproductive performance, piglet uniformity, and longevity in parity 1 to 3 sows.

Chapter II. Review of Literature

1. Amino acid requirement of sow

1.1 Primiparous sow

Inadequate feed intake during lactation was considered as a limiting factor in sow nutrition (O'Grady et al., 1985; Lynch, 1988). The problem was pariticularly evident in the primiparous sow and was thought to be a cause of second-litter reproductive failure and reduced overall productivity (Johnston et al., 1989). The primiparous sow exhibited poor appetite, usually during the initial phase of lactation, in relation to sow requirements for maintenance and milk production (Mullan and Williams, 1990). Because fetal and mammary tissue growth is rapid during late gestation, the amino acids needs are greater, particularly in primiparous sows. Muscle tissue growth must be accounted for in younger sows as part of their reproductive needs (Kim et al., 2007). The amounts of amino acids required for protein accretion and maintenance were summed to obtain the amino acid needs for pregnant primiparous sows and were used to calculate the Lys-based amino acids ratios (Table 1.).

Tokach et al. (1992) suggested that the interactive effects of lysine and ME intake on yield of milk components and dietary influences were not directly associated with changes in blood precursor metabolite concentrations. These results revealed that sow productivity during lactation was dependent on both lysine and ME intakes, because the influence of one was contingent on the level of the other. They concluded that energy intake must be conserved when one recommends lysine levels for lactating sow diets.

Trottier and Easter (1995) demonstrated that the early phase of lactation was associated with a high plasma tryptophan:branch chained amino acid (BCAA) ratio in primiparous sows fed practical corn-soybean meal diets. Reduction in this ratio through dietary addition of BCAA did not increase feed intake, although a

hyperphagic response to BCAA may require a previoius exposure to a high plasma ratio of tryptophan:BCAA, as observed for sows given the control diet.

Touchette et al. (1998) suggested the lysine requirement of lactating primiparous sows for lactational performance and subsequent reproductive performance. They reported that the maintenance of body reserves was influenced by the level of lysine in the diet. The primiparous sows were mobilized sufficient reserves to maintain a high level of milk production for a 17-d lactation at a low level of digestible lysine intake (27 g/d). In addition, a higher level (45 to 48 g/d) of digestible lysine was need to minimize body protein mobilization.

Jones and Stahly (1999) reported that dietary amino acid restriction (0.34% vs. 1.2% lysine) during lactation increased maternal mobilization of proteinaceous tissue and reduced milk nutrient outpu. Also, they showed that maternal protein mobilization was maintained over the entire lactation even though milk outpu was decreased as lactation progresses.

A number of studies had demonstrated that low dietary lysine intake during lactation affect metabolic state, LH secretion, and weaning-to-estrus interval (King and Martin, 1989; Tokach et al., 1992; Jones and Stahly, 1999a) and increased mobilization of body protein (Jones and Stahly, 1999b). These studies focused on the influence of adequate to very low lysine intake during lactation but did not provide data on the responses to very high lysine intake during lactation. Increasing dietary lysine concentration above that required for maximal lactation performance in primiparous sows has shortened theweaning-to-estrus interval (Wilson et al., 1996) and either increased (Tritton et al., 1996) or decreased second litter size (Touchette et al.,1998, Yang et al., 2000b). Yang et al. (2000) demonstrated that low lysine intake during lactation seemed to incrase sow body protein mobilization, and incrased lysine intake seemed to improve the metabolic status of sows. Also, they reported that increasing lysine intake from 16 to 36 g/d incrased LH pulses and estradiol secretion during lactation, but further increasing lysine intake to 56 g/d did not enhance secretion of reproductive hormones.

Table 1. The amino acid contents in maternal tissues and fetus as well as amino acid ratios for protein accretion and maintenance in gilts (Kim et al., 2009).

Item	Amino acid							
	Lys	Thr	Val	Leu	Ile	Phe	Arg	His
Protein accretion (d 0 to 60 of gestation)								
Carcass, g/d	2.97	1.43	1.86	2.78	1.57	1.45	2.78	1.19
Gastrointestinal tract, g/d	0.01	0.004	0.006	0.008	0.004	0.004	0.008	0.002
Uterus, g/d	0.42	0.24	0.33	0.46	0.22	0.25	0.51	0.14
Liver, g/d	-0.06	-0.04	-0.05	-0.08	-0.04	-0.04	-0.05	-0.02
Remaining viscera, g/d	-0.04	-0.02	-0.04	-0.05	-0.02	-0.02	-0.04	-0.01
Mammary gland, g/d	0.18	0.10	0.14	0.21	0.10	0.10	0.15	0.06
Fetus, g/d	0.45	0.22	0.27	0.44	0.19	0.23	0.38	0.12
Sum, g/d	3.93	1.94	2.52	3.77	2.03	1.97	3.74	1.48
Ratio relative to Lys, %	100	49.4	64.1	95.9	51.8	50.2	95.3	37.7
Maintenance (d 0 to 60 of gestation)								
Amount, g/d	1.64	2.48	1.10	1.15	1.23	0.82	1.23	0.52
Ratio relative to Lys[1], %	100	151	67	70	75	50	75	32
Protein accretion + maintenance (d 0 to 60 of gestation)								
Amount, g/d	5.57	4.42	3.62	4.92	3.26	2.79	4.97	2.00
Ratio relative to Lys, %	100.0	79.4	65	88.3	58.6	50.1	89.3	35.9
Protein accretion (d 60 to 114 of gestation)								
Carcass, g/d	3.13	1.51	1.97	2.94	1.66	1.53	2.94	1.26
Gastrointestinal tract, g/d	-0.14	-0.08	-0.11	-0.15	-0.08	-0.08	-0.15	-0.05
Uterus, g/d	0.55	0.31	0.42	0.59	0.29	0.33	0.66	0.18
Liver, g/d	-0.002	-0.001	-0.002	-0.003	-0.001	-0.002	-0.002	-0.001
Remaining viscera, g/d	-0.026	-0.02	-0.02	-0.03	-0.02	-0.02	-0.03	-0.01
Mammary gland, g/d	1.18	0.70	0.92	1.39	0.68	0.70	1.00	0.42
Fetus, g/d	2.3	1.13	1.46	2.38	1.00	1.20	2.83	0.74
Sum, g/d	7.00	3.56	4.64	7.11	3.53	3.65	7.25	2.55
Ratio relative to Lys, %	100	50.8	66.3	101.6	50.4	52.2	103.6	36.4
Maintenance (d 60 to 114 of gestation)								
Amount, g/d	1.78	2.69	1.19	1.25	1.34	0.89	1.34	0.57
Ratio relative to Lys, %	100	151	67	70	75	50	75	32
Protein accretion + maintenance (d 60 to 114 of gestation)								
Amount, g/d	8.78	6.25	5.83	8.36	4.87	4.54	8.59	3.12
Ratio relative to Lys, %	100	71.2	66.4	95.3	55.5	51.8	97.9	35.5

[1]Obtained from NRC (1998), and the ratio of Arg to Lys was adjusted to 75% based on Mateo et al. (2007), Wu and Morris (1998), and Wu et al. (1997, 2008)

1.2 Gestation

The protein and amino acids needs of pregnancy are for maintenance, deposition of reproductive tissue, conceptus tissue and for maternal gain. Once the requirements of fetal development have been satisfied, the remaining dietary protein can be used for maternal growth and recover. The amino acids and protein requirements for gestation are lower than for lactation and the pregnant sow is able to withstand protein deprivation by protecting the developing litter at the expense of maternal tissue

Lysine requirement is considered in the sample calculation of daily protein for maintenance, conceptus and maternal gain (Table 2)

Table 2. Sample calculation of daily protein and lysine requirements of gestating sows (g/d). Sow liveweight 200 kg; conceptus weight gain 20 kg and maternal weight gain 25 kg

	Total lysine	Ileal digestible lysine	Ideal protein
Maintenance[1]	2.1	1.9	32.7[5]
Conceptus gain[2]	4.4[3]	4.0[4]	30.7
Maternal weight gain[2]	5.5[3]	5.0[4]	38.4
Total	12.0	10.9	101.85

[1] Based on 36 mg/kg $BW^{0.75}$/d (Fuller et al., 1989) and 90% digestibility
[2] Based on 17.5% crude protein and 114 day gestation
[3] Based on 0.143 g total lysine / 1 g tissue protein (NRC, 1998)
[4] Based on 0.129 g true ileal lysine / 1 g tissue protein (NRC, 1998)
[5] Based on lysine/0.065 (Fuller et al., 1989). Crude protein values will be higher as they incorporate the excesses of feed formulation.

While differences in liveweight through changes in maintenance needs will influence lysine requirements, the major component is maternal weight gain. A mature sow of 200 kg liveweight, gaining 25 kg liveweight and 20 kg conceptus weight has a total lysine requirement of 12 g/day (Close and Cole, 2000).

For each of the five protein pools, such as placental tissue, mammary tissue, total fluid (chorioallantoic fluid), uterine tissue, body tissue of dam and fetus, lysine content and amino acid profiles relative to lysine for the protein deposition were presented in Table 3 (NRC, 2012).

Table 3. Lysine content and amino acid profile of maternal and fetal body protein, and of placenta, uterus, chorioallantoic fluid, udder, and milk expressed as a percentage of lysine content (NRC, 2012)

	Maternal body	Fetal body	Uterus	Placenta + fluid	Udder	Milk
	Lysine, g/100 g CP					
	6.74	4.99	6.92	6.39	6.55	7.01
Amino Acid	g Amino Acid/100 g Lysine					
Arg	105	113	103	101	84	69
His	47	36	35	42	35	43
Ile	54	50	52	52	24	56
Leu	101	118	116	122	123	120
Lys	100	100	100	100	100	100
Met	29	32	25	25	23	27
Met+Cys	45	54	50	50	51	50
Phe	55	60	63	68	63	58
Phe+Tyr	97	102	-	-	-	115
Thr	55	56	61	66	80	61
Trp	13	19	15	19	24	18
Val	69	73	75	83	88	71

NRC(2012) suggested that gestating sow model consisted of six different protein pools: fetus, placenta plus fluids, uterus, mammary tissue, time-dependent maternal protein deposition, and energy intake-dependent maternal protein deposition. The protein content of the fetus is estimated using natural logarithmic values and as a function of time (t, days into gestation) and anticipated litter size at farrowing (NRC, 2012). Typical protein deposition patterns for fetus, mammary tissue, placenta and fluids, maternal protein as a function of time, and maternal protein as a function of energy intake during gestation in parity2 sows based on an anticipated litter size of 13.5 piglets and a mean birth weight of 1.4 kg (Figure 1).

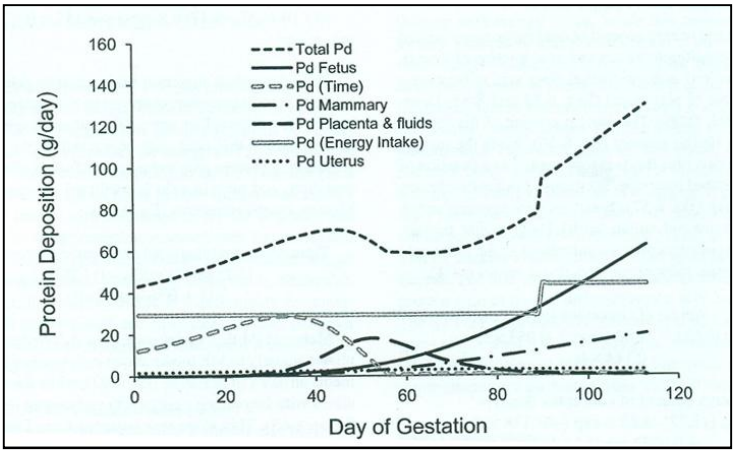

Figure 1. Typical protein deposition (Pd) patterns for fetus, mammary tissue, placenta and fluids, maternal protein as a function of time, and maternal protein as a function of energy intake during gestation in parity-2 sows based on an anticipated litter size of 13.5 piglets and a mean birth weight of 1.4 kg (NRC, 2012).

Total SID lysine requirements represent the sum of SID lysine requirements to cover endogenous gut lysine losses and integument lysine losses and SID lysine requirements for lysine retention. Changes in SID lysine requirements (g/day) during gestation were shown in Figure 2.

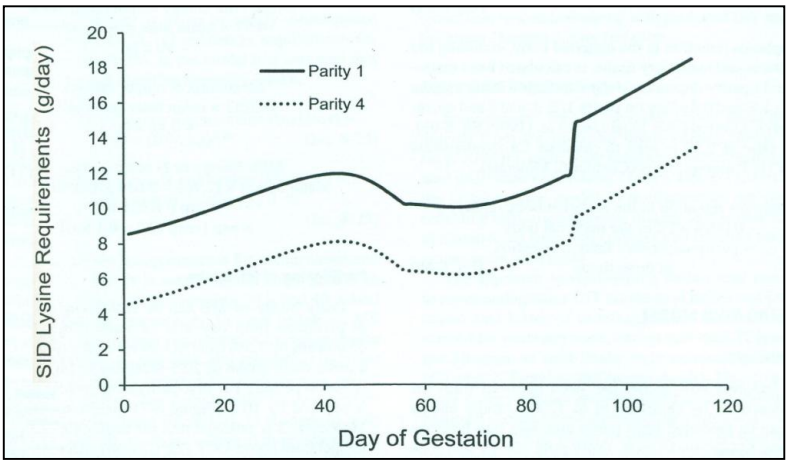

Figure 2. Simulated SID lysine requirements (g/day) of primiparous (body weight at mating 140 kg; anticipated total gain 65 kg; mean litter size 12.5; mean piglet birth weight 1.4 kg) and parity-4 (body weight at mating 205 kg; anticipated total gain 45 kg; mean litter size 13.5; mean piglet birth weight 1.4 kg) gestating sows. (NRC, 2012)

1.3 Lactation

Nutritional requirements of the modern lactating sow have increased continuously because of genetic improvements for litter size (Boyd and Kensinger, 1998). Considering status of lactating sows, nutrient requirements for lactation result from the needs of maintenance and milk production. The requirement is reduced by any contribution associated with the mobilization of maternal tissues. In early lactation milk production is more dependent on body reserves while in later lactation it is more dependent on both dietary intake and body reserves. The partition of protein between milk production and conservation of maternal tissues varies with both breed and degree of maturity (Sinclair et al., 1996).

Speer (1990) suggested that efficiency of utilization of absorbed essential amino acids is 100% for maintenance and 80% for milk production which will further influence the establishment of the total requirement. Sow's milk contains approximately 5.6% crude protein and has the amino acids composition given in Table 4. Also, the amino acid requirements for lactation are closely correlated with the composition of sow's milk. Although the composition may change to some degree during the lactation period, it appears that a crude protein value of 5.6% of which 7.6% is lysine is appropriate (Elliot et al., 1971; ARC, 1981). The high concentration of lysine in sow's milk is an indication of the importance of dietary lysine in lactation diets and estimates of this will be considered first.

Requirements increase as milk production gets higher since lactation per se is the major quantitative influence. Thus, requirement follows the shape of the lactation curve (Figure 3), and it is interesting to observe that depending on the level of lactation, maintenance makes up from 4 to 6% of total daily lysine requirement in gilts and 5 to 8% in sows.

Table 4. Typical analysis of sows milk, essential amino acid balance and daily intakes of individual amino acids (total) for lactating sows (Close and Cole, 2000).

	Sow milk (% of lysine)		Sows' milk (g/kg)	Dietary balance (% of lysine)	Daily intake (g/day)
Lys	100[1]	100[2]	17.02	100	55
Thr	54	59	9.19	60	33
Met	-	26	-	25	14
Met + Cys	42	47	7.15	50	28
Val	72	71	12.25	70[3]	39
Ile	58	55	9.87	60[3]	33
Leu	112	115	19.06	112	62
Phe	-	55	-	55	30
Phe + Tyr	107	112	18.21	110	61
Trp	15	17	2.55	18	10
His	36	42	6.13	35	19

[1] Speer (1990) based on a survey of the literature

[2] van der Peet-Schwering et al (1998) based on a survey of the literature.

[3] Richert et al. (1996; 1997).

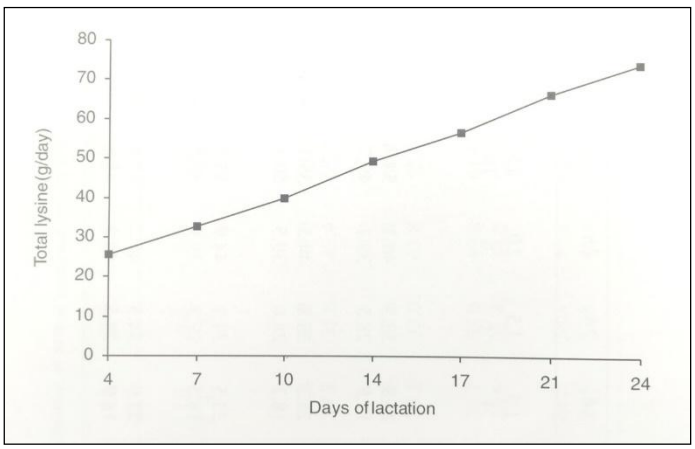

Figure 3. Typical dietary lysine requirements during lactation (28 days) for a 200 kg sow having 2 kg/d litter growth rate and no maternal weight loss (Close and Cole, 2000)

Increasing dietary lysine level of primiparous sows to 1.3% was associated with a large increase in the subsequent litter size (Tritton et al., 1996). Young sows needed a very high level of dietary lysine in lactation and the requirement for maximum prolificacy is greater than the requirement for milk production. However, the daily lysine intake at which piglet growth rate and subsequent litter size were similar, it was 60.6 g/day and in accord with factorial estimates (Tritton et al., 1996). The feed intake of the sows was low and the dietary lysine content had to be increased to 13.1 g/kg to provide the lysine requirement to ensure the highest litter growth rate.

2. Sow nutrition and piglet uniformity

2.1. Factors affecting piglet birth weight variation

2.1.1. Genetic selection and litter size

The genetic improvement over the past 10 years resulted in an increase of 1.8 piglets per litter in sows (Quesnel et al., 2008). It was in agreement with other researches which were reported a successful genetic selection for litter size (Merks, 2000; Foxcroft, 2008). Once the number of fully formed fetuses that can be maintained by the uterus until farrowing is limited, the correlation between increased number of fetuses and individual fetal growth is negative (Wolf et al., 2008). Therefore, various researches reported an increased within-litter variation in piglet birth weight and a decrease in average birth weight of the litter, because of the genetic selection for litter size (Lund et al., 2002; Tribout et al., 2003; Foxcroft, 2008; Quesnel et al., 2008). A greater number of fetuses exceeding the uterine capacity have been related to piglets with limited number of muscle fibers, which results in a compromised fetal growth and development (Foxcroft et al., 2006). In addition, Quiniou et al. (2002) suggested that increased litter size induces an increased proportion of light piglets, a concomitant decrease in litter uniformity and lower piglet birth weight, having negative effects on the piglets' viability and performance. Consequently, modern sows with high prolificacy leads to negative impacts on the fetal growth and development, as large litters are associated with reduced rates of fetal oxygen and nutrient uptakes, and also with reduced utero-placental blood flow per fetus (Reynolds and Redmer, 2001).

2.1.2. Angiogenesis and placental development

The placenta is the organ through which respiratory gases, nutrients and wastes are exchanged between the maternal and fetal systems. Thus, the fetal growth and development is dependent of the maternal capacity to provide all the metabolic demands required for the fetuses. The efficiency of this process is influenced by the placental blood flow rates, which are dependent on placental vascularization and vasodilatation (Reynolds et al., 1992; Ford, 1995; Reynolds and

Redmer, 2001). Placental angiogenesis is regulated by vascular endothelial growth factor, fibroblast growth factor and the angiopoietin protein families, and also their respective receptors (Reynolds and Redmer, 2001). This process begins with the capillary proliferation and culminates in the formation of a new microcirculatory bed, composed of arterioles, capillaries and venules, and angiogenic factors interact with the local vasodilator nitric oxide to coordinate placental angiogenesis and blood flow (Reynolds and Redmer, 2001).

One of the factors that influence the fetal growth and development is the utero-placental blood flow. The placental circulation has a critical role in the transplacental exchange rates and in the delivery of nutrients for fetal growth. Endogenous relaxant nitric oxide is involved in the vasodilatation of the maternal systemic circulation, regulation of uterine and fetus-placental blood flow (Reynolds and Redmer, 2001). Pere and Etienne (2000) demonstrated that uterine blood flow increased with litter size, but the uterine blood flow per fetus decreased when the litter size increased. It suggested that uterine blood flow adapts to litter size, but within limits. Also, Reynolds et al. (1985) reported that uterine blood flow was positively correlated with the number of fetuses. However, the blood flow per fetus was negatively correlated with the number of fetuses in the uterine horn.

2.2. Improve piglet uniformity

2.2.1. Insulin and IGF-1 mediated nutrition

The effect of preovulatory nutrition on follicles and oocytes is often associated with the effect of nutrition on circulating metabolic hormone concentrations, such as growth hormone and leptin concentrations, but especially insulin and insulin like growth factor -1 (IGF-1) concentrations. Blood concentrations of insulin and IGF-1 are considered to be important for mediating the effect of nutrition on the ovaries. Increasing plasma insulin during the late luteal phase or the early follicular phase, increased ovulation rate irrespective of changes in plasma LH, may be related to the ability of insulin to decrease atresia in small

and medium sized follicles (Prunier and Quesnel, 2000b). Prunier and Quesnel (2000a) demonstrated that insulin had a positive influence on the nutrient supply, growth and development of follicular cells.

Increased insulin and IGF-1 before or at weaning are positively associated with LH pulsatility after weaning. Higher levels of LH stimulate the development receptors and not LH receptors, and then small follicles will be less stimulated and become atretic (Van Den Brand et al., 2009). For this reason, the follicle population becomes more uniform, and a more uniform follicle population seems to result in more uniform oocyte quality (Van Den Brand et al., 2009). For instance, Dextrose supplementation diet during the WEI resulted in higher piglet birth weight uniformity in sows (Van Den Brand et al., 2006). In addition, sows supplemented dextrose plus lactose during a prolonged period before and during follicular phase showed numerically lower within-litter birth weight variation (Van Den Brand et al., 2009). Thse findings are possibly related with the results that dextrose and lactose supplementation possibly increases plasma levels of insulin and IGF-1 (Van Den Brand et al., 2009)

2.2.2. Dietary energy and protein effect

Noblet et al (1985) showed a direct relationship between maternal nutrition and fetal weight, where a decrease in 28% the feed intake after day 80 of gestation resulted in a reduction in fetal growth in gilts. On the other side, some researches insisted that the dams have the ability to mobilize maternal nutrient reserves to support placental and fetal development when these animals are subjected to a restricted energy diet (Anderson, 1975; Pluske et al., 1995; Bee, 2004). So, several studies also reported no effects of low energy supply in the fetal growth (Liao and Veum, 1994; Jindal et al., 1996). Bee (2004) found that different energy intake levels (6.6 amd 10.7 MJ DE/kg) during early gestation in multiparous sows did not affect the average birth weight, weaning weight, number of piglets born alive or number of piglets at weaning, when considering all progenies. Lawlor

et al. (2007) found no influence in birth weight, weaning weight and uniformity of piglet weight when five different dietary digestible energy levels were provided during different gestation phases. Kongsted (2005) suggested that pregnancy rate and litter size can be influenced by energy intake.

Proteins have different funcions and biological activities include structural roles, nutrition, enzymatic catalyses, molecular transport, organism defense and other functions (Lehninger et al., 1993). Therefore, dietary protein intakes during gestation play a critical role in the maternal and fetal growth and development. Wu et al. (1998) demonstrated that dietary protein reduction decreased the activities of nitric oxide synthase, citrulline synthesis from arginine and ornithine decarboxylase activity in placenta and endometrium. It may decrease the maternal ability to transfer nutrients and oxygen to the fetus, resulting in negative impacts on within-litter birth weight uniformity. In agreement with these findings, other studies reported negative effects on intrauterine growth retardation, decreased piglet vitality and birth weight of sow progeny by restricted-protein diets during gestation (Atinmo et al., 1974; Pond et al., 1992; Schoknecht et al., 1994; Wu et al., 2006). Similarly, Redmer et al. (2004), evaluating the effect of nutrient intake during pregnancy, demonstrated that maternal nutrition can have a profound effect on fetal growth and development by changing placental growth and vascular development.

2.2.3. Increased feed intake during gestation

Several studies have been conducted to evaluate the effects of an increased amount of feed during gestation. Mahan (1998) observed that the sows that received a greater quantity of feed, equivalent to 130 g additional feed per day, farrowed more total and live piglet compared with the control group that was given a feed intake similar to the NRC recommendations (NRC, 1988). Similarly, Cromwell et al. 1(1989) concluded that additional feed in late gestation (+ 1.36 kg of feed/day from day 90 of gestation to farrowing) improves the reproductive performance. The results showed a greater total litter weight at birth, an increased birth weight in sows fed extra amounts of feed when compared with a control group.

Nevertheless, several studies have shown no effect of feeding levels during gestation on the sows' reproductive performance. Dwyer et al. (1994) reported that litter size, pig mortality and birth weights were not significantly affected by different quantities of feed during specific periods of gestation (2.5 vs 5.0 kg/day). However, they concluded that the increased maternal nutrition during early to middle gestation can lead to an increased production of secondary myofibers in the fetus in agreement with results of Gatford et al. (2003) and Bee (2004).

By evaluating different nutritional strategies during gestation, Nissen et al. (2003) found no beneficial effects on average piglet birth weight, litter size at birth and at weaning, when sows ere fed '*ad libitum*' during different gestation phases (25-50 and 25-70 days of gestation) compared with a control group (restricted diet), demonstrating no beneficial effect in fetal growth and development. In agreement, no differences were observed on within-litter birth and weaning weight variation, total number born and piglets born alive, when sows received 50% more of the same feed compared with the control group (Cerisuelo et al., 2008). Rehfeldt and Kuhn (2006) reported no effect of maternal overnutrition on birth weight of their progeny. Similarly, other studies did not find effect of increased feed intake in sow reproductive performance (Miller et al., 2000; Pond et al., 1981; Sterling and Cline, 1986). In contrast, Lawlor et al. (2007), evaluating different diets during specific gestation phases, reported that an expressive increase in the number of piglets born dead per litter, when sows were overfed from 50 to 80 days of gestation. Also, Musser et al. (2006), evaluating the effects of maternal feed intake during gestation on the fetal muscle development, observed that sows tended to have lower number of pigs born alive when compared with sows fed with the control diet (3.63 vs 1.81 kg/day of gestation). Considered these results, the lower reproductive performance might be that the maternal nutritional status influences the circulating progesterone, which can modify endometrial development and secretory activity, and affects the composition of allantoic fluids that provide nutrients to the fetus (Ashworth, 1991). A detrimental effect of high feed intake on embryo survival was demonstrated as an inverse relationship between nutrition levels and circulating progesterone

concentrations in pigs (Dyck et al., 1980; Prime et al., 1988).

2.2.4. Amino acids

There are some evidences that the arginine family of amino acids (AFAAs; arginine, glutamine, glutamate, proline, aspartate, asparagine, ornithine and citrulline, of which the last two are not substrates for protein synthesis) have an important role in placental vascularization and development, especially during the first half of pregnancy (Wu et al., 2007). The AFAAs have an important role in placental angiogenesis and placental, embryonic and fetal development. AFAAs are interconvertible via complex interorgan metabolism in pigs (Wu et al., 2007). Wu et al. (1996b) have shown an unusual abundance of arginine and ornithine in porcine allantoic fluid from 35 to 40 days of pregnancy as the period of rapid placental growth). Glutamine was the most abundant amino acid in the amniotic fluid during the early fetal stage of pregnancy (days 30 to 45) and was also abundant in the allantoic fluid. For these reason, they concluded that the allantoic fluid may serve as a nutrient-rich reservoir for arginine, ornithine and glutamine, at least during this stage of pregnancy. In addition, being the building blocks of proteins and polypeptides, functional amino acids, such as arginine, cysteine, glutamine, leucine, proline and tryptophan, are important regulators of key metabolic pathways that are crucial for maintenance, growth, reproduction and immunity (Wu, 2009). According to Wu et al. (2010), nitric oxide, polyamines, arginine and other functional amino acids (glutaimine, leucine and proline) may regulate embryonic and fetal muscle growth and development via cell signaling through the mammalian target of rapamycin. Also, they concluded that arginine supplementation increases litter size and litter birth weight, and its combination with glutamine, leucine and proline can reduce variation in birth weights of piglets.

2.3. Effects of arginine supplement

2.3.1. Arginine metabolism

Arginine is one of the most versatile amino acids in animal cells, serving

as a precursor for the synthesis of proteins, nitric oxide and polyamines (Figure 4, Luiking et al., 2004). Arginine is particularly abundant in porcine allantoic fluid (4-5 mmol/L) at d 40 of gestation. Also, arginine and ornithine in porcine allantoic fluid accounted for 50% of the total free amino acid nitrogen in allantoic fluid (Wu et al., 1996).

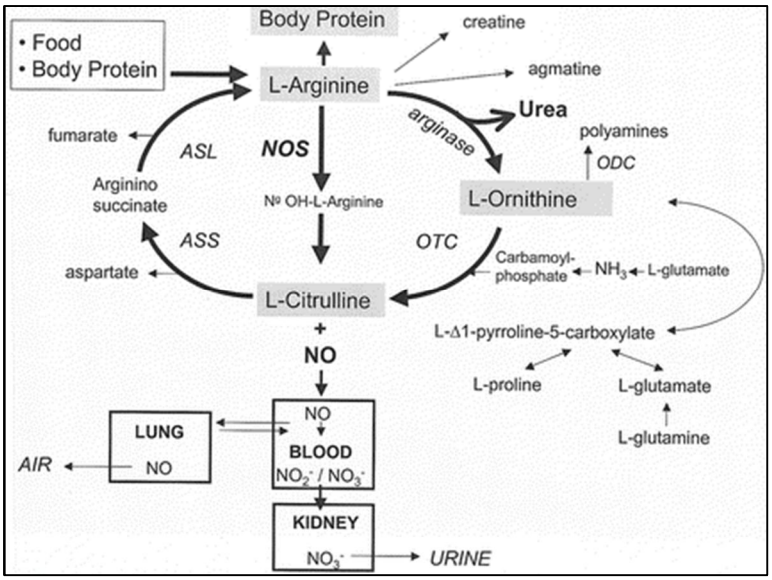

Figure 4. Metabolic pathways of arginine (Luking et al., 2004)

Nitric oxide is an endogenous relaxant factor. It is produced from arginine via nitric oxide synthase and is involved in the vasodilation of the maternal systemic circulation, regulation of uterine and feto-placental blood flow (Wu and Morris, 1988; Wu et al., 2006).

Evidences suggest an interaction between angiogenic factors and nitric oxide to coordinate placental angiogenesis and blood flow, which are crucial events for the placental vascularization and, consequently, fetal growth (Reynolds and Redmer, 2001). Sladek et al. (1997) demonstrated an increased uterine blood flow when stimulators of endogenous nitric oxide were infused into the uterine circulation in sheep and a reduced plasma volume and newborn weights caused by chronic administration of nitric oxide inhibitors to pregnant rats. However, low

nitric oxide from embryonic mesenchymal precursor induced that adipocytes increased and myocytes decreased. Furthermore, nitric oxide (NO) and polyamines concentrations were decreased, and then, secondary fibers (d50-90 in pigs) and numbers of muscle fibers at birth were reduced. Finally, low concentration of nitric oxide during fetus develop phase resulted in poor postnatal muscle growth (Figure 5, Wu et al., 2010)

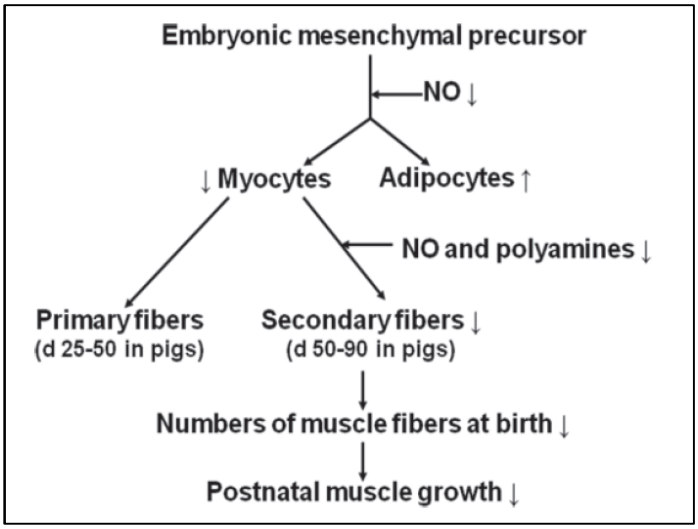

Figure 5. Nitric oxide and polyamines act to fetus development (Wu et al., 2010)

The unusual abundance of the arginine-family amino acids in fetal fluids is associated with the highest rates of NO and polyamine syntheses in ovine placentae in the first half of pregnancy (Kwon et al., 2003; Kwon et al., 2004).

Polyaminses are related with protein synthesis regulation and cell function and differentiation. The inhibition of placental polyamine synthesis is related to decreased placental size and lower fetal growth (Wu et al., 2004). Polyamines are organic compounds that are derived from ornithine by the arginase pathway, resulting in the synthesis of putrescine, spermidine and spermine (Lehninger et al., 1993; Wang et al., 2003). However, the polyamine synthesis in the porcine placenta is dependent on the conversion of arginine into ornithine and proline via the arginase pathway in other maternal tissues, as arginase activity is not detected in the

maternal placenta (Figure 6, Wu et al., 2010).

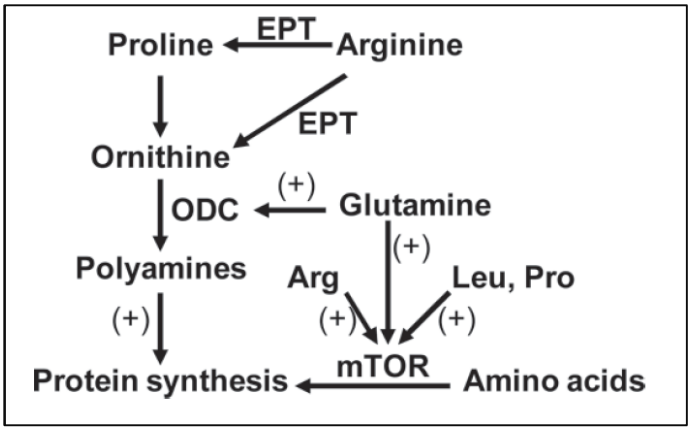

Figure 6. Role of functional amino acid in regulating synthesis in porcine placentae (Wu et al., 2010)

2.3.2. Effects of arginine on piglet uniformity

For the higher prolificacy, higher nutritional requirements for supporting the metabolic needs of both the sow and their fetuses are required (Kim et al., 2005). Unbalanced maternal nutrition with respect to increased requirements to support the increased number of fetuses in the uterus may be associated with fetal growth retardation, and, as a results, negative effects on the piglet performance, such as decreased piglet uniformity and decreased piglet birth weight. Kim et al. (2009) insisted greater body weight variations among fetuses mainly after 45 days of gestation, which could be associated with the limitation of sows to provide sufficient nutrient support through blood for maximal growth of all fetuses (Wu et al., 2006).

The relevance of arginine in fetal growth and development have been recognized, because of the participation of nitric oxide and polyamines in critical events during gestation, such as angiogenensis, placental vascularization and embryogenesis (Flynn et al., 2002; Wu et al., 2006).

Mateo et al. (2007) reported an increased number of piglets born alive

(22%) and live litter birth weights (24%) without any reduction in the average birth weight of piglets in gilts supplemented with 1% of L-arginine·HCl from days 30 to 114 of gestation compared with a control group that received a control diet (1.7% L-arginine-isonitrogenous diet). In addition, the piglet mortality decreased (65%), the plasma concentration of arginine and its metabolites (ornithine and proline) increased and the birth weight variation of all piglets born alive increased but was not significant. According to the Mateo et al. (2007), the arginine supplementation may have increased the nitric oxide and polyamine synthesis, and thus the increasing placental angiogenesis and growth, enhance the utero placental blood flow, the nutrient transfer from mother to fetus and, consequently, fetal survival and development. For the effects of arginine supplementation, 1% arginine treatment had greater the number of total piglets born alive per litter and litter birth weight of all piglets born alive, but less the number of piglets born dead per litter (Mateo et al., 2007). In blood profiles, the concentration of urea at gestation 90 day and 110d was lower in arginine 1% treatment, and plasma arginine, prolife, ornithine concentration were greater in arginine 1% treatment. In other study of Che et al. (2013), supplementation of additional arginine during gestation from day 30 to 114 had greater number of total pigs born alive and less number of total pigs born dead rather than other treatments (control, arginine supplemented from day 30 to 90). Also, total litter weight and live litter weight were greater in sows supplemented arginine during whole gestation period (d30-114). With supplementation of additional arginine during gestation period, the concentration of urea was increased significantly at day 90 and 110 of gestation. In addition, a higher number of live piglets were observed in sows supplemented with 25g L-arginine per day from 14 to 28 days of gestation, without any effect in the average birth weight (Ramaekers et al., 2006).

3. Nutrition for longevity

3.1. Gilt

Gilt development nutritional trials have had a mixture of positive and negative impacts on sow longevity. Kirkwood (1990) reported that a relationship between body composition at mating and longevity was merely reflecting the consequences of subjecting improved pigs to conventional management and modern gilts are subjected to good management that minimizes weight and condition loss during lactation. Also, he reported that there is no association between live weight or backfat depth at first successful breeding and subsequent reproductive performance. Long et al. (1998) reported that sows fed a high energy, high protein diet *ad libitum* from 120 days of age until 180 days of age had significantly poorer stayability through four parities than gilts fed a high energy, low protein diet *ad libitum* or a restricted-fed high protein diet. In addition, it has been demonstrated that high energy intake during rearing can lead to reduced mammary gland growth of gilts (Han et al., 2000). Boyd et al. (2002) provide numerous nutritional and management recommendations to maximize lifetime sow productivity. This report describes nutritional methods that can support different rates of growth during pregnancy and recommended feed intakes based on differing body condition scores such that body reserves can be replenished. Also, they demonstrated that lactation feeding strategies including predicted energy and lysine needs for first litter sows and offered feed intake targets based on the litter size the sow is nusing and stage of lactation.

Some minimum level of backfat is needed on replacement gilts so that they maximize lifetime number of piglets born alive. Challinor et al. (1996) reported that gilts that had 18 to 22 mm of backfat at an average weight of 150 kg averaged 7.2 more piglets over five parities than did gilts with 14 to 16 mm backfat. Similarly, Brisbane and Chenais (1996) reported that the difference in survival of sows until at least the fourth parity was 10% higher in gilts from the highest backfat category (>18 mm) when compared to gilts from the leanest backfat category (<10 mm) when backfat probe was adjusted to 100kg. Tummaruk et al. (2001) found that

gilts with higher backfat adjusted to a 100kg constant weight had more live born piglets in their second parity when compared to gilts with low bakcfat. On the other hands, Young et al. (1991) reported that backfat thickness of gilts that averaged 106.8 kg at first oestrus did not account for a substantial amount of variation in the number of piglets born alive in the first parity or total number of piglets born alive per initial sow started on the trial. Similarly, Rozeboom et al. (1996) insisted that body composition at first breeding when average gilt weight was 106.5kg did not affect litter size at pairty one, two, or three, ore overall. In addition, they showed that age at first mating was not associated with the number of piglets born alive in parity one, two, three, or overall. Also, Young et al. (1991) reported that age had no appreciable effect on number of piglets born alive when evaluated on individual sows or on a per initial sow basis. Newton and Mahan (1993) found no relationship between breeding weights of 120, 135, or 150 kg and the ability of gilts to reproduce over three parities when gilts were fed to alter daily gain from 80 kg to breeding.

It is well known that if gilts reach puberty at an earlier age, sow longevity and life reproductive performance will be improved. Chapman et al. (1978) found that selecting gilts that reached puberty and conceived earlier improved reproductive performance. These results appear to be supported by Young and King (1981) who found small differences when gilts were mated at puberty rather than mated at the second or third oestrus and Holder et al. (1995), who reported a higher percentage of gilts that produced five parities in gilts that reached puberty earlier. However, Brooks and Smith (1980) reported that no difference in the number of sows completing five parities, nor the number or weight of pigs born in any of the first five parities in a study where puberty was induced at 160 or 200 days of age. There is a traditional perception among pork producers that increasing age of gilts at first successful breeding will improve sow longevity. Pomeroy (1960) reported that average number of litters and lifetime total pigs born per sow was highest among sows farrowing their first litter at 14 to 16 months of age when compared to gilts at 12 to 14 months of age. These results are not supported by MacPherson et al. (1977),

who found no difference in total number of pigs born at the end of three parities from gilts bred on either their first, second, or third oesturs. Babot et al. (2003) reported that the greatest lifetime productivity was attained in gilts in which the first mating occurred from 221 to 240 days of age compared to gilts that were mated less than 221 or greater than 240 days of age. Kirkwood et al. (2000) showed no difference in the number of pigs born alive over four parities in gilts that were bred at natural oestrus when compared to gilts that were stimulated by exogenous hormone administration to reach oestrus.

3.2. Nutrition

3.2.1. Gestating sow

Over three reproductive cycles, long term effects of four levels of energy levels (from 12.5 to 31.4 MJ ME/d) during gestation with ad libitum feeding during lactation, the number of sows completing three reproductive cycles tended to be lower for both the lowest and the highest level of energy supply (Frobish et al., 1973). In that study, lower energy intake was dominant reason of conceive failure and leg abnormalities were the major factor causing removal of sows receiving the highest energy intake. Walker et al. (1983), Whittemore et al. (1988) and Simmins et al. (1992) found that culling rate was higher for a low energy supply (19.1, 22.6 and 24.3 MJ DE/d), but lameness was not increased with a high energy supply (31.8, 30.1 and 30.7 MJ DE/d). In a 4 years study, Castaing et al. (1983) compared the long term effects of three levels of energy allowance during gestation (29.9, 33.1, 36.6 MJ DE/d). The proportion of sows completing 4 reproductive cycles was lower with the higher energy level. Culling for reproductive failure tended to be lower for the medium level, whereas significantly more sows fed the higher energy supply were discarded because of locomotion problems. In other result of Hoppe et al. (1990), who compared over four parities, 25.1 and 37.6 MJ ME/d in gestation with *ad libitum* feeding during lactation. In that study, culling for lameness was only 5% and was not related to the diet. Culling rate for other reasons was also not affected by energy levels. The effect of energy level during pregnancy on reproduction

failure after weaning is not clear. It seems that in some conditions, both very high and very low feeding levels can increase reproduction problems, especially after the first and the second weaning. For intermediate feeding levels, return to oestrus and conception rate are generally not affected (Dourmad et al., 1994). Young et al. (1990) observed that significantly fewer sows receiving the lowest energy level during gestation (22.2 MJ ME/d) completed three parities and many of the sows which were discarded had 10 mm or less P2 backfat thickness when removed. In most studies, energy levels lower than 25 MJ ME/d during gestation were then associated with delayed return to oestrus after weaning and reduced longevity, suggesting that the increased lactation feed intake was not sufficient to compensate for the low pregnancy supply (Dourmad et al., 1994). Furthermore, Dourmad et al. (1994) suggested that Extreme levels must be avoided and optimal level in pregnancy is closely related to housing conditions and, reproductive performance and energy feeding level during lactation.

Lavorel et al. (1981) compared the long term effect of 276 or 330 g protein/d during gestation. Culling rate after the first weaning (35%) and proportion of sows weaning four litters were the same for the two treatments. It can be suggested that increasing protein supply during pregnancy is associated with a higher maternal net gain (Dourmad, 1987; Everts and Dekker, 1993) and heavier sows at farrowing, which could lead to higher occurrence of locomotion problems. Mahan (1979) reported that more sows were not observed in oestrus within 30 days after weaning in the group receiving 9% protein during pregnancy, but increasing the protein level above 9% did not improve the return to oestrus after weaning. Considering previous studies, in practical conditions, poor performance are much more likely related to low energy supply during pregnancy rather than to low levels of protein and amino acids.

3.2.2. Lactating sow

Sows, especially primiparous sow, restricted in feed during lactation and losing a large amount of body weight and backfat thickness have a delayed return to

oestrus. Delayed return to oestrus is associated with a higher proportion of sows not mated within a reasonable time after weaning and the culling rate due to anoestrus will then depend on the maximum acceptable weaning to oestrus interval (Baidoo, 1989). In the study of Kirkwood et al. (1987), sows fed 3kg/d compared to 6kg/d had a higher incidence of post-weaning anoestrus, longer interval between weaning and mating and a lower pregnancy rate.

Reese et al. (1982) noticed that the mean ME intake during lactation was below 50MJ/d delayed post-weaning oesturs occurred and the number of sows not in oestrus before 21 days increased. Nelssen et al. (1985) reported that the onset of post-weaning oestrus tended to be delayed in first litter sows receiving 42 MJ ME/d, compared to those receiving 50.2 or 58.5 MJ ME/d. Weaning to oestrus interval was no affected when the energy supply during lactation decreased from 63 to 45 MJ DE/d (King and Dunkin, 1986), however it was increased with 27 MJ DE/d (King and Williams, 1984). In modern hybrid genotypes, sows are often thinner and milk production is generally much higher. Different with previous studies, the minimal energy supply for optimal return into oesturs should be higher.

Svajgr et al. (1974) demonstrated that sows that were weaned on day 2, 13, 24 or 35 of lactation had mean pregnancy rates in the next parity of 68, 92, 100, and 100%, respectively. Average time between weaning and oestrus was 10.1, 8.2, 7.1, and 6.8 for the four groups, respectively. It should be clear from these data that weaning at early ages could adversely impact sow longevity through increased culling due to reproductive failure, the number one reason sows are culled from commercial pig breeding herds. Koketsu et al. (1995) showed sows lactating 7 days or less had significantly higher percentages that were irregular in returning to oestrus. The percantages of sows that irregularly returned to oestrus tended to be higher after 1-7 day lactation lengths compared to 14 to 16 day lactation periods. Thus, shortened lactation lengths have a negative impact on sow longevity.

3.3. Body condition

The thin sow problem or degree of body composition adversely contributes to poor reproductive performance and sow longevity (King, 1987; Elsley et al., 1968). MacLean (1968) reported that the thin sow problem as starting with unusually high weight loss in lactation, followed by failure to gain enough weight prior to farrowing the next litter. Furthermore, the weight loss becomes progressive, leading to reproductive failure, emaciation, and even death. Also, MacLean (1968) insisted that herds with a high percentage of thin sows tended to have extended lactation periods (over 6 weeks) and poor lactation feed intake (3-5 kg/d loss). Whittemore et al. (1980) demonstrated that fat and weight losses far exceeded their gain from mating after parity 1 to the next farrowing. They found that low backfat at weaning was indicative of an eventual “thin sow problem”, reproductive failure, and early culled from the breeding herd. These results were supported by Reese et al. (1982) and Tantasuparuk et al. (2001), who found sows that had restricted energy intake or were extremely thin at weaning had prolonged intervals from weaning to oestrus.

Williams (1989) showed that a low feeding level during lactation (2.0 kg/d) was deleterious when body reserves at farrowing were either high or low, whereas the negative effect of low body energy reserves at the beginning of lactation disappeared when feeding level during lactation was high. Reese et al. (1984) reported that catabolism of body fat during lactation was more deleterious to a rapid onset of oestrus after weaning than catabolism of muscle tissue. However, from the regression equations calculated by King (1987) to predict weaning to oestrus interval in primiparous sows and those from Yang et al. (1989), it seems that both loss of body protein and fat during lactation, but also absolute levels at weaning, may affect return to oestus after weaning.

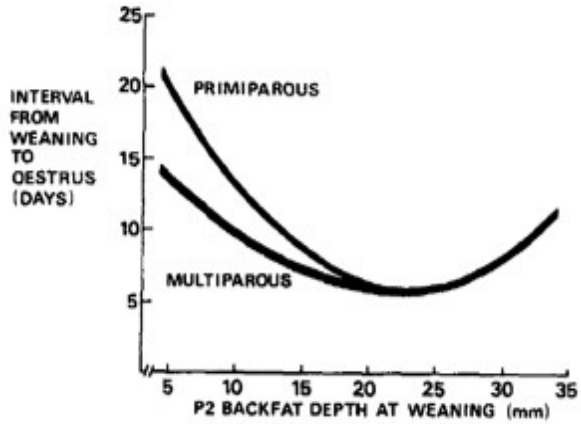

Figure 7. The relationship between interval from weaning to oestrus and the depth of backfat on sows at the P2 site (Whittemore and Morgan, 1990).

A general relationship between backfat depth at weaning and interval from weaning to oestrus was proposed by Whittemore and Morgan (1990) (Figure 7). The relationship between nutrition and return into oestrus is similar in the different parities, even though multiparous sows are less sensitive than primiparous sows.

Consequently, improving body condition at weaning is likely to have potential benefits that include decreased sow mortality, improved replacement rates, lower weaning to oestrus intervals, improved animal welfare, and better reproductive performance in the next litter (Stalder et al., 2004).

3.4. Effects of lysine supplement

3.4.1. Lysine metabolism

Among essential amino acids, lysine is the first limiting amino acid in swine nutrition management because it is the most deficient amino acid in nearly all typical swine diets based on cereal grains (Lewis, 2001; NRC, 2012). Lysine is a cationic or basic AA with a long side chain, and its metabolism begins with the intestinal uptake from digesta mainly via a Na^+-independent transport system. After absorption, the free lysine in excess of the needs for syntheses of proteins and other substances will be catabolized in a cell- and tissue-specific manner (Gatrell et al.

2013). The catabolism of lysine is very unique relative to the catabolism of other AAs in that it proceeds mainly through two distinct metabolic routes, the saccharopine pathway and the pipecolate pathway. These two pathways differ in that the saccharopine pathway is predominantly mitochondrial, whereas the pipecolate pathway is predominantly peroxisomal and cytosolic (Hallen et al. 2013).

The primary pathway of lysine catabolism is thought to be the saccharopine pathway in liver (Papes et al., 1999; Gatrell et al., 2013). In this pathway, lysine first combines with α-ketoglutarate (α-KG) to form an adduct, saccharopine, by the catalysis of lysineketoglutarate reductase (LKR). Then saccharopine is converted to α-aminoadipic-6-semialdehyde and glutamate by saccharopine dehydrogenase (SDH), which is a part of a single polypeptide, bifunctional aminoadipate δ-semialdehyde synthase (AASS) as LKR is (Gatrell et al., 2013). The α-aminoadipate-6-semialdehyde is subsequently converted into acetyl-CoA via a few more steps (Wu 2013a). This pathway is unusual in the way that the ε-amino group is transferred to α-KG and then into the general nitrogen pool. The further oxidation of acetyl-CoA produces CO_2 and energy via TCA cycle.

Small portion of lysine are catabolized in the brain through pipecolate pathway (Chang, 1976). In this pathway, the α-amino group rather than ε-amino group of lysine is removed during the conversion of lysine to pipecolate or pipecolic acid in cellular peroxisomes. The intermediates of this pathway include α-keto-ε-aminocaproic acid, Δ1-piperideine-2-carboxylic acid, and Δ1-piperideine-6-carboxylate (Broquist 1991; Wu 2013a).

While the amino groups of lysine are converted to ammonia, which is further converted to urea or uric acid through the urea cycle, the end product of the carbon skeleton catabolism is acetyl-CoA, which is further catabolized for energy via TCA cycle or converted to ketone bodies or fatty acids (Figure 8; Lehninger, 2008).

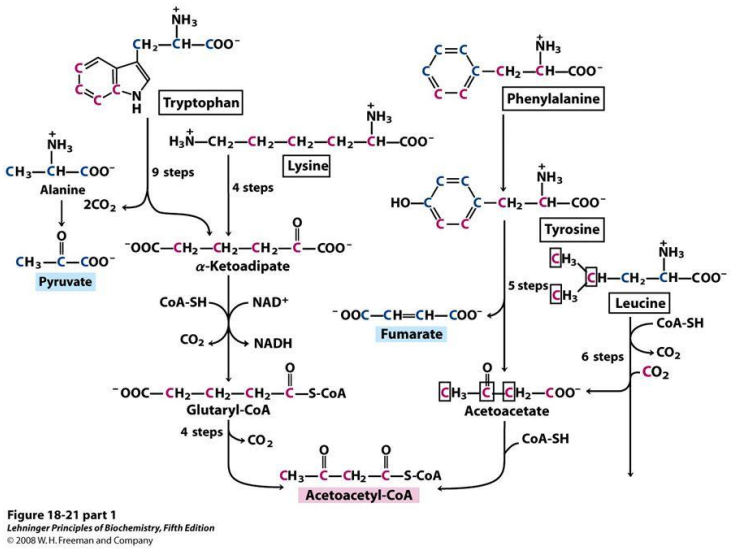

Figure 8. Catabolic pathway for lysine (Lehninger, 2008)

The arginine-nitric oxide (NO) pathway can be modulated by elevated levels of lysine in endothelial cells because lysine is a natural inhibitor of arginine transport through shared y+ system (Liaudet et al. 1997). With lipopolysaccharide-treated neonatal pigs, Carter et al. (2004) reported that the NO synthesis in isolated lung was significantly inhibited by lysine perfusion. Due to the lysine-arginine antagonism, administration of these two AAs together may have some antagonism elimination effect. It was reported that oral administration of a combination of lysine (1.2 g) and arginine (1.2 g) to young and healthy male human volunteers provoked a release of GH and insulin to the blood (Isidori et al. 1981). However, oral administration of arginine (3 g) and lysine (3 g) in old men did not increase serum GH or IGF-1 concentration (Corpas et al. 1993).

3.4.2. Effects of lysine on sow reproduction

Huang et al. (2013) evaluated the effect of lysine and protein intake over two consecutive lactations on lactation and subsequent reproductive performance in multiparous sows. The 1.10% lysine diets increased the first and second lactating sow lysine intake than the 0.95% lysine diets. Compared with the 0.95% lysine diets,

the 1.10% lysine diets decreased the first lactating sow bod weight loss, and the culling rate of sows failing to display estrus within 21 d after weaning. In contrast, the 1.10% lysine diets increased the second lactation sow body weight loss and the culling rate of sow failing to display estrus within 21 d after weaning than 0.95% lysine diets. Also, average weight at weaning, litter weight at weaning, little weight gain, and litter growth rate were not affected by treatments.

Cooper et al. (2001) reported that gestation BW gain from d 0 to 110 was affected by parity (1, 2, 3+) but not by gestation lysine level (0.44% or 0.55% lysine). Also, total piglets born and total litter weight born alive were affected by parity and gestation BW gain. Thus total lysine intakes greater than 10.6 g/d in gestation did not improve sow productivity. Heo et al. (2007) conducted the experiment about dietary energy and lysine intake during late gestation and lactation. Three energy levels (3,265, 3,330, 3,400 ME kcal/kg) and two lysine levels (0.62%, 0.82% gestation, 1.05%, 1.33% lactation) were used. Gilts with high lysine intake had more weight and backfat thickness gain during gestation and lactation. In addition, high lysine intake resulted in higher litter birth weight, weaning weight, growth rate, and shortened wean-to-estrus interval. Gilts with high lysine intake had higher insulin and lower creatinine levels during postfarrowing and weaning, while triglyceride concentration at weaning increased with increasing of energy intake. They concluded that higher lysine intake than recommended by NRC(1998) could improve performance during late gestation and lactation in primiparous sows.

Zhang et al. (2011) conducted experiment to determine the effect of lysine intake (0.46, 0.56, 0.65 or 0.74% lysine) from mid-gestation until farrowing, increasing dietary lysine concentration improved sow body condition at farrowing and increased litter weights. Also dietary lysine level had a significant effect on the dry matter and protein content of colostrum. Although increased lysine tended to decrease BUN, increased lysine intake increased serum insulin concentration and serum prolactin content. Knabe et al. (1996) insisted that dietary lysine (0.60, 0.75 and 0.90%) did not affect body weight or backfat loss during lactation, sow ADFI, interval from weaning to estrus, or litter size at birth or at 21 d of age. Mean pig

weights at birth and at 21 d of age increased quadratically to increasing lysine, with improvements found at all stations from increasing lysine from 0.60 to 0.75%.

Santos et al. (2006) demonstrated that the reproductive performance in the subsequent farrowing was not affected by the lysine levels (0.75, 0.90, 1.05 and 1.20%) and ME (3,250 and 3,400 kcal ME/kg) hence, neither the total born nor the born alive differed among the treatments. Xue et al. (2012) reported that feeding lactating sows a diet with an optimal ME concentration improved body condition and voluntary feed intake of sows and increased litter growth. Litter growth rate was maximized when ME was 3.25 and 3.24 Mcalkg for parity 3+ sows and the overall cohort of sows, respectively. This result can be expressed as 2.65 and 2.66 g/Mcal of SID-Lys:ME ratio. Parity had significant effects on body weight loss, voluntary feed intake, and weaning-to-estrus interval of sows. Based on the results obtained in the present studies, the optimum SID-Lys:ME ratio appears to be 3.05 g/Mcal for lactating sows fed at the ME level of 3.25 Mcal/kg in the diets.

Coma et al. (1996) indicated that adult sows nursing 10-pig litters with an average growth of 2.22 kg/d required 55.3 g/d of dietary total lysine to minimized plasma urea nitrogen concentrations and, therefore, presumably to minimized body protein mobilization. Touchette et al. (1998) suggested that primiparous sows are able to mobilize sufficient body reserves to maintain a high level of milk production at low levels of lysine intake (27, 34 g/d) during a 17-d lactation. Higher levels (45 to 48 g/d) of digestible lysine are required to minimize body protein loss.

Increasing lysine intake in primiparous lactating sows beyond normal increased the size of the second litter dramatically in one study (Tritton et al., 1996), but it decreased the size of the second litter in two other studies (Touchette et al., 1998; Yang et al., 1998). In the result of Yang et al. (2000), low lysine (0.4% lysine) intake in primiparous lactating sows impaired follicular development and reduced the ability of follicles to support oocyte maturation. However, high (1.6% lysine) compared with medium lysine (1.0% lysine) intake had no further positive effects on ovarian function.

4. Literature cited

Almeida, F. R., Kirkwood, R. N., Aherne, F. X., & Foxcroft, G. R. 2000. Consequences of different patterns of feed intake during the estrous cycle in gilts on subsequent fertility. Journal of Animal Science, 78(6), 1556-1563.

Anderson, L. L. 1975. Pigs. In E. S. E. Hafez (Ed.) Reproduction in Farm Animals (3rd Ed.). Lea and Febiger, Philadelphia.

Ashworth, C. J. 1991. Effect of pre-mating nutritional status and post-mating progesterone supplementation on embryo survival and conceptus growth in gilts. Animal Reproduction Science, 26(3-4), 311-321.

Atinmo, T., Pond, W. G., & Barnes, R. H. 1974. Effect of Maternal Energy Protein Restriction on Growth and Development of Progeny in Swine. Journal of animal science, 39(4), 703-711.

Babot, D., Chavez, E. R., & Noguera, J. L. 2003. The effect of age at the first mating and herd size on the lifetime productivity of sows. Animal Research, 52(1), 49-64.

Baidoo, S. K. 1989. Influence of nutrition on the endocrinological status of the lactation and post-weaning sow. Dissertation sschrift, University of Alberta.

Bee, G. 2004. Effect of early gestation feeding, birth weight, and gender of progeny on muscle fiber characteristics of pigs at slaughter. Journal of Animal Science, 82(3), 826-836.

Boyd, R. D., & Kensinger, R. S. 1998. Metabolic precursors for milk synthesis. The Lactating Sow. Wageningen Press, Wageningen, The Netherlands, 71-95.

Boyd, R. D., Touchette, K. J., Castro, G. C., Johnston, M. E., Lee, K. U., & Han, I. K. 2000. Recent advances in amino acid and energy nutrition of prolific sows. Asian Australasian Journal of Animal Sciences, 13(11), 1638-1652.

Boyd, R. D., Castro, G. C., & Cabrera, R. A. 2002. Nutrition and management of the sow to maximize lifetime productivity. Advances in Pork Production, 13(1), 1-12.

Brisbane, J. R., & Chenais, J. P. 1996. Relationship between backfat and sow longevity in Canadian Yorkshire and Landrace pigs. Proc. Nat. Swine Impr. Fed. Ottawa, Ontario, Canada, 12-23.

Brooks, P. H., & Smith, D. A. 1980. The effect of mating age on the reproductive performance, food utilisation and liveweight change of the female pig. Livestock

Production Science, 7(1), 67-78.

Broquist, H. P. 1991. Lysine-pipecolic acid metabolic relationships in microbes and mammals. Annual Review of Nutrition, 11(1), 435-448.

Carter, B. W., Chicoine, L. G., & Nelin, L. D. 2004. L-lysine decreases nitric oxide production and increases vascular resistance in lungs isolated from lipopolysaccharide-treated neonatal pigs. Pediatric Research, 55(6), 979-987.

Castaing, J., Coudure, R., Fekete, J., & Leuillet, M. 1983. Contribution à la définition d'un rationnement énergétique de gestation: recherche d'un niveau optimum. J. Rech. Porc. France, 15, 267-284.

Cerisuelo, A., Sala, R., Gasa, J., Chapinal, N., Carrión, D., Coma, J., & Baucells, M. D. 2008. Effects of extra feeding during mid-pregnancy on gilts productive and reproductive performance. Spanish Journal of Agricultural Research, 6(2), 219-229.

Challinor, C. M., Dams, G., Edwards, B., & Close, W. H. 1996. The effect of body condition of gilts at first mating on long-term sow productivity. Animal Science, 62, 660.

Chang, Y. F. 1976. Pipecolic acid pathway: the major lysine metabolic route in the rat brain. Biochemical and Biophysical Research Communications, 69(1), 174-180.

Chapman, J. D., Thompson, L. H., Gaskins, C. T., & Tribble, L. F. 1978. Relationship of age at first farrowing and size of first litter to subsequent reproductive performance in sows. Journal of Animal Science, 47(4), 780-787.

Che, L., Yang, P., Fang, Z., Lin, Y., & Wu, D. 2013. Effects of dietary arginine supplementation on reproductive performance and immunity of sows. Czech Journal of Animal Science, 58(4), 167-175.

Close, W. H., Close, D. J. A. W. H., & Cole, D. J. A. 2000. Nutrition of sows and boars (No. SF 396.5. C56 2000).

Coma, J., Zimmerman, D. R., & Carrion, D. 1996. Lysine requirement of the lactating sow determined by using plasma urea nitrogen as a rapid response criterion. Journal of Animal Science, 74(5), 1056-1062.

Cooper, D. R., Patience, J. F., Zijlstra, R. T., & Rademacher, M. 2001. Effect of energy and lysine intake in gestation on sow performance. Journal of Animal Science, 79(9), 2367-2377.

Corpas, E., Blackman, M. R., Roberson, R., Scholfield, D., & Harman, S. M. 1993. Oral arginine-lysine does not increase growth hormone or insulin-like growth factor-I in old

men. Journal of Gerontology, 48(4), M128-M128.

Cromwell, G. L., Hall, D. D., Clawson, A. J., Combs, G. E., Knabe, D. A., Maxwell, C. V., ... & Prince, T. J. 1989. Effects of additional feed during late gestation on reproductive performance of sows: a cooperative study. Journal of Animal Science, 67(1), 3-14.

Dourmad, J. Y. 1987. Composition du gain de poids de la truie gestante: prévision en fonction des apports énergétiques et protéiques. Journées Rech. Porcine en France, 19, 203-214.

Dourmad, J. Y., Etienne, M., Prunier, A., & Noblet, J. 1994. The effect of energy and protein intake of sows on their longevity: a review. Livestock Production Science, 40(2), 87-97.

Dwyer, C. M., Stickland, N. C., & Fletcher, J. M. 1994. The influence of maternal nutrition on muscle fiber number development in the porcine fetus and on subsequent postnatal growth. Journal of Animal Science, 72(4), 911-917.

Dyck, G. W., Palmer, W. M., & Simaraks, S. 1980. Progesterone and luteinizing hormone concentration in serum of pregnant gilts on different levels of feed consumption. Canadian Journal of Animal Science, 60(4), 877-884.

Elliott, R. F., Vander Noot, G. W., Gilbreath, R. L., & Fisher, H. 1971. Effect of dietary protein level on composition changes in sow colostrum and milk. Journal of Animal Science, 32(6), 1128-1137.

Elsley, F. W. H., MacPherson, R. M., & McDonald, I. 1968. The influence of intake of dietary energy in pregnancy and lactation upon sow productivity. The Journal of Agricultural Science, 71(2), 215-222.

Everts, H., & Dekker, R. A. 1993. The effect of nitrogen supply during pregnancy on the nitrogen excretion by breeding sows. EAAP Publication (Netherlands).

Flynn, N. E., Meininger, C. J., Haynes, T. E., & Wu, G. 2002. The metabolic basis of arginine nutrition and pharmacotherapy. Biomedicine & Pharmacotherapy, 56(9), 427-438.

Ford, S. P. 1995. Control of blood flow to the gravid uterus of domestic livestock species. Journal of Animal Science, 73(6), 1852-1860.

Foxcroft, G. R., Dixon, W. T., Novak, S., Putman, C. T., Town, S. C., & Vinsky, M. D. A. 2006. The biological basis for prenatal programming of postnatal performance in pigs. Journal of Animal Science, 84(suppl 13), E105-E112.

Foxcroft, G. 2008. Hyper-prolificacy and acceptable post-natal development–a possible contradiction. Advances in Pork Production, 19, 205-211.

Frobish, L. T., Steele, N. C., & Davey, R. J. 1973. Long term effect of energy intake on reproductive performance of swine. Journal of Animal Science, 36(2), 293-297.

Gatford, K. L., Ekert, J. E., Blackmore, K., De Blasio, M. J., Boyce, J. M., Owens, J. A., ... & Owens, P. C. 2003. Variable maternal nutrition and growth hormone treatment in the second quarter of pregnancy in pigs alter semitendinosus muscle in adolescent progeny. British Journal of Nutrition, 90(2), 283-293.

Gatrell, S. K., Berg, L. E., Barnard, J. T., Grimmett, J. G., Barnes, K. M., & Blemings, K. P. 2013. Tissue distribution of indices of lysine catabolism in growing swine. Journal of Animal Science, 91(1), 238-247.

Hallen, A., Jamie, J. F., & Cooper, A. J. 2013. Lysine metabolism in mammalian brain: an update on the importance of recent discoveries. Amino acids, 45(6), 1249-1272.

Heo, S., Yang, Y. X., Jin, Z., Park, M. S., Yang, B. K., & Chae, B. J. 2008. Effects of dietary energy and lysine intake during late gestation and lactation on blood metabolites, hormones, milk compositions and reproductive performance in primiparous sows. Canadian Journal of Animal Science, 88(2), 247-255.

Holder, R. B., Lamberson, W. R., Bates, R. O., & Safranski, T. J. 1995. Lifetime productivity in gilts previously selected for decreased age at puberty. Animal Science, 61(1), 115-121.

Hoppe, M. K., Libal, G. W., & Wahlstrom, R. C. 1990. Influence of gestation energy level on the production of Large White x Landrace sows. Journal of Animal Science, 68(8), 2235-2242.

Huang, F. R., Liu, H. B., Sun, H. Q., & Peng, J. 2013. Effects of lysine and protein intake over two consecutive lactations on lactation and subsequent reproductive performance in multiparous sows. Livestock Science, 157(2), 482-489.

Isidori, A., Lo Monaco, A., & Cappa, M. 1981. A study of growth hormone release in man after oral administration of amino acids. Current Medical Research and Opinion, 7(7), 475-481.

Jindal, R., Cosgrove, J. R., Aherne, F. X., & Foxcroft, G. R. 1996. Effect of nutrition on embryonal mortality in gilts: association with progesterone. Journal of Animal Science, 74(3), 620-624.

Kim, S. W., Wu, G., & Baker, D. H. 2005. Ideal protein and dietary amino acid

requirements for gestating and lactating sows. Pig News and Information, 26(4), 91N.

Kim, S. W., Mateo, R. D., Yin, Y. L., & Wu, G. 2007. Functional amino acids and fatty acids for enhancing production performance of sows and piglets. Asian Australasian Journal of Animal Sciences, 20(2), 295.

Kim, S. W., Hurley, W. L., Wu, G., & Ji, F. 2009. Ideal amino acid balance for sows during gestation and lactation. Journal of Animal Science, 87(Suppl 14), E123-E132.

King, R. H., & Williams, I. H. 1984. The effect of nutrition on the reproductive performance of first-litter sows 2. Protein and energy intakes during lactation. Animal Science, 38(2), 249-256.

King, R. H. 1987. Nutritional anoestrus in young sows. Pig News Info, 8, 15-22.

Kirkwood, R. N., Baidoo, S. K., Aherne, F. X., & Sather, A. P. 1987. The influence of feeding level during lactation on the occurrence and endocrinology of the postweaning estrus in sows. Canadian Journal of Animal Science, 67(2), 405-415.

Knabe, D. A., Brendemuhl, J. H., Chiba, L. I., & Dove, C. R. 1996. Supplemental lysine for sows nursing large litters. Journal of Animal Science, 74(7), 1635-1640.

Koketsu, Y., G. Dial, V. King, P. Bahnson, J. L. Xue, and T. Lucia.1995. Reproductive failure observed on commercial swine farms. Recent Advance Swine Production Health 5:113–123.

Kongsted, A. G. 2005. A review of the effect of energy intake on pregnancy rate and litter size–discussed in relation to group-housed non-lactating sows. Livestock Production Science, 97(1), 13-26.

Kwon H, Spencer TE, Bazer FW, Wu G. 2003a. Developmental changes of amino acids in ovine fetal fluids. Biol Reprod 68:1813–1820

Kwon, H., Wu, G., Meininger, C. J., Bazer, F. W., & Spencer, T. E. 2004. Developmental changes in nitric oxide synthesis in the ovine placenta. Biology of reproduction, 70(3), 679-686.

O. Lavorel, J. Fekete, J.P. Bouard, M. Leuillet. 1981. Influence du niveau azoté de gestation sur les performances à long terme des truies et des porcelets en élevage intensif. J. Rech. Porc. France, 13, pp. 109-124

Lawlor, P. G., Lynch, P. B., O Connell, M. K., Mcnamara, Louise, Reid, P. A. U. L. A., & Stickland, N. C. 2007. The influence of over feeding sows during gestation on reproductive performance and pig growth to slaughter. Arch. Tierz., Dummerstorf, 50(I), 82.

Lehninger, A. L., Nelson, D. L., & Cox, M. M. 1993. Bioenergetics and metabolism. Principles of Biochemistry, 2.

Lehninger, A., Nelson, D., & Cox, M. M. 1993. Biosynthesis of amino acids, nucleotides and related molecules. Principles of Biochemistry, 688-734.

Lehninger, A. L., Nelson, D. L., & Cox, M. M. 2008. Lehninger principles of biochemistry. Macmillan.

Long, H. F., Ju, W. S., Piao, L. G., and Kim, Y. Y. 2010. Effect of dietary energy levels of gestating sows on physiological parameters and reproductive performance. Asian Australas Journal of Animal Science. 23:1080–1088.

Luiking, Y. C., Poeze, M., Dejong, C. H., Ramsay, G., & Deutz, N. E. 2004. Sepsis: an arginine deficiency state?. Critical Care Medicine, 32(10), 2135-2145.

Lund, M. S., Puonti, M., Rydhmer, L., & Jensen, J. 2002. Relationship between litter size and perinatal and pre-weaning survival in pigs. Animal Science, 74(2), 217-222.

Liao, C., & Veum, T. L. 1994. Effects of dietary energy intake by gilts and heat stress from days 3 to 24 or 30 after mating on embryo survival and nitrogen and energy balance. Journal of Animal Science, 72(9), 2369-2377.

Liaudet, L., Gnaegi, A., Rosselet, A., Markert, M., Boulat, O., Perret, C., & Feihl, F. 1997. Effect of L-lysine on nitric oxide overproduction in endotoxic shock. British Journal of Pharmacology, 122(4), 742-748.

MacPherson, R. M., Hovell, F. D., & Jones, A. S. 1977. Performance of sows first mated at puberty or second or third oestrus, and carcass assessment of once-bred gilts. Animal Science, 24(3), 333-342.

MacLean, C. W. 1968. The thin sow problem. Veterinary Record, 83, 308-316.

Mahan, D. C. 1979. Effect of dietary protein sequence on long-term sow reproductive performance. Journal of Animal Science, 49(2), 514-521.

Mahan, D. C. 1998. Relationship of gestation protein and feed intake level over a five-parity period using a high-producing sow genotype. Journal of Animal Science, 76(2), 533-541.

Mateo, R. D., Wu, G., Bazer, F. W., Park, J. C., Shinzato, I., & Kim, S. W. 2007. Dietary L-arginine supplementation enhances the reproductive performance of gilts. The Journal of Nutrition, 137(3), 652-656.

Merks, J. W. 2000. One century of genetic changes in pigs and the future needs. BSAS occasional publication, 8-19.

Miller, H. M., Foxcroft, G. R., & Aherne, F. X. 2000. Increasing food intake in late gestation improved sow condition throughout lactation but did not affect piglet viability or growth rate. Animal Science, 71(1), 141-148.

Mullan, B. P., & Williams, I. H. 1989. The effect of body reserves at farrowing on the reproductive performance of first-litter sows. Animal Science, 48(2), 449-457.

Musser, R. E., Davis, D. L., Tokach, M. D., Nelssen, J. L., Dritz, S. S., & Goodband, R. D. 2006. Effects of high feed intake during early gestation on sow performance and offspring growth and carcass characteristics. Animal Feed Science and Technology, 127(3), 187-199.

National Research Council. 1988. Nutrient requirements of swine, 9th ed. National Academy Press, Washington, DC.

National Research Council. 1998. Nutrient requirements of swine, 10th ed. National Academy Press, Washington, DC.

National Research Council. 2012. Nutrient requirements of swine, 11th ed. National Academy Press, Washington, DC.

Nelssen, J. L., Lewis, A. J., Peo, E. R., & Crenshaw, J. D. 1985. Effect of dietary energy intake during lactation on performance of primiparous sows and their litters. Journal of Animal Science, 61(5), 1164-1171.

Newton, E. A., & Mahan, D. C. 1993. Effect of initial breeding weight and management system using a high-producing sow genotype on resulting reproductive performance over three parities. Journal of Animal Science, 71(5), 1177-1186.

Nissen, P. M., Danielsen, V. O., Jorgensen, P. F., & Oksbjerg, N. 2003. Increased maternal nutrition of sows has no beneficial effects on muscle fiber number or postnatal growth and has no impact on the meat quality of the offspring. Journal of Animal Science, 81(12), 3018-3027.

Noblet, J., Close, W. H., Heavens, R. P., & Brown, D. 1985. Studies on the energy metabolism of the pregnant sow. British Journal of Nutrition, 53(2), 251-265.

Papes, F., Kemper, E. L., Germano, C. N., Langone, F., & Arruda, P. 1999. Lysine degradation through the saccharopine pathway in mammals: involvement of both bifunctional and monofunctional lysine-degrading enzymes in mouse. Biochemical Journal, 344(2), 555-563.

Père, M. C., & Etienne, M. 2000. Uterine blood flow in sows: effects of pregnancy stage and litter size. Reproduction Nutrition Development, 40(4), 369-382.

Pluske, J. R., Williams, I. H., & Aherne, F. X. 1995. Nutrition of the neonatal pig. The neonatal pig: development and survival, 187-235.

Pomeroy, R. W. 1960. Infertility and neonatal mortality in the sow I. Lifetime performance and reasons for disposal of sows. The Journal of Agricultural Science, 54(1), 1-17.

Pond, W. G., Yen, J. T., Maurer, R. R., & Christenson, R. K. 1981. Effect of doubling daily energy intake during the last two weeks of pregnancy on pig birth weight, survival and weaning weight. Journal of Animal Science, 52(3), 535-541.

Pond, C. M., Mattacks, C. A., Colby, R. H., & Ramsay, M. A. 1992. The anatomy, chemical composition, and metabolism of adipose tissue in wild polar bears (Ursus maritimus). Canadian Journal of Zoology, 70(2), 326-341.

Prime, G. R., Varley, M. A., & Symonds, H. W. 1988. The effect of food intake during lacation and early pregnancy on plasma progesterone concentrations and prolificacy in multiparous sows. In Animal Production (Vol. 46, pp. 499-499). Winton Lea Pencaitland, East Lothian, Scotland EH34 5AY: Durrant Periodicals.

Prunier, A., & Quesnel, H. 2000a. Nutritional influences on the hormonal control of reproduction in female pigs. Livestock Production Science, 63(1), 1-16.

Prunier, A., & Quesnel, H. 2000b. Influence of the nutritional status on ovarian development in female pigs. Animal Reproduction Science, 60, 185-197.

Quesnel, H., Brossard, L., Valancogne, A., & Quiniou, N. 2008. Influence of some sow characteristics on within-litter variation of piglet birth weight. Animal, 2(12), 1842-1849.

Quiniou, N., Dagorn, J., & Gaudré, D. 2002. Variation of piglets' birth weight and consequences on subsequent performance. Livestock Production Science, 78(1), 63-70.

Ramaekers, P., B. Kemp, and T. van der Lende. 2006. Progenos in sows increases number of piglets born. Journal of Animal Science 84(Suppl. 1):394.(Abstr.).

Redmer, D. A., Wallace, J. M., & Reynolds, L. P. 2004. Effect of nutrient intake during pregnancy on fetal and placental growth and vascular development. Domestic Animal Endocrinology, 27(3), 199-217.

Reese, D. E., Moser, B. D., Peo, E. R., Lewis, A. J., Zimmerman, D. R., Kinder, J. E., & Stroup, W. W. 1982. Influence of Energy Intake during Lactation on the Interval from Weaning to First Estrus in Sows. Journal of Animal Science, 55(3), 590-598.

Reese, D. E., Peo, E. R., & Lewis, A. J. 1984. Relationship of lactation energy intake and occurence of postweaning estrus to body and backfat composition in sows. Journal of

Animal Science, 58(5), 1236-1244.

Rehfeldt, C., & Kuhn, G. 2006. Consequences of birth weight for postnatal growth performance and carcass quality in pigs as related to myogenesis. Journal of animal science, 84(Suppl 13), E113-E123.

Reynolds, L. P., Ford, S. P., & Ferrell, C. L. 1985. Blood flow and steroid and nutrient uptake of the gravid uterus and fetus of sows. Journal of Animal Science, 61(4), 968-974.

Reynolds, L. P., Killilea, S. D., & Redmer, D. A. 1992. Angiogenesis in the female reproductive system. The FASEB journal, 6(3), 886-892.

Reynolds, L. P., & Redmer, D. A. 2001. Angiogenesis in the placenta. Biology of Reproduction, 64(4), 1033-1040.

Rozeboom, D. W., Pettigrew, J. E., Moser, R. L., Cornelius, S. G., & El Kandelgy, S. M. 1996. Influence of gilt age and body composition at first breeding on sow reproductive performance and longevity. Journal of Animal Science, 74(1), 138-150.

Santos, J. M. G. D., Moreira, I., & Martins, E. N. 2006. Lysine and metabolyzable energy requirements of lactating sows for subsequent reproductive performance. Brazilian Archives of Biology and Technology, 49(4), 575-581.

Schoknecht, P. A., Newton, G. R., Weise, D. E., & Pond, W. G. 1994. Protein restriction in early pregnancy alters fetal and placental growth and allantoic fluid proteins in swine. Theriogenology, 42(2), 217-226.

Simmins, P. H., Edwards, S. A., Spechter, H. H., & Riley, J. E. 1992. Lifetime performance of sows given different rearing and pregnancy feeding regimes. Anim. Prod, 54, 457.

Sinclair, A. G., Edwards, S. A., Hoste, S., McCartney, A., & Fowler, V. R. 1996. Partitioning of dietary protein during lactation in the Meishan synthetic and European White breeds of pig. Animal Science, 62(2), 355-362.

Sladek, S. M., Magness, R. R., & Conrad, K. P. 1997. Nitric oxide and pregnancy. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 272(2), R441-R463.

Speer, V. C. 1990. Partitioning nitrogen and amino acids for pregnancy and lactation in swine: a review. Journal of Animal science, 68(2), 553-561.

Stalder, K. J., Knauer, M., Baas, T. J., Rothschild, M. F., & Mabry, J. W. 2004. Sow longevity. Pig News and Information, 25(2), 53N.

Sterling, L. G., & Cline, T. R. 1986. The effect of energy level in late gestation and lactation

on the sow and litter: growth and reproductive performance. Journal of Animal Science, 63, 115.

Svajgr, A. J., Hays, V. W., Cromwell, G. L., & Dutt, R. H. 1974. Effect of lactation duration on reproductive performance of sows. Journal of Animal Science, 38(1), 100-105.

Touchette, K. J., Allee, G. L., Newcomb, M. D., & Boyd, R. D. 1998. The lysine requirement of lactating primiparous sows. Journal of Animal Science, 76(4), 1091-1097.

Tribout, T., Caritez, J. C., Gogué, J., Gruand, J., Billon, Y., Bouffaud, M., ... & Guéblez, R. 2003. Estimation, par utilisation de semence congelée, du progrès génétique réalisé en France entre 1977 et 1998 dans la race porcine Large White: résultats pour quelques caractères de reproduction femelle. Journées de la Recherche Porcine en France, 35, 285-292.

Tritton, S. M., King, R. H., Campbell, R. G., Edwards, A. C., & Hughes, P. E. 1996. The effects of dietary protein and energy levels of diets offered during lactation on the lactational and subsequent reproductive performance of first-litter sows. Animal Science, 62(3), 573-579.

Tummaruk, P., Lundeheim, N., Einarsson, S., & Dalin, A. M. 2001. Effect of birth litter size, birth parity number, growth rate, backfat thickness and age at first mating of gilts on their reproductive performance as sows. Animal Reproduction Science, 66(3), 225-237.

Tantasuparuk, W., Lundeheim, N., Dalin, A. M., Kunavongkrit, A., & Einarsson, S. 2001. Weaning-to-service interval in primiparous sows and its relationship with longevity and piglet production. Livestock Production Science, 69(2), 155-162.

Van den Brand, H., Soede, N. M., & Kemp, B. 2006. Supplementation of dextrose to the diet during the weaning to estrus interval affects subsequent variation in within-litter piglet birth weight. Animal Reproduction Science, 91(3), 353-358.

Van den Brand, H., Van Enckevort, L. C. M., Van der Hoeven, E. M., & Kemp, B. 2009. Effects of dextrose plus lactose in the sows diet on subsequent reproductive performance and within litter birth weight variation. Reproduction in Domestic Animals, 44(6), 884-888.

Walker, N. 1983. The effects of food intake in gestation on sows lactating for 14 days. Animal Science, 37(1), 25-31.

Whittemore, C. T., Franklin, M. F., & Pearce, B. 1980. Fat changes in breeding sows. Animal Science, 31(2), 183-190.

Whittemore, C. T., Smith, W. C., & Phillips, P. 1988. Fatness, live weight and performance responses of sows to food level in pregnancy. Animal Science, 47(1), 123-130.

Whittemore, C. T., & Morgan, C. A. 1990. Model components for the determination of energy and protein requirements for breeding sows: a review. Livestock Production Science, 26(1), 1-37.

Wolf, J., Žáková, E., & Groeneveld, E. 2008. Within-litter variation of birth weight in hyperprolific Czech Large White sows and its relation to litter size traits, stillborn piglets and losses until weaning. Livestock Science, 115(2), 195-205.

Wu, G., Bazer, F. W., Tuo, W., & Flynn, S. P. 1996. Unusual abundance of arginine and ornithine in porcine allantoic fluid. Biology of reproduction, 54(6), 1261-1265.

Wu, G, & Morris, S. M. 1998. Arginine metabolism: nitric oxide and beyond. Biochemical Journal, 336(1), 1-17.

Wu, G., Bazer, F. W., Wallace, J. M., & Spencer, T. E. 2006. Board-invited review: intrauterine growth retardation: implications for the animal sciences. Journal of Animal Science, 84(9), 2316-2337.

Wu, G., Bazer, F. W., Davis, T. A., Jaeger, L. A., Johnson, G. A., Kim, S. W., ... & Yin, Y. L. 2007. Important roles for the arginine family of amino acids in swine nutrition and production. Livestock Science, 112(1), 8-22.

Wu, G. 2009. Amino acids: metabolism, functions, and nutrition. Amino acids, 37(1), 1-17.

Wu, G., Bazer, F. W., Burghardt, R. C., Johnson, G. A., Kim, S. W., Li, X. L., ... & Spencer, T. E. 2010. Impacts of amino acid nutrition on pregnancy outcome in pigs: mechanisms and implications for swine production. Journal of Animal Science, 88(13), E195-E204.

Wu, G. 2013. Amino acids: biochemistry and nutrition. CRC Press.

Xue, L., Piao, X., Li, D., Li, P., Zhang, R., Kim, S. W., & Dong, B. 2012. The effect of the ratio of standardized ileal digestible lysine to metabolizable energy on growth performance, blood metabolites and hormones of lactating sows. Journal of Animal Science and Biotechnology, 3(1), 11.

Yang, H., Eastham, P. R., Phillips, P., & Whittemore, C. T. 1989. Reproductive performance, body weight and body condition of breeding sows with differing body fatness at parturition, differing nutrition during lactation, and differing litter size. Animal Science, 48(1), 181-201.

Yang, H., Pettigrew, J. E., Johnston, L. J., Shurson, G. C., & Walker, R. D. 2000a. Lactational and subsequent reproductive responses of lactating sows to dietary lysine

(protein) concentration. Journal of Animal Science, 78(2), 348-357.

Yang, H., Foxcroft, G. R., Pettigrew, J. E., Johnston, L. J., Shurson, G. C., Costa, A. N., & Zak, L. J. 2000b. Impact of dietary lysine intake during lactation on follicular development and oocyte maturation after weaning in primiparous sows. Journal of Animal Science, 78(4), 993-1000.

Young, L. G., & King, G. J. 1981. Reproductive Performance of Gilts Bred on First Third Estrus. Journal of Animal Science, 53(1), 19-25.

Young, L. G., King, G. J., Walton, J. S., McMillan, I., & Klevorick, M. 1990. Age, weight, backfat and time of mating effects on performance of gilts. Canadian Journal of Animal Science, 70(2), 469-481.

Young, L. G., King, G. J., Shaw, J., Quinton, M., Walton, J. S., & McMillan, I. 1991. Interrelationships among age, body weight, backfat and lactation feed intake with reproductive performance and longevity of sows. Canadian Journal of Animal Science, 71(2), 567-575.

Zhang, R. F., Hu, Q., Li, P. F., Xue, L. F., Piao, X. S., & Li, D. F. 2011. Effects of lysine intake during middle to late gestation (day 30 to 110) on reproductive performance, colostrum composition, blood metabolites and hormones of multiparous sows. Asian-Australasian Journal of Animal Sciences, 24(8), 1142-1147.

Chapter III: Effects of Arginine Levels Compared with Increased Feeding during Late Gestation on Reproductive Performance and Piglet Uniformity in Sows

Trial 1. Effects of arginine supplementation during late gestation on reproductive performance and piglet uniformity in sows

ABSTRACT: This study was conducted to evaluate the effects of arginine supplementation levels during late gestation on reproductive performance and piglet uniformity in sows. A total of 40 F1 multiparous sows (Yorkshire × Landrace), body weight 246.1 kg; was allotted to one of four treatments in a completely randomized design (CRD). Dietary treatments were divided by the supplementation level of arginine during late-gestation period; 1) Arg0.72% : corn-SBM based diet + L-Arg 0% (Arg 0.72%), 2) Arg1.0% : basal diet + L-Arg 0.28% (Arg 1.0%), 3) Arg1.5% : basal diet + L-Arg 0.79% (Arg 1.5%), and 4) Arg2.0% : basal diet + L-Arg 1.35% (Arg 2.0%). Same lactation diet was provided *ad libitum* during lactation period. There were no significant differences in body weight and backfat thickness during gestation and lactating sows. In addition, dietary arginine effects had no significant differences in the number of total born, stillbirth, total born, and piglet growth during lactation. Increasing arginine supplemented levels improved total litter weight (linear, P=0.08) and alive litter wieght (quadratic, P=0.07). However, additional arginine effect did not showed the piglet uniformtiy in piglet weight at birth and 21 day of lactation. Although there was no significant difference in blood profiles in gestating sows, BUN of lactating sows was increased as dietary arginine level increased (linear, P<0.05). Additional arginine supplementation had no influence on casein, lactose, protein contents of colostrum and milk. Consequently, dietary arginine up to 1.5% in late-gestation diet improved total litter weight and alive litter weight at farrowing, but it did not affect piglet uniformity.

Key words: Arginine, Late gestation, Sow, Reproductive performance, Piglet uniformity, Increased feeding scheme

INTRODUCTION

Arginine is one of functional amino acids signaling for embryonic and fetal development (Wu, 2009). It is serving as a precursor for the synthesis of proteins, nitric oxide and polyamine (Luiking et al., 2004). The relevance of arginine in fetal growth and development had been reported, because of the participation of nitric oxide and polyamines in angiogenesis, placental vascularization and embryogenesis during gestation (Flynn et al., 2002; Wu et al., 2006). Thus, arginine family of aminoi acids had funtions for placental growth, fetal growth, and postnatal production such as preweaning and postweaning growth (Wu and Meininger, 2000; Wu and Meininger, 2002; Flynn et al., 2002)

Recently, NRC (2012) suggested the 0.32/0.42% (<90d/>90d), 0.27/0.37% (<90d/>90d), 0.23/0.32% (<90d/>90d), 0.21/0.29% (<90d/>90d) as arginine requirement during gestation period in parity 1, 2, 3, and 4+, respectively. Also, this requirement can be met sufficiently by the arginine content in corn-soybean meal (SBM) based diet.

However, 1% of L-arginine·HCl, from days 30 to 114 of gestation in gilts, increased number of piglets born alive and live litter birth weight (Mateo et al., 2007), and sows supplemented L-arginine·HCl 1% diet during gestation from day 30 to 114 had greater number of total pigs born alive, total litter weight, and live litter weight rather than that of sows supplemented with corn-SBM control diet during gestation and arginine 1% diet during day 30 to 90 of gestation (Che et al., 2013). In other hands, Bass et al. (2011) reported that there were no differences in litter size and lactation performance between controls versus gilts and sows receiving an additional 1% L-arginine.

Since the effects of 1% arginine in previous studies were not shown apparently at the end of gestation, current study was conducted to verify the effect of arginine supplementation levels during late gestation period on sows.

MATERIALS AND METHODS

Animals

All experimental procedures involving animals were conducted in accordance with the Animal Experimental Guidelines provided by the Seoul National University Institutional Animal Care and Use Committee.

A total of 40 F1 multiparous sows (Yorkshire × Landrace) with average body weight (BW) of 246.1 kg, average backfat thickness of 18.7 mm, and a average parity of 5.1 was allotted to one of four treatments considering BW, backfat thickness, and pairty in completely randomized design when sows be day 70 of gestation. All sows took two times of artificial insemination service according to estrus cycle after weaning and checked pregnancy at day 35 of gestation by utrasound scanner (Donjin BLS, Korea). Before starting the experiment, second parity sow were fed 2.2 kg/d gestation diet and over third parity sows were fed 2.4 kg/d gestation diet

Experimental design and diet

The treatments were different levels of arginine content in gestation diet as followed: 1) Arginine 0.72%: corn-soybean meal (SBM) based diet with L-Arg 0% and L-Ala 1.63%, 2) Arginine 1.00%: corn-SBM based diet with L-Arg 0.28% and L-Ala 1.01%, 3) Arginine 1.50%: corn-SBM based diet with L-Arg 0.79% and L-Ala 0%, 4) Arginine 2.00%: corn-SBM based diet with L-Arg 1.35% and L-Ala 0%.

Alanine was chosen for the isonitrogenous control because Ala is not toxic and is not a substrate for Arg synthesis, but is extensively catabolized by pigs (Kohly et al., 2004; Mateo et al., 2007). The experimental diet contained 3,265 kcal of ME/kg, 13.55% crude protein , 0.74% total lysine, 0.23% total methionine, 0.45% total threonine, and 0.11% total tryptophan. Lactation diet contained 3,265 kcal of ME/kg, 13.68% crude protein. L-Arginine and L-Alanine (Ajinomoto Co. Inc., Tokyo, Japan) in dry form was supplemented in basal diet according to designated treatments. Calcium and total phosphorus of experimental diets were met the

nutrient requirement of NRC (1998), other nutrients of experimental diets were met or exceeded the nutrient requirement of NRC (2012). Formula and chemical composition of experimental diet were presented in Table 1.

Animal management

All sows were fed 2.2 kg/d or 2.4 kg/d of experimental diet once a day (08:00) by their parity and reduced feed 0.2kg/d gradually for 5 days before due date of parturition. After farrowing, sows were fed lactation diet 1 to 5 kg/d during 5 days postpartum and fed diet *ad libitum* until weaning.

All sows were accommodated in individual gestation stall (2.20 × 0.64 m) where the indoor temperature was regulated average 20℃ by automatic ventialtion system. At day 110 of gestation, sows were moved from gestation barn to farrowing crates (2.50 × 1.80 m) after washing and disinfecting their body, especially breast and vulva. All sows did not treat delivery inducer and they were taken an assistance when dystocia was happened. The room temperature of lactating barn were kept 28 ± 2℃ and baby house under heating lamp were kept 32± 2℃. Air condition of lactating barn was regulated automatically by ventilation system and air-conditioner. After weaning, sows were moved to breeding barn for the next estrus cycle.

After farrowing, piglets were cross-fostered within treatment until 24 hrs postpartum to balance suckling intensity of sows with equalization of litter size, and thus to minimize any effect of initial litter size potentially affecting litter growth. Fe-dextran 150 ppm (Gleptosil®, Alstoe, UK) injection, tail docking, and castration (for male piglets) were practiced to all piglets. All piglets were fed breast milk only and creep feed were not provided until weaning.

Body weight, backfat thickness, lactation feed intake

Body weight and backfat thickness of sows were measure at day 70, 90, 110 of gestation, 24 hrs postpartum, and 21 day of lactation. Body weight of sow was measured by electric scale (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea) for

sow and backfat thickness was measured at P_2 position (mean value form both side of the last rib and 65 mm away from the backbone) by ultrasound device (Lean Meter®, Renco Corp., Minneapolis, USA). Daily feed wastage was recorded during lactation and lactation feed intake was measured when measuring body weight and backfat thickness of lactating sows at day 21 of lactation.

Reproductive performance

After farrowing, the number of piglets for total born, stillbirth, mummy, alive piglet was recorded and measured bodyweight of alive piglets, stillborn, and mummy by electric scale (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea). When measuring the body weight of piglets, ear notching was practiced for experiment. After then, cross-fostering the piglets within same treatment was done within 12hrs postpartum for equalizing litter size. The number and body weight of piglets was measured again at 21 day of lactation for calculating litter weight, piglet weight and both weight gain. Parturition time was recorded from start time of farrowing to totally release out of placenta. After the parturition, the whole placenta was measured `by electric scale (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea). Helping frequency during farrowing was recorded when sows happened dystocia.

Piglet uniformity

To observe piglet uniformity, coefficient of variation (CV) and standard deviation (SD) was calculated from each weight of total born except mummy in 24hrs postpartum. Also CV and SD were calculated again from body weight of piglets at birth and day 21 of lactation

Blood profiles

Blood collection from sows (n=4 for each treatment) was taken by venipuncture of the jugular vein using 10 ml disposable syringes at day 70, 90, 110 day of gestation, 24hrs postpartum and 21 day of lactation. Blood of suckling piglets (n=4 for each treatment) was collected from the anterior vena cava using 3

ml disposable syringes at 24hrs postpartum and 5 ml disposable syringes at 21 day of lactation. All blood samples were enclosed into serum tube (SST^{TM} Ⅱ Advance, BD Vacutainer, Becton Dickinson, Plymouth, UK) as well as EDTA tube (BD Vacutainer K_2E, Becton Dickinson, Plymouth, UK) and centrifuged at 3000 rpm and 4 °C for 15 min (5810R, Eppendorf, Hamburg, Germany) after clotting at room temperature for 30 min. The upper liquid (serum) of the blood was separated to a microtube (Axygen, Union City, CA, USA) and stored at −20 °C freezer until later analysis. Serum glucose (enzymatic kinetic assay, Roche, Germany), insulin (ECLIA, Roche, Germany), blood urea nitrogen (kinetic UV assay, Roche, Germany), total protein (colorimetry, Roche, Germany), creatinine (kinetic colorimetry assay, Roche, Germany), and urea (kinetic UV assay, Roche, Germany) were analyzed by Modular analytics (Hitachi, Japan). Plasma amino acid was analyzed by LC-MS/MS (3200 Q TRAP, AB SCIEX, USA)

Milk composition

Colostrum samples (n=4 for each treatment) were taken from functional mammary glands at 24 hrs postpartum and milk samples (n=4 for each treatment) were taken at 21 day of lactation. Colostrum and milk were collected in a 50ml conical tubes (SPL Life Sciences Co., Ltd., Pocheon-si, Gyeonggi-do, Korea) from the first and second teats after an intravascular injection with 5 IU oxytocin (Komi oxytocin inj., Komipharm International Co., Ltd., Siheung-si, Gyeonggi-do, Korea) in the ear. After collection, samples were stored in a freezer (−20 °C) until further analysis. Proximate analysis of colostrum and milk was determined using a Milkoscan FT 120 (FOSS, Hillerod, Denmark).

Statistical analysis

All collected data were carried out by least squares mean comparisons and were evaluated with the General Linear Model (GLM) procedure of SAS (SAS Institute, 2004). Orthogonal polynomial contrasts were used to determine linear and quadratic effects by increasing arginine supplementation level. Individual sow was

used as the experimental unit in growth performance, reproductive performance, blood profiles, milk composition. Their litter was used as the experimental unit in piglet growth and piglet uniformity. The differences were declared significant at $P<0.05$ or highly significant at $P<0.01$ and the determination of tendency for all analysis was $P \geq 0.05$ and $P<0.10$.

RESULTS

Supplementation levels of arginine in late-gestating sows had no signficant influence on their body weight or backfat thickness at day 90 and day 110 of gestation, or weight gain during gestation (Table 2). In addition, changes in body weight and backfat thickness during lactation (0-21 days postpartum) were not affected by arginine supplementation levels in late gestation (Table 3). There were no significant difference in average daily feed intake during lactation.

Sow and litter performance were shown in Tables 4 and 5, respectively. Although increasing arginine supplementation levels did not affect number of piglets in the total born, stillborn, mummy, or born alive, total litter weight tended to increase linearly (linear, P=0.08) and alive litter weight showed a quadratic increase (quadratic, P=0.07), but piglet birth weight was not increased. Further, there were no significant differences in parturition time, helping frequency, or placental weight at farrowing. Litter weight or piglet weight after fostering and at 21 days of lactation, or their weight gain during lactation did not show any significant effects with arginine supplementation in late gestation (70–110d). Regarding piglet uniformity, standard deviation and coefficient of variation in piglet birth weight (Table 4) or body weight at day 21 of lactation (Table 5) were not significantly affected by arginine supplementation levels.

In blood profiles of gestating sows (Table 6), there were no significant variations in glucose, creatinine, blood urea nitrogen, total protein, or urea. During lactation (Table 7), serum glucose level of sows at 24 h postpartum showed a quadratic response as arginine supplementation level increased (quadratic, P=0.03). Blood urea nitrogen was found to increase linearly at 24 h postpartum (linear, P=0.03) and day 21 of lactation (linear, P=0.02) as dietary arginine increased. Serum glucose and creatinine concentrations of nursery piglets at day 21 day of lactation showed a quadratic response by dietary arginine supplementation (quadratic, P<0.01, P=0.03), but blood urea nitrogen did not (Table 8).

As seen from milk composition of lactating sows (Table 9), milk fat in colostrum showed a quadratic increase (quadratic, $P<0.01$) as well as a linear increase (linear, $P=0.08$) as dietary arginine levels increased during late gestation. However, there were no significant differences in other components such as casein, protein, lactose, or FFA in colostrum and milk, respectively.

DISCUSSION

Mateo et al. (2007) found that dietary supplementation with 1 % L-arginine·HCl during gestation and lactation did not appear to affect body weight or backfat thickenss in gilts. In contrast, Bass et al. (2011) reported that supplementation of gestation diets with 1 % L-arginine from day 93 to 110 of gestation improved body weight gain in gilts and sows in 1 parity. However, there was no difference in body weight gain during late gestation comparing control and arginine-supplemented parity 2+ sows. They also demonstrated that supplementation with arginine 1 % at least partially met the arginine requirement of parity 0 and 1 gilts and sows, but not that of parity 2+ sows. Therefore, the supplementation level of arginine used, from 0.72 % to 2 % in the current trial, may have been met or exceed for growth of sows and utilized in other processes in 2+ parity of sows.

Mateo et al. (2007) reported that 1 % arginine supplementation resulted in greater litter birth weight of all piglets born alive, and Che et al. (2013) also found similar results. Further, 1% arginine supplementation from day 30 to day 114 of gestation showed a greater total litter weight and live litter weight compared with those in sows fed the same 1% arginine diet from day 30 to day 90 of gestation. Supplementation of arginine was found to increase nitric oxide, enhancing delivery of essential nutrients from maternal to fetal blood (Sladek et al., 1997; Gardner et al., 2001; Fan et al., 1998), and increase polyamines necessary for embryogenesis and

placental growth (Wu and Morris, 1998; Wu et al., 2004; Kim et al., 2007). Thus, additional arginine supplementation, specifically during late gestation is likely to improve placental growth and fetal development via the above mechanism, dietary 1.5% arginine level improved total litter weight and alive litter weight among dietary treatment.

In the present study, dietary arginine levels in late-gestating sows caused no significant difference in litter or piglet growth during lactation (Table 5). Quesnel et al. (2014) reported that litter growth rate during lactation and litter size at weaning were not influenced by dietary arginine levels. Mateo et al. (2008) showed that 1 % arginine supplementation during lactation had a significant influence on piglet body weight and weight gain during lactation. However, no significant changes in the above parameters were caused by arginine supplementation during gestation. Litter weight gain is correlated with milk production and nutrient concentrations in milk (Noblet and Etienne, 1987; King et al., 1993). Mateo et al. (2008) suggested that increased piglet or litter weight gain in arginine-supplemented lactating sows may be indicative of increased milk production or increased nutrient concentrations in milk. Although there were no agrining effect on the contents of colostrum and milk at day 21 of lactation, additional arginine intake may have resulted in increased milk fat synthesis in colostrum. Colostrum fat levels measured in the present study were not likely to have affected litter growth significantly, demonstrating that arginine supplemented in late gestation had no direct effects on lactating piglet growth.

Piglet uniformity showed no significant difference with dietary arginine supplementation levels in the present study. Mateo et al. (2007) found that there were no significant differences in birth weight variation in total piglets born or those born alive, in gilts supplemented 1% arginine. In addition, Che et al. (2013) showed that 1 % arginine supplementation during gestation had no effect on CV in total born piglet weight and no significant difference in incidence of intrauterine growth restricted pigs. However, Quesnel et al. (2014) demonstrated that the CV in piglet birth weight was lesser in litters from sows supplemented with 25.5 g/d arginine

from day 77 of pregnancy until farrowing, compared with those from control sows and sows given dextrose during the week before insemination. The present study showed that arginine levels had no effect on piglet uniformity.

Blood urea nitrogen is in accordance with varies based on nitrogen retention in the body (Whang and Easter, 2000) and protein availability decreased (Hong et al., 2016) and with increased the excretion of the nitrogen as urea form (Han et al., 2001). Thus, increase of BUN concentration indicates excessive amino acid levels, metabolized inefficiently and circulating in blood before excretion (Hong et al., 2016). Increasing arginine intake during late gestation may result in amino acid imbalance in lactating sows, which would be in catabolic status to support milk production. Amino acid utilization in mammary glands is affected by amino acid concentration in blood and efficiency of uptake into mammary cells (Hurley et al., 2000), and amino acid excess or imbalance during lactation could reduce amino acid availability in mammary glands (Guan et al., 2004). Moreover, antagonism between lysine and arginine could have further led to amino acid imbalance, reflected in blood urea nitrogen levels of lactating sows. Blood creatinine level is positively correlated with total muscle mass (Baxmann et al., 2008) and mass of striated muscle (Schultte et al., 1981). Increasing level of arginine supplementation in late gestating sows did not affect blood creatinine concentrations of piglets after farrowing. It demonstrated that arginine supplementation did not affect development of fetal muscle fiber during late gestation.

CONCLUSION

Supplementation with L-arginine 1.5% in late gestation improved total litter weight and alive litter weight at farrowing. It had no significant influence on piglet growth during lactation and uniformity of piglet birth weight.

REFERENCES

Bass, B. E., Bradley, C. L., Johnson, Z. B., Boyd, R. D., Usry, J. L., Maxwell, C. V., & Frank, J. W. 2011. Influence of dietary L-arginine supplementation to sows during late gestation on sow and litter performance during lactation. Research Series, 597, 151-155.

Baxmann, A. C., Ahmed, M. S., Marques, N. C., Menon, V. B., Pereira, A. B., Kirsztajn, G. M., & Heilberg, I. P. 2008. Influence of muscle mass and physical activity on serum and urinary creatinine and serum cystatin C. Clinical Journal of the American Society of Nephrology, 3(2), 348-354.

Che, L., Yang, P., Fang, Z., Lin, Y., & Wu, D. 2013. Effects of dietary arginine supplementation on reproductive performance and immunity of sows. Czech Journal of Animal Science, 58(4), 167-175.

Fan, W. Q., Smolich, J. J., Wild, J., Victor, Y. H., & Walker, A. M. 1998. Major vasodilator role for nitric oxide in the gastrointestinal circulation of the mid-gestation fetal lamb. Pediatric Research, 44(3), 344-350.

Flynn, N. E., Meininger, C. J., Haynes, T. E., & Wu, G. 2002. The metabolic basis of arginine nutrition and pharmacotherapy. Biomedicine & Pharmacotherapy, 56(9), 427-438.

Gardner, P. R., Martin, L. A., Hall, D., & Gardner, A. M. 2001. Dioxygen-dependent metabolism of nitric oxide in mammalian cells. Free Radical Biology and Medicine, 31(2), 191-204.

Guan, X., Bequette, B. J., Ku, P. K., Tempelman, R. J., & Trottier, N. L. 2004. The amino acid need for milk synthesis is defined by the maximal uptake of plasma amino acids by porcine mammary glands. The Journal of Nutrition, 134(9), 2182-2190.

Han, I. K., Lee, J. H., Piao, X. S., & Li, D. 2001. Feeding and management system to reduce environmental pollution in swine production. Asian Australasian Journal of Animal Sciences, 14(3), 432-444.

Hong, J. S., Lee, G. I., Jin, X. H., & Kim, Y. Y. 2016. Effect of dietary energy levels and phase feeding by protein levels on growth performance, blood profiles and carcass characteristics in growing-finishing pigs. Journal of Animal Science and Technology, 58(1), 37.

Hurley, W. L., Wang, H., Bryson, J. M., & Shennan, D. B. 2000. Lysine uptake by mammary gland tissue from lactating sows. Journal of Animal Science, 78(2), 391-395.

Kim, S. W., Mateo, R. D., Yin, Y. L., & Wu, G. 2007. Functional amino acids and fatty acids for enhancing production performance of sows and piglets. Asian Australasian Journal of Animal Sciences, 20(2), 295.

King, R. H., Toner, M. S., Dove, H., Atwood, C. S., & Brown, W. G. 1993. The response of first-litter sows to dietary protein level during lactation. Journal of Animal Science, 71(9), 2457-2463.

Kohli, R., Meininger, C. J., Haynes, T. E., Yan, W., Self, J. T., & Wu, G. 2004. Dietary L-arginine supplementation enhances endothelial nitric oxide synthesis in streptozotocin-induced diabetic rats. The Journal of Nutrition, 134(3), 600-608.

Luiking, Y. C., Poeze, M., Dejong, C. H., Ramsay, G., & Deutz, N. E. 2004. Sepsis: an arginine deficiency state?. Critical Care Medicine, 32(10), 2135-2145.

Mateo, R. D., Wu, G., Bazer, F. W., Park, J. C., Shinzato, I., & Kim, S. W. 2007. Dietary L-arginine supplementation enhances the reproductive performance of gilts. The Journal of Nutrition, 137(3), 652-656.

Mateo, R. D., Wu, G., Moon, H. K., Carroll, J. A., & Kim, S. W. 2008. Effects of dietary arginine supplementation during gestation and lactation on the performance of lactating primiparous sows and nursing piglets. Journal of Animal Science, 86(4), 827-835.

National Research Council. 1998. Nutrient requirements of swine, 10th ed. National Academy Press, Washington, DC.

National Research Council. 2012. Nutrient requirements of swine, 11th ed. National Academy Press, Washington, DC.

Noblet, J., & Etienne, M. 1987. Metabolic utilization of energy and maintenance requirements in lactating sows. Journal of Animal Science, 64(3), 774-781.

Quesnel, H., Quiniou, N., Roy, H., Lottin, A., Boulot, S., & Gondret, F. 2014. Supplying dextrose before insemination and-arginine during the last third of pregnancy in sow diets: Effects on within-litter variation of piglet birth weight. Journal of Animal Science, 92(4), 1445-1450.

Schutte, J. E., Longhurst, J. C., Gaffney, F. A., Bastian, B. C., & Blomqvist, C. G. 1981. Total plasma creatinine: an accurate measure of total striated muscle mass. Journal of Applied Physiology, 51(3), 762-766.

Sladek, S. M., Magness, R. R., & Conrad, K. P. 1997. Nitric oxide and pregnancy. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 272(2), R441-R463.

Whang, K. Y., & Easter, R. A. 2000. Blood urea nitrogen as an index of feed efficiency and lean growth potential in growing-finishing swine. Asian Australasian Journal or Animal Science, 13(6), 811-816.

Wu, G, & Morris, S. M. 1998. Arginine metabolism: nitric oxide and beyond. Biochemical Journal, 336(1), 1-17.

Wu, G., & Meininger, C. J. 2000. Arginine nutrition and cardiovascular function. The Journal of Nutrition, 130(11), 2626-2629.

Wu, G., & Meininger, C. J. 2002. Regulation of nitric oxide synthesis by dietary factors. Annual Review of Nutrition, 22(1), 61-86.

Wu, G., Jaeger, L. A., Bazer, F. W., & Rhoads, J. M. 2004. Arginine deficiency in preterm infants: biochemical mechanisms and nutritional implications. The Journal of Nutritional Biochemistry, 15(8), 442-451.

Wu, G., Bazer, F. W., Wallace, J. M., & Spencer, T. E. 2006. Board-invited review: intrauterine growth retardation: implications for the animal sciences. Journal of Animal Science, 84(9), 2316-2337.

Wu, G. 2009. Amino acids: metabolism, functions, and nutrition. Amino acids, 37(1), 1-17.

Table 1. The formulas and chemical composition of gestation diet

Item	Dieatry arginine, %[1)]			
	0.72	1.00	1.50	2.00
Ingredients, %				
Corn	75.16	75.38	76.02	76.59
Soybean meal-46	12.57	12.57	12.26	9.04
Wheat bran	1.64	1.93	2.35	3.74
Palm kernel meal	3.00	3.00	3.00	3.00
Tallow	2.48	2.32	2.07	2.65
L-lysine HCl (78%)[2)]	0.26	0.26	0.26	0.37
DL-methionine (99%)[3)]	0.05	0.04	0.04	0.05
L-arginine (99%)[4)]	0.00	0.28	0.79	1.35
L-alanine (98%)[5)]	1.63	1.01	0.00	0.00
MDCP	1.46	1.46	1.46	1.45
Limestone	1.15	1.15	1.15	1.16
Vit. mix[6)]	0.10	0.10	0.10	0.10
Min. mix[7)]	0.10	0.10	0.10	0.10
Choline chloride-50	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Chemical composition [8)]				
ME, kcal/kg	3,265.03	3,265.07	3,265.03	3,265.00
Crude protein, %	13.55	13.55	13.55	13.55
Total lysine, %	0.74	0.74	0.74	0.74
Total methionine, %	0.24	0.23	0.23	0.23
Total threonine	0.45	0.45	0.45	0.40
Total tryptophan	0.11	0.11	0.11	0.09
Calcium, %	0.75	0.75	0.75	0.75
Total phosphorus, %	0.60	0.60	0.60	0.60

[1)] Treatment : Arginine 0.72%: corn-soybean meal (SBM) based diet with L-Arg 0% and L-Ala 1.63%, Arginine 1.00%: corn-SBM based diet with L-Arg 0.28% and L-Ala 1.01%, Arginine 1.50%: corn-SBM based diet with L-Arg 0.79% and L-Ala 0%, Arginine 2.00%: corn-SBM based diet with L-Arg 1.35% and L-Ala 0%.

[2)] L-lysine·HCl (Daesang, Korea)

[3)] DL-methionine (CJcheiljedang, Korea)

[4)] L-arginine (Ajinomoto Co. Inc., Japan)

[5)] L-alanine (Ajinomoto Co. Inc., Japan)

[6)] Provided per kg of diet : Vitamin A, 8,000 IU; Vitamin D_3, 1,600 IU; Vitamin E, 32 IU; d-biotin, 64g; Riboflavin, 3.2mg; Calcium pantothenic acid, 8mg; Niacin, 16mg; Vitamin B_{12}, 12㎍; vitamin K, 2.4mg.

[7)] Provided per kg of diet : Se, 0.1mg; I, 0.3mg; Mn, 24.8mg; CuSO4, 54.1mg; Fe, 127.3mg; Zn, 84.7mg; Co, 0.3mg.

[8)] Calculated value.

Table 2. Effects of arginine supplementation levels on body weight and back-fat thickness in gestating sows

	Dietary arginine[1], %				SEM[2]	P-value[3]	
	0.72	1.0	1.5	2.0		Lin.	Quad.
Body weight, kg							
70 day	242.5	249.8	245.9	245.0	4.64	0.97	0.72
90 day	251.0	258.7	252.7	251.8	4.56	0.88	0.72
110 day	248.6	251.9	247.6	244.6	4.38	0.66	0.80
BW gain (70-110d)	6.1	2.1	1.7	-0.4	1.70	0.14	0.87
Backfat thickness, mm							
70 day	18.1	19.7	17.5	18.6	0.92	0.89	0.98
90 day	18.6	20.6	19.3	19.7	1.00	0.87	0.79
110 day	20.4	21.1	19.1	21.5	1.02	0.89	0.60
BF gain (70-110d)	2.3	1.4	1.6	2.9	0.39	0.60	0.21

[1] Arginine 0.72%: corn-SBM based diet with arginine 0%, Arginine 1.0%: corn-SBM based diet with arginine 0.28%, Arginine 1.5%: corn-SBM based diet with arginine 0.79%, Arginine 2.0%: corn-SBM based diet with arginine 1.35%.
[2] Standard error of mean.
[3] Abbreviation: Lin. (linear) and Quad. (quadratic).

Table 3. Effects of arginine supplementation levels on body weight, back-fat thickness and average daily feed intake in lactating sows

	Dietary arginine[1], %				SEM[2]	P-value[3]	
	0.72	1.0	1.5	2.0		Lin.	Quad.
Body weight, kg							
24hrs postpartum	229.7	231.3	225.7	223.2	4.76	0.55	0.91
Day 21 of lactation	227.5	234.8	226.2	225.2	4.56	0.66	0.77
BW changes, (0-21d)	-2.2	3.5	0.5	2.0	2.10	0.34	0.83
Backfat thickness, mm							
24hrs postpartum	20.3	20.2	18.7	20.4	1.03	0.92	0.60
Day 21 of lactation	19.2	19.6	18.8	20.2	0.88	0.76	0.74
BF changes, (0-21d)	-1.1	-0.6	0.1	-0.2	0.36	0.40	0.84
ADFI, kg/d	5.08	5.29	5.50	5.64	0.157	0.20	0.81

[1] Arginine 0.72%: corn-SBM based diet with arginine 0%, Arginine 1.0%: corn-SBM based diet with arginine 0.28%, Arginine 1.5%: corn-SBM based diet with arginine 0.79%, Arginine 2.0%: corn-SBM based diet with arginine 1.35%.
[2] Standard error of mean.
[3] Abbreviation: Lin. (linear) and Quad. (quadratic).

Table 4. Effects of arginine supplementation levels on reproductive performance in gestating sows

	Dietary arginine[1], %				SEM[2]	P-value[3]	
	0.72	**1.0**	**1.5**	**2.0**		**Lin.**	**Quad.**
No. of piglets							
Total born	11.85	15.57	15.00	14.43	0.677	0.32	0.13
Stillbirth	0.14	0.71	0.86	0.71	0.139	0.18	0.17
Mummy	0	0.57	0.14	0	0.103	0.47	0.16
Born alive	11.71	14.29	14.00	13.72	0.624	0.39	0.28
Total litter weight, kg	18.31	21.63	22.74	21.57	0.654	0.08	0.05
Alive litter weight, kg	17.97	20.81	21.93	20.60	0.637	0.15	0.07
Piglet birth weight, kg	1.63	1.49	1.60	1.53	0.047	0.98	0.68
Standard deviation	289.4	252.0	251.4	263.3	13.36	0.60	0.38
Coefficient of variation	18.45	19.45	16.10	17.10	1.131	0.47	0.82
Parturition time, min.	169.0	195.8	168.2	168.7	10.61	0.70	0.69
Helping frequency	0.57	0.33	0.75	1.11	0.181	0.19	0.55
Placenta weight, g	3,123	3,304	4,006	3,275	266.2	0.67	0.32

[1] Arginine 0.72%: corn-SBM based diet with arginine 0%, Arginine 1.0%: corn-SBM based diet with arginine 0.28%, Arginine 1.5%: corn-SBM based diet with arginine 0.79%, Arginine 2.0%: corn-SBM based diet with arginine 1.35%.
[2] Standard error of mean.
[3] Abbreviation: Lin. (linear) and Quad. (quadratic).

Table 5. Effects of arginine supplementation levels on litter performance in lactating sows

	Dietary arginine[1], %				SEM[2]	P-value[3]	
	0.72	1.0	1.5	2.0		Lin.	Quad.
No. of piglets							
After-fostering	11.28	11.42	11.43	11.29	0.164	0.96	0.69
21d of lactation	10.71	10.43	10.29	10.71	0.174	1.00	0.31
Litter weight, kg							
After-fostering	17.18	16.84	17.74	16.89	0.437	0.98	0.68
Day 21 of lactation	57.33	55.71	55.88	60.15	1.680	0.53	0.43
Weight gain (0-21d)	40.15	38.87	38.14	43.26	1.660	0.53	0.36
Piglet weight, kg							
After-fostering	1.54	1.47	1.56	1.49	0.041	0.86	0.92
Day 21 of lactation	5.35	5.34	5.41	5.62	0.142	0.51	0.76
Weight gain (0-21d)	3.81	3.87	3.85	4.13	0.129	0.43	0.71
Piglet uniformity (21d)							
Standard deviation	1187	1273	1120	1353	72.4	0.60	0.54
Coefficient of variation	22.2	25.7	21.5	24.1	1.47	0.97	0.96

[1] Arginine 0.72%: corn-SBM based diet with arginine 0%, Arginine 1.0%: corn-SBM based diet with arginine 0.28%, Arginine 1.5%: corn-SBM based diet with arginine 0.79%, Arginine 2.0%: corn-SBM based diet with arginine 1.35%.
[2] Standard error of mean.
[3] Abbreviation: Lin. (linear) and Quad. (quadratic).

Table 6. Effects of arginine supplementation levels on blood profiles in gestating sows

	Dietary arginine[1], %				SEM[2]	P-value[3]	
	0.72	1.0	1.5	2.0		Lin.	Quad.
Glucose, mg/dL							
70 day	----------62.5----------						
90 day	62.0	65.5	61.5	55.5	1.75	0.10	0.26
110 day	82.7	81.7	88.2	73.7	3.85	0.55	0.37
Creatinine, mg/dL							
70 day	----------1.77----------						
90 day	2.07	2.18	2.06	2.08	0.101	0.89	0.90
110 day	3.04	2.75	3.37	2.61	0.135	0.57	0.24
BUN, mg/dL							
70 day	----------11.27----------						
90 day	10.00	11.12	10.50	9.92	0.452	0.76	0.46
110 day	13.52	13.65	14.30	14.15	0.556	0.65	0.84
Total protein, g/dL							
70 day	----------6.37----------						
90 day	6.62	6.90	6.12	6.42	0.177	0.38	0.72
110 day	7.12	6.55	7.42	6.52	0.231	0.69	0.56
Urea, mg/dL							
70 day	----------24.1----------						
90 day	21.4	23.8	22.4	21.2	0.96	0.76	0.46
110 day	28.9	29.2	30.6	30.2	1.19	0.65	0.84

[1] Arginine 0.72%: corn-SBM based diet with arginine 0%, Arginine 1.0%: corn-SBM based diet with arginine 0.28%, Arginine 1.5%: corn-SBM based diet with arginine 0.79%, Arginine 2.0%: corn-SBM based diet with arginine 1.35%.
[2] Standard error of mean.
[3] Abbreviation: Lin. (linear) and Quad. (quadratic).

Table 7. Effects of arginine supplementation levels on blood profiles in lactating sows

	Dietary arginine[1], %				SEM[2]	P-value[3]	
	0.72	1.0	1.5	2.0		Lin.	Quad.
Glucose, mg/dL							
24hrs postpartum	83.7	93.0	102.7	78.0	4.23	0.70	0.03
Day 21 of lactation	73.5	79.2	77.0	72.5	2.32	0.73	0.36
Insulin, μU/mL							
24hrs postpartum	1.17	0.45	1.32	1.15	0.179	0.51	0.69
Day 21 of lactation	1.27	1.80	1.70	3.20	0.357	0.08	0.51
Creatinine, mg/dL							
24hrs postpartum	2.84	2.91	2.58	3.19	0.133	0.52	0.27
Day 21 of lactation	2.24	2.36	2.23	2.27	0.078	0.92	0.92
BUN, mg/dL							
24hrs postpartum	12.00	11.80	14.05	17.17	0.977	0.03	0.51
Day 21 of lactation	12.37	14.62	16.02	15.92	0.579	0.02	0.17

[1] Arginine 0.72%: corn-SBM based diet with arginine 0%, Arginine 1.0%: corn-SBM based diet with arginine 0.28%, Arginine 1.5%: corn-SBM based diet with arginine 0.79%, Arginine 2.0%: corn-SBM based diet with arginine 1.35%.
[2] Standard error of mean.
[3] Abbreviation: Lin. (linear) and Quad. (quadratic).

Table 8. Effects of arginine supplementation levels on blood profiles in piglets

	Dietary arginine[1], %				SEM[2]	P-value[3]	
	0.72	1.0	1.5	2.0		Lin.	Quad.
Glucose, mg/dL							
24hrs postpartum	116.7	111.2	102.5	103.0	4.71	0.29	0.66
Day 21 of lactation	109.5	120.0	129.7	111.0	2.92	0.67	<0.01
Creatinine, mg/dL							
24hrs postpartum	0.72	0.81	1.57	0.95	0.226	0.52	0.34
Day 21 of lactation	0.79	0.65	0.63	0.73	0.028	0.55	0.03
BUN, mg/dL							
24hrs postpartum	18.80	17.32	20.27	18.62	1.101	0.79	0.83
Day 21 of lactation	7.62	12.62	7.63	8.92	1.028	0.76	0.58
Total protein, g/dL							
24hrs postpartum	6.07	4.95	6.02	5.85	0.295	0.78	0.61
Day 21 of lactation	4.60	4.52	4.87	4.80	0.088	0.24	0.76

[1] Arginine 0.72%: corn-SBM based diet with arginine 0%, Arginine 1.0%: corn-SBM based diet with arginine 0.28%, Arginine 1.5%: corn-SBM based diet with arginine 0.79%, Arginine 2.0%: corn-SBM based diet with arginine 1.35%.
[2] Standard error of mean.
[3] Abbreviation: Lin. (linear) and Quad. (quadratic).

Table 9. Effects of arginine supplementation levels on milk composition in lactating sows

	Dietary arginine[1], %				SEM[2]	P-value[3]	
	0.72	1.0	1.5	2.0		Lin.	Quad.
Casein, %							
Colostrum	6.61	7.56	5.67	6.36	0.759	0.71	0.92
Milk (21d)	4.00	4.43	3.86	4.29	0.172	0.90	0.83
Fat, %							
Colostrum	5.99	2.93	4.31	7.27	0.560	0.08	<0.01
Milk (21d)	4.05	6.84	5.95	6.87	0.486	0.10	0.35
Protein, %							
Colostrum	8.10	10.00	7.41	8.22	1.078	0.80	0.94
Milk (21d)	4.83	4.77	4.34	4.65	0.165	0.57	0.49
Lactose, %							
Colostrum	5.22	4.08	4.46	4.23	0.269	0.39	0.47
Milk (21d)	5.33	6.36	5.73	6.24	0.198	0.29	0.64
Total solid, %							
Colostrum	21.46	20.03	18.50	22.25	1.225	0.88	0.32
Milk (21d)	15.79	19.34	17.29	19.06	0.737	0.30	0.66
Solid not fat, %							
Colostrum	13.63	14.74	12.37	12.80	0.874	0.56	0.98
Milk (21d)	10.50	11.06	10.15	10.91	0.255	0.92	0.68
Free fatty acid, %							
Colostrum	5.29	5.19	4.14	4.82	0.315	0.45	0.42
Milk (21d)	5.77	8.44	7.46	6.67	0.648	0.90	0.26

[1] Arginine 0.72%: corn-SBM based diet with arginine 0%, Arginine 1.0%: corn-SBM based diet with arginine 0.28%, Arginine 1.5%: corn-SBM based diet with arginine 0.79%, Arginine 2.0%: corn-SBM based diet with arginine 1.35%.
[2] Standard error of mean.
[3] Abbreviation: Lin. (linear) and Quad. (quadratic).

Trial 2. Effects of arginine supplementation levels compared with increased feeding during late gestation on reproductive performance and piglet uniformity in sows.

ABSTRACT: This study was conducted to evaluate the effects of arginine supplementation levels compared with increased feeding during late-gestation on reproductive performance and piglet uniformity in sows. A total of 44 F1 multiparous sows (Yorkshire × Landrace), body weight 229.5 kg; was allotted to one of four treatments in a completely randomized design (CRD). Dietary treatments were consisted of arginine diet with 0.72%, 1.0%, and 1.5% content (2.2kg/d for 2 parity, 2.4 kg/d for 3+ parity), and IF(increased feeding treatment; 3.0kg/d arginine 0.72% diet). Same lactation diet was provided *ad libitum* during lactation period. There was no significant differences in body weight and backfat thicness of sows and lactation feed intake among dietary treatments. Also, additional arginine effects had no significant influences on reproductive performance and growth of their progeny compared with increased feeding treatment. Additiona arginine up to 1.5% improved litter weight at 3 week and its gain linearly (Linear, P=0.06, P=0.05). Additional arginine intake during late gestation had no significant difference in blood profiles compared with that of increased feeding treatment. On the other hand, 1.5% arginine treatment had more advantages to protein utilization with blood urea nitrogen after farrowing rather than 1.0% arginine treatment (P=0.05). Significant effect of additional arginine levels comparing increased feeding scheme were not observed in reproductive performance and the growth of their progeny. Consequently, supplementation of arginine 1.5% in late-gestation diet had an equivalent effect with increased feeding for piglet birth weight and their uniformity.

INTRODUCTION

Most feeding programs for gestating sows are characterized by increased feed intake for a rapid fetal growth during late gestation, because sows need more energy, protein, and amino acid intake at that time (NRC, 2012). Many studies have therefore suggested that increased feed intake in late gestation is likely to meet nutrient requirements of sows (Shields and Mahan, 1983; Walker and Young, 1992) and improve piglet birth weight (Noblet et al., 1985; Mahan, 1998). On the other hand, such increased feed intake has shown negative effects on reproduction such as delayed WEI and postpartum agalactia (Johnston et al., 1989; Dourmad et al., 1994), resulting in poor milk production and lactation feed intake (Mullan and William, 1989; Weldon et al., 1994). Recent study have also demonstrated that increased feed intake during late gestation had no effect on piglet birth weight (Shelton et al., 2009; van Wettere et al., 2012).

Amino acid intake has been shown to be more important than energy intake in late gestation for increasing litter birth weight by fetal development and growth (Moehn and Ball, 2013). Arginine has been used to improve piglet birth weight and piglet uniformity (Mateo et al., 2007; Che et al., 2013). Additional arginine intake has been shown to cause increased nitric oxide (NO) and polyamines (Wu and Morris, 1998; Kim et al., 2007). The nitric oxide thus produced resulted in increased blood flow to the placenta (Sladek et al., 1997; Fan et al., 1998) and improved delivery of essential nutrients from maternal to fetal blood (Gardner et al., 2001). Polyamines also showed positive effects on embryogenesis and placental growth (Reynolds and Redmer, 2001). Thus, arginine was shown to influence placental growth and fetal development via the above mechanism (Wu et al., 2004; 2010).

With the effects of arginine, if the nutrient delivery efficiency from dam to fetus in late gestation increased by arginine supplementation, it can be expected to improving litter birth weight effect with the increased feeding during late gestation.

Therefore, the aim of present study was to compare effects of additional arginine supplementation with those of increased feeding on reproductive performance and piglet uniformity in late-gestating sows.

MATERIALS AND METHODS

Animals

All experimental procedures involving animals were conducted in accordance with the Animal Experimental Guidelines provided by the Seoul National University Institutional Animal Care and Use Committee.

A total of 44 F1 multiparous sows (Yorkshire × Landrace) with average body weight (BW) of 229.5 kg, average backfat thickness of 22.2 mm, and a average parity of 4.8 was allotted to one of four treatments considering BW, backfat thickness, and pairty in completely randomized design when sows be day 70 of gestation. All sows took two times of artificial insemination service according to estrus cycle after weaning and checked pregnancy at day 35 of gestation by utrasound scanner (Donjin BLS, Korea). Before starting the experiment, sows of second parity fed 2.2 kg/d gestation diet and sows of over third parity fed 2.4 kg/d gestation diet

Experimental design and diet

The treatments were as followed: 1) CON: corn-soybean meal (SBM) based diet with L-Arg 0% (Arg 0.72%), 2) Arg10: corn-SBM based diet with L-Arg 0.28% and L-Ala 1.01% (Arg 1.0%) Arg15: corn-SBM based diet with L-Arg 0.79% and L-Ala 0% (Arg 1.5%), 4) IF: increased feeding 3.0 kg/d with corn-SBM based diet (arginine 0.72%). Treatments of CON, Arg10, Arg15 were fed 2.2 kg/d (second parity) or 2.4 kg/d (over third parity) experimental diet, but treatment of IF was fed 3.0kg/d same diet with CON treatment. The dietary arginine content during late gestation (from 70 to 110 day) was as followed; CON: 17.3 g/d, Arg10: 24 g/d,

Arg15: 36 g/d, and IF: 21.2 g/d. Alanine was chosen for the isonitrogenous control because Ala is not toxic and is not a substrate for Arg synthesis, but is extensively catabolized by pigs (Kim and Wu, 2004; Kohly et al., 2004; Mateo et al., 2007). The experimental diet contained 3,265 kcal of ME/kg, 13.55% crude protein , 0.74% total lysine, 0.23% total methionine, 0.45% total threonine, and 0.11% total tryptophan. Lactation diet contained 3,265 kcal of ME/kg, 13.68% crude protein. Arginine and Alanine (Ajinomoto Co. Inc., Tokyo, Japan) in dry form was supplemented in basal diet according to designated treatments. Calcium and total phosphorus of experimental diets were met the nutrient requirement of NRC (1998), other nutrients of experimental diets were met or exceeded the nutrient requirement of NRC (2012). Formula and chemical composition of experimental diet were presented in Table 1.

Animal management

All sows were fed 2.2 kg/d or 2.4 kg/d of experimental diet once a day (08:00) by their parity and reduced feed 0.2kg/d gradually for 5 days before due date of parturition. After farrowing, sows were fed lactation diet 1 to 5 kg/d during 5 days postpartum and fed diet *ad libitum* until weaning.

All sows were accommodated in individual gestation stall (2.20 × 0.64 m) where the indoor temperature was regulated average 20℃ by automatic ventialtion system. At day 110 of gestation, sows were moved from gestation barn to farrowing crates (2.50 × 1.80 m) after washing and disinfecting their body, especially breast and vulva. All sows did not treat delivery inducer and they were taken an assistance when dystocia was happened. The room temperature of lactating barn were kept 28 ± 2℃ and baby house under heating lamp were kept 32± 2℃. Air condition of lactating barn was regulated automatically by ventilation system and air-conditioner. After weaning, sows were moved to breeding barn for the next estrus cycle.

After farrowing, piglets were cross-fostered within treatment until 24 hrs postpartum to balance suckling intensity of sows with equalization of litter size, and

thus to minimize any effect of initial litter size potentially affecting litter growth. Fe-dextran 150 ppm (Gleptosil®, Alstoe, UK) injection, tail docking, and castration (for male piglets) were practiced to all piglets. All piglets were fed breast milk only and creep feed were not provided until weaning.

Body weight, backfat thickness, lactation feed intake

Body weight and backfat thickness of sows were measure at day 70, 90, 110 of gestation, 24 hrs postpartum, and 21 day of lactation. Body weight of sow was measured by electric scale (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea) for sow and backfat thickness was measured at P_2 position (mean value form both side of the last rib and 65 mm away from the backbone) by ultrasound device (Lean Meter®, Renco Corp., Minneapolis, USA). Daily feed wastage was recorded during lactation and lactation feed intake was measured when measuring body weight and backfat thickness of lactating sows at day 21 of lactation.

Reproductive performance

After farrowing, the number of piglets for total born, stillbirth, mummy, alive piglet was recorded and measured bodyweight of alive piglets, stillborn, and mummy by electric scale (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea). When measuring the body weight of piglets, ear notching was practiced for experiment. After then, cross-fostering the piglets within same treatment was done until 12 hrs postpartum for equalizing litter size. The number and body weight of piglets was measured again at 21 day of lactation for calculating litter weight, piglet weight and both weight gain. Parturition time was recorded from start time of farrowing to totally release out of placenta. After the parturition, we collected whole placenta in bucket and recorded the whole placenta by electric scale (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea). Helping frequency was recorded during farrowing time when sows happened dystocia.

Piglet uniformity

To observe piglet uniformity, coefficient of variation (CV) and standard deviation (SD) was calculated from each weight of total born except mummy in 24hrs postpartum. Also, CV and SD were calculated again from body weight of piglets at brith and day 21 of lactation

Blood profiles

Blood collection from sow (n=4 for each treatment) was taken by venipuncture of the jugular vein using 10 ml disposable syringes at day 70, 90, 110 of gestation, 24hrs postpartum and 21 day of lactation. Blood of suckling piglets (n=4 for each treatment) was collected from the anterior vena cava using 3 ml disposable syringes at 24hrs postpartum and 5 ml disposable syringes at 21 day of lactation. All blood samples were enclosed into serum tube (SST^{TM} Ⅱ Advance, BD Vacutainer, Becton Dickinson, Plymouth, UK) as well as EDTA tube (BD Vacutainer K_2E, Becton Dickinson, Plymouth, UK) and centrifuged at 3000 rpm and 4 °C for 15 min (5810R, Eppendorf, Hamburg, Germany) after clotting at room temperature for 30 min. The upper liquid (serum) of the blood was separated to a microtube (Axygen, Union City, CA, USA) and stored at −20 °C freezer until later analysis. Serum glucose (enzymatic kinetic assay, Roche, Germany), insulin (ECLIA, Roche, Germany), BUN (kinetic UV assay, Roche, Germany), total protein (colorimetry, Roche, Germany), creatinine (kinetic colorimetry assay, Roche, Germany), and urea (kinetic UV assay, Roche, Germany) were analyzed by Modular analytics (Hitachi, Japan). Plasma amino acid was analyzed by LC-MS/MS (3200 Q TRAP, AB SCIEX, USA)

Milk composition

Colostrum samples (n=4 for each treatment) were taken from functional mammary glands at 24 hrs postpartum and milk samples (n=4 for each treatment) were taken at 21 day of lactation. Colostrum and milk were collected in a 50ml conical tubes (SPL Life Sciences CO., Ltd., Pocheon-si, Gyeonggi-do, Korea) from the first and second teats after an intravascular injection with 5 IU oxytocin (Komi

oxytocin inj., Komipharm International Co., Ltd., Siheung-si, Gyeonggi-do, Korea) in the ear. After collection, samples were stored in a freezer (−20 °C) until further analysis. Proximate analysis of colostrum and milk was determined using a Milkoscan FT 120 (FOSS, Hillerod, Denmark).

Statistical analysis

All collected data were carried out by least squares mean comparisons and were evaluated with the General Linear Model (GLM) procedure of SAS (SAS Institute, 2004). Orthogonal polynomial contrasts were used to determine linear and quadratic effects by increasing arginine supplementation level. Individual sow was used as the experimental unit in growth performance, reproductive performance, blood profiles, milk composition. Their litter was used as the experimental unit in piglet growth and piglet uniformity. The differences were declared significant at $P<0.05$ or highly significant at $P<0.01$ and the determination of tendency for all analysis was $P \geq 0.05$ and $P<0.10$.

RESULTS

There were no significant differences in body weight and backfat thickness during late gestation (Table 2). Also, body weight, backfat thiness, their changes, or lactation daily feed intake were not affected by dietary treatment in lactation period (Table 3).

Comparing dietary arginine supplementation and increased feeding, number of piglets in total born, stillbirth, mummy, or born alive were affected (Table 4). In otherwise of the previous experiment, the effect on the dietary arginine levels did not appeared significant compared with increased feeding scheme in total litter weight, alive litter weight, and piglet birth weight. Moreover, arginine supplementation or increased feeding during late gestation had no effects on parturition time, helping frequency, or placenta weight. During lactation (0–21 days), litter weight, piglet weight at 24 hrs postpartum and at 21 days of lactation, or their weight gain were not significantly influenced by the dietary treatments (Table 5).

The effect of dietary arginine supplementation or increased feeding in late-gestating sows on piglet uniformity was shown in Table 6. There were no significant differences in standard deviation and CV in piglet birth weight or piglet weight at 21 days of lacation.

There were no significant effects on serum glucose, blood urea nitrogen, total protein, or urea among the dietary treatments (Table 7). Blood urea nitrogen in Arg15 treatment showed significant higher in lactating sows at 24 hrs postpartum (Table 8, P=0.05). Additional arginine supplementation or increased feeding did not have any significant effects on other blood parameters of lactating sows (Table 8) or those of their progeny (Table 9).

As shown in Table 10, composition of colostrum and milk at 21 days of lactation showed no significant influence of dietary treatment. However, the content of free fatty acid in colostrum was showed highly in increased feeding treatment (P=0.01).

DISCUSSION

Additional feed intake during late gestation was found to increase maternal weight gain (Weldon et al., 1994, Van der Peet-Schwering et al., 2004). In contrast, Soto et al. (2011) showed that additional feed intake form day 100 of gestation to farrowing had no effects on sows' body status. Although Coffey et al. (1994) showed that additional feed inatke during late gestation diminished feed intake during lactatinon, Cromwell et al. (1989) found no such effects. In studies using arginine, Mateo et al (2007) showed that 1% dietary arginine supplementation during gestation and lactation did not affect the phyisological changes of sows. In the present study, neither dietary argnine nor additional feed intake during late gestation had any influence on body weight and backfat thickness in gestating sows, or maternal loss lactating sows.

Increased feeding was applied to late gestating sows for meeting nutrient reqruiement for sows (Shields and Mahan, 1983; Walker and Young, 1992) and fetus (Noblet et al., 1985; Mahan, 1998). Some studies have reported that additional feed intake during late gestation improved piglet birth weight (Cromwell et al., 1989; Soto et al., 2011). In other studies, no significant effects on piglet birth weight or litter birth weight occurred by increased feeding (Weldon et al., 1994; Shelton et al., 2009; Miller et al., 2000; van Wettere et al., 2012). Similarly, additional energy intake duirng late gestation improved piglet birth weight in one study (Coffey et al., 1994) but not in another (Van der Peet-Schwering et al., 2004). According to results of the trial 1, increasing level of dietary arginine improved total litter weight linearly, but the current trial did not show any significant effects on total litter weight or piglet birth weight. Mateo et al. (2007) showed that 1 % arginine supplementation did not have any influence on average litter birth weight of all piglets born, or birth weight of all piglets born or those born alive. Che et al. (2013) also found no significant differences in birth weight of total pigs born and live pigs born due to dietary arginine supplementation. However, total litter weight and live litter weight with 1.5 % arginine supplementation were greater than those

in increased feeding, numerically. Consequently, additional argnine supplementation and increased feeding during late gestation did not showed any significant effects on reproductive performance in sows.

Increased fetal weight variation during late gestation may be due to a limitation of sows to provide sufficient nutrient support through blood for maximal growtht of all fetuses (Wu et al., 2006). Supplementation with additional arginine could address this limitation by increasing placental blood flow and inducing fetal development (Wu et al., 2004; Kim et al., 2007). Mateo et al. (2007) reported no significant differences in birth weight variation in all piglets born or those born alive due to 1 % arginine supplementation to gilts. Che et al. (2013) also showed that 1 % arginine supplementation during gestation had no effect on CV in birth weight of total born piglets. In agreement with the above results, the present study did not find any significant effects on piglet uniformity at birtrh and the day 21 of lactation. Moreover, increased feed intake showed the similar coefficient variance and standard deviation in piglet weight at birth and at day 21 of lactation. Consequently, additional arginine or increased feed intake did not have any positive effects on piglet uniformity at birth and the day 21 of lactation.

High energy intake or increased feed intake in late gestation has been found to result in low insulin sensitivity and glucose tolerance affecting pre-weaning survival (Weldon et al., 1994; Van der Peet-Schwering et al., 2004). Piao et al. (2010) suggested that increased feed intake in gestating gilts may cause sows to become insensitive to insulin, thereby exhibiting a smaller response in glucose clearance and decreased feed intake during lactation. In the present study, additional intake of arginine in late gestation did not have any negative effects on glucose-insulin homeostasis. Supplementation with 1.0 % arginine resulted in the highest level of blood urea nitrogen in sows at 24 hrs postpartum. Using blood urea nitrogen as an indicator of amino acid limitation (Kim et al., 2009), a high concentration of blood urea may be derived from excessive ammonia caused by reduced protein synthesis and increased amino acid oxidation (Wu and Morris, 1998). In contrast, serum creatinine and total protein concentration, related to protein metabolism in

lactating sows, were not affected by dietary arginine or increased feeding. Consequently, additional supplementation of arginine in late gestation had no significant effect on blood parameters compared with that of increased feeding.

As with previous result of trial I, the addition of arginine 0.72 to 1.5 % did not have a significant effect on the composition of colostrum and milk at day 21 of lactation including free fatty acid content. Free fatty acid content of colostrum was higher with increased feeding, because total feed intake during late gestation was relatively higher in the increased feeding group than in the arginine supplementation group. Thus, milk composition did not change due to arginine supplementation or increased feeding, and the difference in FFA content was attributed to extra nutrient intake.

CONCLUSION

Increased arginine intake had no significant effects on reproductive performance and growth of progeny compared with increased feeding. Although additional arginine up to 1.5% mproved litter weight and its gain linearly, there were no difference with increased feeding. Consequently, addition of dietary arginine 1.5% in late gestation showed equivalent effects on piglet birth weight and uniformity compared with increased feeding.

REFERENCES

Bass, B. E., Bradley, C. L., Johnson, Z. B., Boyd, R. D., Usry, J. L., Maxwell, C. V., & Frank, J. W. 2011. Influence of dietary L-arginine supplementation to sows during late gestation on sow and litter performance during lactation. Research Series, 597, 151-155.

Che, L., Yang, P., Fang, Z., Lin, Y., & Wu, D. 2013. Effects of dietary arginine supplementation on reproductive performance and immunity of sows. Czech Journal of Animal Science, 58(4), 167-175.

Coffey, M. T., Diggs, B. G., Handlin, D. L., Knabe, D. A., Maxwell, C. V., Noland, P. R., ... & Gromwell, G. L. 1994. Effects of dietary energy during gestation and lactation on reproductive performance of sows: a cooperative study. S-145 Committee on Nutritional Systems for Swine to Increase Reproductive Efficiency. Journal of Animal Science, 72(1), 4-9.

Cromwell, G. L., Hall, D. D., Clawson, A. J., Combs, G. E., Knabe, D. A., Maxwell, C. V., ... & Prince, T. J. 1989. Effects of additional feed during late gestation on reproductive performance of sows: a cooperative study. Journal of Animal Science, 67(1), 3-14.

Dourmad, J. Y., Etienne, M., Prunier, A., & Noblet, J. 1994. The effect of energy and protein intake of sows on their longevity: a review. Livestock Production Science, 40(2), 87-97.

Fan, W. Q., Smolich, J. J., Wild, J., Victor, Y. H., & Walker, A. M. 1998. Major vasodilator role for nitric oxide in the gastrointestinal circulation of the mid-gestation fetal lamb. Pediatric Research, 44(3), 344-350.

Gardner, P. R., Martin, L. A., Hall, D., & Gardner, A. M. 2001. Dioxygen-dependent metabolism of nitric oxide in mammalian cells. Free Radical Biology and Medicine, 31(2), 191-204.

Johnston, L. J., Fogwell, R. L., Weldon, W. C., Ames, N. K., Ullrey, D. E., & Miller, E. R. 1989. Relationship between body fat and postweaning interval to estrus in primiparous sows. Journal of Animal Science, 67(4), 943-950.

Kim, S. W., Mateo, R. D., Yin, Y. L., & Wu, G. 2007. Functional amino acids and fatty acids for enhancing production performance of sows and piglets. Asian Australasian Journal of Animal Science, 20(2), 295.

Kim, S. W., Hurley, W. L., Wu, G., & Ji, F. 2009. Ideal amino acid balance for sows during gestation and lactation. Journal of Animal Science, 87(Suppl 14), E123-E132.

Mahan, D. C. 1998. Relationship of gestation protein and feed intake level over a five-parity period using a high-producing sow genotype. Journal of Animal Science, 76(2), 533-541.

Mateo, R. D., Wu, G., Bazer, F. W., Park, J. C., Shinzato, I., & Kim, S. W. 2007. Dietary L-arginine supplementation enhances the reproductive performance of gilts. The Journal of Nutrition, 137(3), 652-656.

Mateo, R. D., Wu, G., Moon, H. K., Carroll, J. A., & Kim, S. W. 2008. Effects of dietary arginine supplementation during gestation and lactation on the performance of lactating primiparous sows and nursing piglets. Journal of Animal Science, 86(4), 827-835.

Miller, H. M., Foxcroft, G. R., & Aherne, F. X. 2000. Increasing food intake in late gestation improved sow condition throughout lactation but did not affect piglet ivability or growth rate. Animal Science, 71(1), 141-148.

Moehn, S., & Ball, R. O. 2013. Nutrition of pregnant sows. In Proceedings of the 2013 London Swine Conference, Managing for Production, London, Ontario, 55-63.

Mullan, B. P., & Williams, I. H. 1989. The effect of body reserves at farrowing on the reproductive performance of first-litter sows. Animal Science, 48(2), 449-457.

National Research Council. 1998. Nutrient requirements of swine, 10th ed. National Academy Press, Washington, DC.

National Research Council. 2012. Nutrient requirements of swine, 11th ed. National Academy Press, Washington, DC.

Noblet, J., Close, W. H., Heavens, R. P., & Brown, D. 1985. Studies on the energy metabolism of the pregnant sow. British Journal of Nutrition, 53(2), 251-265.

Piao, L. G., Ju, W. S., Long, H. F., & Kim, Y. Y. 2010. Effects of various feeding methods for gestating gilts on reproductive performance and growth of their progeny. Asian-Australasian Journal of Animal Sciences, 23(10), 1354-1363.

Reynolds, L. P., & Redmer, D. A. 2001. Angiogenesis in the placenta. Biology of Reproduction, 64(4), 1033-1040.

Schutte, J. E., Longhurst, J. C., Gaffney, F. A., Bastian, B. C., & Blomqvist, C. G. 1981. Total plasma creatinine: an accurate measure of total striated muscle mass. Journal of Applied Physiology, 51(3), 762-766.

Shelton, N. W., Neill, C. R., DeRouchey, J. M., Tokach, M. D., Goodband, R. D., Nelssen, J. L., & Dritz, S. S. 2009. Effects of increasing feeding level during late gestation on sow and litter performance. Kansas State University, Swine day conference, Manhattan, KS.

Shields, R. G., & Mahan, D. C. 1983. Effects of pregnancy and lactation on the body composition of first-litter female swine. Journal of Animal Science, 57(3), 594-603.

Sladek, S. M., Magness, R. R., & Conrad, K. P. 1997. Nitric oxide and pregnancy. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology, 272(2), R441-R463.

Soto, J., Greiner, L., Connor, J., & Allee, G. 2011. Effect of increasing feeding levels in sows during late gestation on piglet birth weights. J. Anim. Sci, 89 (Suppl 2), 239.

Van der Peet-Schwering, C. M. C., Kemp, B., Binnendijk, G. P., Den Hartog, L. A., Vereijken, P. F. G., & Verstegen, M. W. A. 2004. Effects of additional starch or fat in late-gestating high nonstarch polysaccharide diets on litter performance and glucose tolerance in sows. Journal of Animal Science, 82(10), 2964-2971.

Van Wettere, W. H. E. J., Herde, P., & Hughes, P. E. 2012. Supplementing sow gestation diets with betaine during summer increases litter size of sows with greater numbers of parities. Animal Reproduction Science, 132(1), 44-49.

Walker, B., & Young, B. A. 1992. Modelling the development of uterine components and sow body composition in response to nutrient intake during pregnancy. Livestock Production Science, 30(3), 251-264.

Weldon, W. C., Thulin, A. J., MacDougald, O. A., Johnston, L. J., Miller, E. R., & Tucker, H. A. 1991. Effects of increased dietary energy and protein during late gestation on mammary development in gilts. Journal of Animal Science, 69(1), 194-200.

Weldon, W. C., Lewis, A. J., Louis, G. F., Kovar, J. L., Giesemann, M. A., & Miller, P. S. 1994. Postpartum hypophagia in primiparous sows: I. Effects of gestation feeding level on feed intake, feeding behavior, and plasma metabolite concentrations during lactation. Journal of Animal Science, 72(2), 387-394.

Wu, G, & Morris, S. M. 1998. Arginine metabolism: nitric oxide and beyond. Biochemical Journal, 336(1), 1-17.

Wu, G., Jaeger, L. A., Bazer, F. W., & Rhoads, J. M. 2004. Arginine deficiency in preterm infants: biochemical mechanisms and nutritional implications. The Journal of Nutritional Biochemistry, 15(8), 442-451.

Wu, G., Bazer, F. W., Wallace, J. M., & Spencer, T. E. 2006. Board-invited review: intrauterine growth retardation: implications for the animal sciences. Journal of Animal Science, 84(9), 2316-2337.

Wu, G., Bazer, F. W., Burghardt, R. C., Johnson, G. A., Kim, S. W., Li, X. L., ... & Spencer,

T. E. 2010. Impacts of amino acid nutrition on pregnancy outcome in pigs: mechanisms and implications for swine production. Journal of Animal Science, 88(13), E195-E204.

Table 1. The formulas and chemical composition of gestation diet

Item	Treatment[1)]			
	CON	Arg10	Arg15	IF
Ingredients, %				
Corn	75.16	75.38	76.02	76.59
Soybean meal-46	12.57	12.57	12.26	9.04
Wheat bran	1.64	1.93	2.35	3.74
Palm kernel meal	3.00	3.00	3.00	3.00
Tallow	2.48	2.32	2.07	2.65
L-lysine HCl (78%)[2)]	0.26	0.26	0.26	0.37
DL-methionine (99%)[3)]	0.05	0.04	0.04	0.05
L-arginine (99%)[4)]	0.00	0.28	0.79	1.35
L-alanine (98%)[5)]	1.63	1.01	0.00	0.00
MDCP	1.46	1.46	1.46	1.45
Limestone	1.15	1.15	1.15	1.16
Vit. mix[6)]	0.10	0.10	0.10	0.10
Min. mix[7)]	0.10	0.10	0.10	0.10
Choline chloride-50	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Chemical composition [8)]				
ME, kcal/kg	3,265.03	3,265.07	3,265.03	3,265.00
Crude protein, %	13.55	13.55	13.55	13.55
Total lysine, %	0.74	0.74	0.74	0.74
Total methionine, %	0.24	0.23	0.23	0.23
Total threonine	0.45	0.45	0.45	0.40
Total tryptophan	0.11	0.11	0.11	0.09
Calcium, %	0.75	0.75	0.75	0.75
Total phosphorus, %	0.60	0.60	0.60	0.60

[1)] CON: corn-SBM based diet contained with 0.72% arginine, Arg10: corn-SBM based diet contained with 1.0% arginine, Arg15: corn-SBM based diet contained with 1.5% arginine, IF: increased feeding of CON diet (IF: 3.0kg/d vs other treatment: 2.2 or 2.4 kg/d).

[2)] L-lysine·HCl (Daesang, Korea)

[3)] DL-methionine (CJcheiljedang, Korea)

[4)] L-arginine (Ajinomoto Co. Inc., Japan)

[5)] L-alanine (Ajinomoto Co. Inc., Japan)

[6)] Provided per kg of diet : Vitamin A, 8,000 IU; Vitamin D_3, 1,600 IU; Vitamin E, 32 IU; d-biotin, 64g; Riboflavin, 3.2mg; Calcium pantothenic acid, 8mg; Niacin, 16mg; Vitamin B_{12}, 12㎍; vitamin K, 2.4mg.

[7)] Provided per kg of diet : Se, 0.1mg; I, 0.3mg; Mn, 24.8mg; CuSO4, 54.1mg; Fe, 127.3mg; Zn, 84.7mg; Co, 0.3mg.

[8)] Calculated value.

Table 2. Effects of arginine supplementation compared with increased feeding during late gestation on body weight and backfat thickness in gestating sows

	Treatment[1)]				SEM[2)]	P-value
	CON	Arg10	Arg15	IF		
Body weight, kg						
70 day	232.6	223.0	232.2	230.2	3.61	0.77
90 day	256.0	249.1	249.1	253.8	3.25	0.85
110 day	266.0	256.1	256.8	265.0	3.42	0.64
BW gain (70-110d)	33.4	33.1	24.6	34.8	2.35	0.41
Backfat thickness, mm						
70 day	22.7	22.8	20.4	23.0	0.83	0.65
90 day	22.9	23.9	21.8	22.4	0.81	0.84
110 day	23.3	23.9	22.0	25.4	0.94	0.64
BF gain (70-110d)	0.6	1.1	1.6	2.4	0.39	0.42

[1)] CON: corn-SBM based diet contained with 0.72% arginine, Arg10: corn-SBM based diet contained with 1.0% arginine, Arg15: corn-SBM based diet contained with 1.5% arginine, IF: increased feeding of CON diet (IF: 3.0kg/d vs other treatment: 2.2 or 2.4 kg/d).

[2)]Standard error of mean.

Table 3. Effects of arginine supplementation compared with increased feeding during late gestation on body weight, backfat thickness, and ADFI in lactating sows

	Treatment[1)]				SEM[2)]	P-value
	CON	Arg10	Arg15	IF		
Body weight, kg						
24hrs postpartum	235.8	227.0	226.6	239.2	3.32	0.44
Day 21 of lactation	223.0	218.1	211.4	220.3	3.50	0.68
BW changes, (0-21d)	-12.8	-8.9	-15.2	-18.9	1.43	0.10
Backfat thickness, mm						
24hrs postpartum	22.3	21.4	20.8	23.9	1.01	0.72
Day 21 of lactation	21.1	19.3	18.3	20.7	0.91	0.70
BF changes, (0-21d)	-1.2	-2.1	-2.5	-3.2	0.51	0.56
ADFI, kg/d	4.52	4.66	4.72	4.46	0.108	0.82

[1)] CON: corn-SBM based diet contained with 0.72% arginine, Arg10: corn-SBM based diet contained with 1.0% arginine, Arg15: corn-SBM based diet contained with 1.5% arginine, IF: increased feeding of CON diet (IF: 3.0kg/d vs other treatment: 2.2 or 2.4 kg/d).
[2)]Standard error of mean.

Table 4. Effects of arginine supplementation compared with increased feeding during late gestation on reproductive performance in sows

	Treatment[1)]				SEM[2)]	P-value
	CON	Arg10	Arg15	IF		
No. of piglets						
Total born	13.87	15.00	15.00	13.50	0.594	0.75
Stillbirth	0.87	1.00	0.87	0.88	0.193	0.99
Mummy	0.87	0.43	0	0.12	0.164	0.23
Born alive	12.13	13.57	14.13	12.50	0.536	0.53
Total litter weight, kg	19.48	19.91	20.93	20.04	0.542	0.82
Alive litter weight, kg	17.96	18.61	20.14	19.19	0.585	0.61
Piglet birth weight, kg	1.53	1.41	1.46	1.55	0.043	0.66
Parturition time, min.	181.2	217.1	239.3	203.1	17.77	0.71
Helping frequency	1.60	2.28	1.75	3.25	0.290	0.29
Placenta weight, kg	4.276	3.927	3.344	3.804	0.2605	0.68

[1)] CON: corn-SBM based diet contained with 0.72% arginine, Arg10: corn-SBM based diet contained with 1.0% arginine, Arg15: corn-SBM based diet contained with 1.5% arginine, IF: increased feeding of CON diet (IF: 3.0kg/d vs other treatment: 2.2 or 2.4 kg/d).
[2)]Standard error of mean.

Table 5. Effects of arginine supplementation compared with increased feeding during late gestation on litter performance in sows

	Treatment[1)]				SEM[2)]	P-value
	CON	Arg10	Arg15	IF		
No. of piglets						
After-fostering	11.75	11.85	12.00	11.87	0.061	0.55
Day 21 of lactation	10.50	10.83	11.62	11.25	0.224	0.30
Litter weight, kg						
After-fostering	17.73	16.27	17.77	18.22	0.428	0.45
Day 21 of lactation[†]	51.45	54.59	61.54	59.56	1.903	0.20
Litter weight gain, kg[†]	33.72	38.32	43.77	41.34	1.758	0.18
Piglet weight, kg						
After-fostering	1.51	1.38	1.48	1.53	0.036	0.49
Day 21 of lactation	4.85	5.07	5.32	5.29	0.131	0.55
Piglet weight gain, kg	3.34	3.69	3.84	3.76	0.119	0.47

[1)] CON: corn-SBM based diet contained with 0.72% arginine, Arg10: corn-SBM based diet contained with 1.0% arginine, Arg15: corn-SBM based diet contained with 1.5% arginine, IF: increased feeding of CON diet (IF: 3.0kg/d vs other treatment: 2.2 or 2.4 kg/d).

[2)]Standard error of mean.

[†]Linear response ($0.05 \leq P < 0.10$) to dietary arginine levels among Con, Arg10, and Arg15 treatment.

Table 6. Effects of arginine supplementation compared with increased feeding during late gestation on piglet uniformity at birth and day 21 of lactation

	Treatment[1)]				SEM[2)]	P-value
	CON	Arg10	Arg15	IF		
Parturition						
SD	340.0	279.2	279.7	329.5	13.39	0.23
CV	24.00	21.86	20.33	22.27	1.104	0.70
Day 21 of lactation						
SD	1289.8	1252.9	1241.0	1304.5	52.98	0.97
CV	29.43	25.42	24.41	24.10	1.295	0.41

[1)] CON: corn-SBM based diet contained with 0.72% arginine, Arg10: corn-SBM based diet contained with 1.0% arginine, Arg15: corn-SBM based diet contained with 1.5% arginine, IF: increased feeding of CON diet (IF: 3.0kg/d vs other treatment: 2.2 or 2.4 kg/d).
[2)]Standard error of mean.

Table 7. Effects of arginine supplementation compared with increased feeding during late gestation on blood profiles in gestating sows

	Treatment[1)]				SEM[2)]	P-value
	CON	Arg10	Arg15	IF		
Glucose, mg/dL						
70 day	----------66.8----------					
90 day	71.6	74.5	72.5	71.5	0.99	0.75
110 day	75.5	64.7	69.7	69.2	3.02	0.70
BUN, mg/dL						
70 day	----------13.2----------					
90 day	12.9	13.1	15.1	12.8	0.65	0.61
110 day	13.9	15.5	16.3	14.4	0.66	0.59
Total protein, g/dL						
70 day	----------7.6----------					
90 day	7.16	7.66	7.50	7.56	0.09	0.27
110 day	6.72	6.65	6.67	6.82	0.07	0.87
Urea, mg/dL						
70 day	----------28.3----------					
90 day	27.6	28.0	32.4	27.5	1.40	0.62
110 day	29.8	33.3	34.9	30.9	1.36	0.59

[1)] CON: corn-SBM based diet contained with 0.72% arginine, Arg10: corn-SBM based diet contained with 1.0% arginine, Arg15: corn-SBM based diet contained with 1.5% arginine, IF: increased feeding of CON diet (IF: 3.0kg/d vs other treatment: 2.2 or 2.4 kg/d).
[2)]Standard error of mean.

Table 8. Effects of arginine supplementation compared with increased feeding during late gestation on blood profiles in lactating sows

	Treatment[1)]				SEM[2)]	P-value
	CON	Arg10	Arg15	IF		
Glucose, mg/dL						
24hrs postpartum	73.7	84.2	80.0	82.0	4.29	0.87
Day 21 of lactation	70.0	56.2	74.2	75.7	3.61	0.21
Creatinine, mg/dL						
24hrs postpartum	3.08	3.15	3.15	3.27	0.116	0.96
Day 21 of lactation	2.36	2.48	2.51	2.80	0.076	0.23
BUN, mg/dL						
24hrs postpartum[††]	12.4	25.7	16.2	16.0	1.88	0.05
Day 21 of lactation	15.0	14.1	14.1	16.3	0.77	0.74
Total protein, g/dL						
24hrs postpartum	6.67	6.52	6.60	6.60	0.102	0.97
Day 21 of lactation	7.55	7.45	7.55	7.55	0.081	0.97
Insulin, μU/mL						
24hrs postpartum	1.97	2.20	1.42	1.40	0.223	0.53
Day 21 of lactation	2.22	2.17	1.40	1.32	0.231	0.37

[1)] CON: corn-SBM based diet contained with 0.72% arginine, Arg10: corn-SBM based diet contained with 1.0% arginine, Arg15: corn-SBM based diet contained with 1.5% arginine, IF: increased feeding of CON diet (IF: 3.0kg/d vs other treatment: 2.2 or 2.4 kg/d).

[2)]Standard error of mean.

[††]Quadratic response (P=0.01) to dietary arginine levels among Con, Arg10, and Arg15 treatment.

Table 9. Effects of arginine supplementation compared with increased feeding during late gestation on blood profiles in piglets

	Treatment[1)]				SEM[2)]	P-value
	CON	Arg10	Arg15	IF		
Glucose, mg/dL						
24hrs postpartum	89.2	92.0	100.7	128.0	9.97	0.54
Day 21 of lactation	117.7	113.0	116.0	114.0	3.03	0.95
Creatinine, mg/dL						
24hrs postpartum	0.76	0.80	0.70	0.74	0.064	0.97
Day 21 of lactation[††]	0.41	0.65	0.78	1.14	0.139	0.34
BUN, mg/dL						
24hrs postpartum	22.5	21.5	22.3	26.9	1.63	0.69
Day 21 of lactation	9.6	7.7	9.2	11.4	1.25	0.80
Total protein, g/dL						
24hrs postpartum	5.82	4.82	6.00	6.72	0.369	0.36
Day 21 of lactation	4.82	4.57	4.27	5.67	0.251	0.23

[1)] CON: corn-SBM based diet contained with 0.72% arginine, Arg10: corn-SBM based diet contained with 1.0% arginine, Arg15: corn-SBM based diet contained with 1.5% arginine, IF: increased feeding of CON diet (IF: 3.0kg/d vs other treatment: 2.2 or 2.4 kg/d).

[2)]Standard error of mean.

[††]Lienar response (P=0.01) to dietary arginine levels among Con, Arg10, and Arg15 treatment.

Table 10. Effects of arginine supplementation compared with increased feeding during late gestation on milk composition in lactating sows

	Treatment[1)]				SEM[2)]	P-value
	CON	Arg10	Arg15	IF		
Casein, %						
Colostrum	6.52	4.60	5.41	8.95	0.714	0.16
Milk (21d)	4.09	4.21	4.31	3.89	0.075	0.21
Fat, %						
Colostrum	7.36	7.92	8.39	8.20	0.252	0.54
Milk (21d)	6.03	6.78	6.68	5.47	0.301	0.38
Protein, %						
Colostrum	8.45	5.82	6.94	11.78	0.990	0.17
Milk (21d)	4.59	4.77	4.87	4.37	0.096	0.26
Lactose, %						
Colostrum	4.21	4.61	4.30	3.66	0.160	0.24
Milk (21d)	6.20	6.14	6.08	6.22	0.051	0.78
Total solid, %						
Colostrum	22.39	20.24	21.91	26.98	1.019	0.11
Milk (21d)	18.00	19.00	18.95	17.12	0.382	0.23
Solid not fat, %						
Colostrum	12.98	10.62	11.52	15.76	0.850	0.16
Milk (21d)	10.88	10.86	10.96	10.58	0.071	0.21
Free fatty acid, %						
Colostrum	3.98[b]	4.27[b]	4.09[b]	4.79[a]	0.105	0.01
Milk (21d)	3.93	3.85	3.73	3.73	0.183	0.98

[1)] CON: corn-SBM based diet contained with 0.72% arginine, Arg10: corn-SBM based diet contained with 1.0% arginine, Arg15: corn-SBM based diet contained with 1.5% arginine, IF: increased feeding of CON diet (IF: 3.0kg/d vs other treatment: 2.2 or 2.4 kg/d).

[2)]Standard error of mean.

Chapter IV : Effects of Dietary Energy and Lysine Levels on Physiological Responses, Reproductive Performance, Blood Profiles, and Milk Composition in Primiparous Sows

ABSTRACT: This experiment was conducted to evaluate the effects of dietary energy and lysine levels on sow and litter performance in primiparous sows. A total of 48 gilts (F1, Yorkshire x Landrace), initial BW of 168.1 ± 9.71 kg and day 35 of gestation, were allotted to one of eight treatments with a 2 x 4 factorial arrangement. The first factor was energy level in diet (3,265 or 3,365 kcal of ME/kg), and the second factor was lysine level in diet (gestation 0.55, 0.65, 0.75, 0.85%, lactation 0.70, 0.85, 1.00, 1.15%). All sows were fed 2.0 kg/d of experimental gestation diet and fed *ad libitum* of lactation diet. High energy group had a greater body weight gain (Energy, P=0.07) and a thicker backfat (Energy, P=0.09) in gestation period. In lactation period, high energy group had a higher body weight (Energy, P=0.09) and less body weight loss (Energy, P=0.05) than low energy group. Backfat thickness also was higher in high energy treatment at 24 hrs postpartum and day 21 of lactation (Energy, P=0.04, P=0.07). Weaning to esturs interval showed shorter in Lys0.55/0.70 and Lys0.75/1.00 (Lysine, P=0.03). In reproductive performance, there was significant interaction in total born and born alive (Interaction, P<0.01, P=0.04). However, dietary energy and lysine levels did not affect total litter weight, alive litter weight, litter weight gain, and piglet uniformity. Sows fed high energy diet had a tendency of greater piglet weight at day 21 of lactation and weight gain (Energy, P=0.08, P=0.08). In blood profiles, blood urea nitrogen was greater in high energy group (Energy, P=0.08) and increased as dietary lysine level increase (Lysine, P=0.09) at day 110 of gestation. In lactating sows, the effect of lysine level had significant influences on blood urea nitrogen at day 21 of lactation (Lysine, P=0.02) and showed lineaer or quadratic decrease in

Lys0.75/1.00 treatment at 24hrs postpartum (Quadratic, P=0.02) and day 21 of lactation (Linear, P<0.01). In composition of colostrum, high energy diet group had higher casein, protein, total solid, solid not fat, and free fatty acid concentration than those in low energy diet group (Energy, P=0.03, P=0.03, P=0.03, P=0.03, and P<0.01, respectively). Free fatty acid of colostrum was higher in Lys0.75/1.0 and Lys0.8/1.15 group (Lysine, P=0.01). Sows fed high energy diet had a tendency to increasing body protein mass in day 21 of lactation (Energy, P=0.05). In addition, body fat mass of sows fed high energy diet tended to increase in whole gestation period and day 21 of lactation (Energy, P=0.06, P=0.08) and they had lower body fat loss during lactation (Energy, P=0.09). Consequently, sows fed 3,365 kcal of ME/kg diet had more gain of body weight and backfat compared with sows fed 3,265 kcal of ME/kg diet. Also, piglets from sows fed 3,365 kcal of ME/kg diet showed greater weight gain during lactation. Although significant effects were not observed in reproductive performance and piglet uniformity, total lysine 0.75% for gestation and total lysine 1.00% for lactation with 3,365 kcal of ME/kg energy levels had better performance for sows and growth of their progeny.

Key words : Energy, Lysine, growth performance, reproductive performance, Primiparous sows

INTRODUCTION

Research on amino acid utilization in primiparous sows was limited due to the complex conceptus products associated with maternal growth, fetal growth, mammary growth, milk production, and maternal nutrient mobilization during gestation and lactation (Kim et al., 2009). Thus, studies on improving productivity and longevity in primiparous sows by supplying adequate energy and amino acids are proceed in many countries.

Some researchers have reported no detectable effects of dietary energy levels on the number of embryos and embryo survival (Liao and Veum, 1994; Pharazyn et al., 1991); However, Jindal et al. (1996) demonstrated that gilts fed a constant energy diet had a decreased embryonic survival rate during early gestation, and Dyck and Strain (1983) indicated that a high-energy diet induced embryonic mortality and reduced the number of embryos. An increase in body weight (BW) of sows with a high-energy intake during gestation has been reported (Dourmad, 1991; van den Brand et al., 2000). Furthermore, excessive weight gain of gestating sows has a negative influence on litter size (Ruiz et al., 1968), lactation feed intake (Dourmard, 1991), and subsequent parity performance (Zak et al., 1997; Han et al., 2000).

Also, primiparous sows have a rapid growth of the fetus and mammary tissues during late gestation and the amino acid requirement are greater than sows in other parity (Kim et al., 2009). Maintenance lysine requirement has been estimated to be 2.1 g/d, based on 36 mg/kg $BW^{0.75}$ (Fuller, 1989), 4.4 g/d for growth of the conceptus and reproductive tissues, and 5.5 g/d for maternal growth (NRC, 1998). As reported by NRC (2012), the total lysine requirement rose from 0.57% to 0.80% in gestating sows and from 0.91% to 0.93% in lactating sows. NRC(2012) suggested that optimal lysine intake was 12.4/19.3 g/d (<90d, >90d) and 52.6-56.5 g/d in gestation and lactation, respectively. In Korea feed standard (2017), optimal lysine intake of primiparous sows was suggested as 12.35 g/d and 42.3-46.1 g/d in gestation and lactation, respectively. Yang et al. (2008) indicated that high lysine

intake increased the gain in BW of gestating sows, and the birth and weaning weights of piglets in primiparous sows. Zhang et al. (2011) reported that increasing the dietary lysine level improved the total litter weight at birth and the average piglet birth weight linearly.

Inadequate energy or lysine intake results in impaired body condition of gestating sows and thus could be a main reason for reproductive problems leading to culling (Young et al., 1990). Therefore, this study was conducted to evaluate the effect of the dietary energy and lysine levels on physiological responses, reproductive performance, blood profiles, and milk composition in primiparous sows.

MATERIALS AND METHODS

Animals and housing

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

A total of 50 gilts (F1, Yorkshire × Landrace; Darby, Korea), average body weight 90kg, were selected and housed in an seperated barn (11×14 m). The gilts were provided feed and water *ad libitum* until reaching 120kg body weight. Then gilts moved to breeding barn and got into individual gestation stall (2.20 × 0.65 m) with concrete slatted floor. The sows were fed gestation diet 800g daily for ADG of 750 g/d. Gilts with average body weight of 135-140kg were taken AI service, after three or four estrus cycles. Estrus and heat detection were diagnosed twice a daily in the presence of two mature boar (Duroc) using the back pressure test. Gilts were artificially inseminated AI) with fresh diluted semen (Dary AI center, Chunju-si, Chungcheongbuk-do, Korea) twice on 12 hours interval. Confirmation of pregnany was practiced at 21 day of gestation by re-estrus check and at 35 day of gestation by ultrasound pregnancy diagnostic device (Easyscan, Dongjin BLS Co. Ltd., Gwangju-si, Gyeonggi-do, Korea).

A total of 48 primiparous sows (F1, Yorkshire × Landrace; Darby, Korea) with an initial BW of 168.1 ± 9.71 kg were used for a trial at a research farm of Seoul National University (Eumseong-gun, Chungcheongbuk-do, Korea). Rest of 2 primiparous sows were out in current study with delayed and weak estrus. Pregnant sows were allotted to each treatment based on body weight and backfat thickness at 35 day of gestation in a completely randomized design (CRD) with 6 replicates. Gestating sows were housed in an individual gestation stall (2.20 × 0.65 m) until 110 day of gestation. Each gestation stall was equipped with a feeder and a waterer. On the 110 day of gestation, sows were moved into farrowing barn and placed in individual farrowing crate (2.50 × 1.80 m). Each farrowing crate was equipped with

a feeder and a waterer and a baby house with heating lamp and a waterer for piglets. The room temperature was maintained average 20℃ ± 3℃ and 28 ± 2℃ for gestating and lactating sows, respectively. Baby house under heating lamp was kept 32± 2℃. All sows were fed 2.0 kg/d of experimental diet once a day (08:00) and reduced feed 0.2kg/d gradually for 5 days before due date of parturition. After farrowing, the lactation diet was increased gradually from 1.0 kg/d to 5 kg/d during 5 days postpartum and fed diet *ad libitum* until weaning.

Experimental design

The experiment was designed as a 2 × 4 factorial arrangement and main factors were dietary energy level and dietary lysine level. The experimental diets were contained different energy levels (3,265 or 3,365 kcal of ME/kg) and lysine levels (total lysine 0.55, 0.65, 0.75, 0.85% or 11.0, 13.0, 15.0, 17.0g/d) for gestating sows. The lactation diets contained different energy levels (3,265 or 3,365 kcal of ME/kg) and lysine levels (total lysine 0.70, 0.85, 1.00, 1.15%) in lactation period. All nutrients of gestation and lactation diets were met or exceeded the the recommendations of NRC (2012). The formula and chemical composition of experimental diets in gestation and lactation were presented in Table 1 and 2, respectively.

Sample collection and analysis

The body weight and backfat thicknes (P_2 position), body length of sows were measured at 35, 110 day of gestation, 24hrs postpartum, 21 day of lactation. Body weight was measured by electric scale (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea) and backfat thickness was measured by ultrasound lean meter (Anyscan BF, Songkang GLC Co. LTD, Seongnam-si, Gyeonggi-do, Korea). The weaning to estrus interval (WEI) of sows was checked from weaning to first estrus period. Voluntary feed intake of lactating sows was measured by record of feed supply and wastage during lactation period.

Within 12hrs postpartum, the number of piglets in total born, born alive,

stillborn, mummy, and their weight were recorded (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea), respectively. In 21 day of lactation, body weight of piglets was measured for litter weight and piglet weight. Also, the piglet body weight at birth and 21 day of lactation from one litter was used for calculating piglet uniformity such as coefficient of variation (CV), standard deviation (SD).

Blood samples (n=4 for each treatment except 2 sows for the highest BW and the lowest BW) were collected from the jugular vein of sows and anterior vena cava or nursery pigs with serum tube (SST^{TM}II Advance, BD Vacutainer, Becton Dickinson, Plymouth, UK) and centrifuged at 3,000 rpm and 4℃ for 15 minutes (5810R, Eppendorf, Hamburg, Germany). After then, serum was transferred into microtube (Axygen, Union City, CA, USA) and stored at -20℃ freezer until further analysis. Total protein (colorimetry, TP2, Roche, Germany), creatinine (kinetic colorimetry assay, CREJ2, Roche, Germany), blood urea nitrogen (kinetic UV assay, UREAL, Roche, Germany), glucose (enzymatic reference method with hexokinase, Glucose HK Gen.3, Roche, Germany). Also, insulin-like growth factor-1 (IGF-1) was analyzed by chemiluminescent immunoassay (CLIA, LIAISON IGF-1, DiaSorin, Italy) by Liaison XL (DiaSorin, USA).

Colostrum at 12hrs postpartum and milk at day 21 of lactation were collected from the first and second teats of sows (n=4 for each treatment with the same sows for blood sampling) after 5 IU of the oxytocin injection (Komi oxytocin inj., Komipharm International Co., Ltd., Siheung-si, Gyeonggi-do, Korea) in ear vein. Collected milk samples were stored at -20℃ freezer until later analysis. Proixmate analysis of colostrum and milk was conducted in National Institute of Animal Science (Wanju-gun, Jeollanbuk-do, Korea) using Milkoscan FT 120 (FOSS, Hillerod, Denmark)

The protein and fat mass, their gain of primiparous sows were calculated using the equations of Dourmad et al. (1997).

$$EBW\ (kg) = 0.905 \times BW^{1.013}$$

$$Fat\ (kg) = -26.4 + 0.221 \times EBW + 1.331 \times backfat\ (mm)$$

Protein (kg) = 2.28 + 0.178 × EBW + 0.333 × backfat (mm)

Statistical Analysis

All of collected data were carried out by least squares mean comparisons and were evaluated with the General Linear Model (GLM) procedure of SAS (SAS Institute, 2004). Individual sows and their litters were used as the experimental unit and were analyzed as a two-way ANOVA. Orthogonal polynomial contrasts were used to detect linear and quadratic responses to lysine levels when significance of lysine effect detected. The differences were declared significant at $P<0.05$ or highly significant at $P<0.01$ and the determination of tendency for all analysis was $0.05 \geq P$ and $P<0.10$.

RESULTS

The effects of dietary energy and lysine levels on body weight and backfat thickness was present in Table 3. Sows fed high energy diet gained more body weight than that of sows fed low energy diet (Energy, P=0.07). In lactation period (Table 4), although sows fed high energy diet had a tendency of greater body weight (Energy, P=0.09), body weight loss occurred smaller in sows fed high energy diet (Energy, P=0.05). High energy treatment had greater backfat thickness at 24hrs postpartum and day 21 of lactation (Energy, P=0.04, P=0.07, respectively). However, lactation daily feed intake was not affected by dietary energy and lysine levels. Sows fed Lys0.55/0.70 and Lys0.75/1.00% diet showed the shorter weaning to estrus interval than other treatment (Lysine, P=0.03).

The effects of dietary energy and lysine levels on reproductive performance and the growth of their progeny were shown in Table 5 and 6, respectively. Sows fed low energy diet showed the trend of decreased number of total born and born alive piglets, but sows fed high energy diet showed the trend of increasing number of total born and born alive piglets (Interaction, P<0.01, P=0.04, respectively). The number of mummy was greater in Lys0.65/0.85 group and lower in Lys0.85/1.15 group (Lysine, P=0.01). There were no significant difference in total litter weight and alive litter weight. However, alive piglet weight was decreased in high energy group and increased in low energy group (Interaction, P=0.02). Piglet uniformity, such as standard deviation and coefficient variation of piglet weight, ratio of irregular birth weight at farrowing, did not showed any significant difference. Litter weight and litter weight gain during lactation were not affected by dietary energy and lysine levels (Table 6). According to energy effect, sows fed high energy diet had a tendency of greater piglet weight at day 21 of lactation and weight gain (Energy, P=0.08, P=0.08, respectively). Like the result of piglet uniformity at farrowing, any treatment effects had no significant influences on standard deviation and coefficient variation of piglet weight from same litter in day 21 of lactation.

In blood profiles of primiparous sows (Table 7), there were no significant effects in total protein concentrations. Blood creatinine was greater in Lys0.65/0.85 and Lys0.75/1.00 groups in 24hrs postpartum (Lysine, P=0.04). In gestating sows, blood urea nitrogen was increased linearly as lysine level increased (Lysine, P=0.09; Linear, P=0.03). However, in lactating sows, blood urea nitrogen was decreased quadratically in Lys0.75/1.00 group (Quadratic, P=0.02). In addition, blood urea nitrogen was decreased as lysine level increased (Linear, P<0.01) and showed significantly lower in Lys0.75/1.00 and Lys0.85/1.15 group (Lysine, P=0.02). In blood profiles of suckling piglet (Table 8), dietary treatment had no effects on glucose, creatinine, BUN, and IGF-1.

In composition of colostrum (Table 9), high energy diet group had greater casein, protein, total solid, solid not fat, and free fatty acid than those of low energy diet group (Energy, P=0.03, P=0.03, P=0.03, P=0.03, and P<0.01, respectively). Otherwise, lactose of colostrum was lower in high energy group (Energy, P=0.02), however, lactose of milk at day 21 of lactation was higher in high energy group (Energy, P=0.04). For lysine effect, Lys0.75/1.00 and Lys0.85/1.15 treatments had high level of FFA rather than Lys0.65/0.85 treatment in milk at day 21 of lactation (Lysine, P=0.01).

In body composition of gestation and lactation period (Table 10), sows fed high energy diet had a tendency to increasing body protein mass in day 21 of lactation (Energy, P=0.05). Body fat mass of sows fed high energy diet tended to increase in whole gestation period and day 21 of lactation (Energy, P=0.06, P=0.08, respectively). Also, body fat loss during lactation period (0-21 days) was reduced in high energy group comparing that of low energy group (Energy, P=0.09).

DISCUSSION

In the present study, high-energy intake resulted in greater BW gain during gestation, and greater BW, backfat thickness, and decreased BW loss during lactation. Increased energy intake (3,100 to 3,400 kcal of ME/kg) during gestation in primiparous sows resulted in greater BW gain (Noblet et al., 1990; Long et al., 2010; Jin et al., 2016). Heo et al. (2007) showed that when treatment is composed of three energy levels (3,265, 3,330, and 3,400 kcal of ME/kg), the energy effect was not observed in gestation BW and backfat thickness, but there was a greater BW loss and backfat loss in the low-energy treatment sows during the lactation period. Sows fed a high-energy diet led to BW and backfat gain during gestation compared to sows fed a low-energy diet and lactation feed intake similar to a high-energy diet reduced the body reserve loss for milk production.

In the current study, there were no lysine effects on BW and backfat thickness during gestation in primiparous sows, which was in agreement with the Cooper et al. (2001) study, in which primiparous sows were used. Cooper et al. (2001) reported that the level of dietary lysine during gestation did not affect gestation BW gain (average of 10.6 and 13.2 g total lysine/d). In addition, supplementation with 16g/d of lysine increased BW gain in primiparous sows during gestation compared with sows fed 4 or 8 g/d of lysine (Kusina et al., 1999a). Total lysine intake during gestation in the current study was 11, 13, 15, and 17 g/d; these values were at or above the nutrient recommendations (9.4-11.4 g and 12.4-19.3 g of total lysine/d) of NRC (1998) and NRC (2012), respectively. Thus, the current results demonstrated that the recommendations of NRC (1998) or NRC (2012), with respect to daily lysine intake, were adequate.

Although there was no significant difference in BW and backfat changes during lactation in the current study, Yang et al. (2000) demonstrated that high-lysine intake (1.6% vs. 1.0% vs. 0.4%) during lactation reduced BW loss and lysine intake during lactation did not affect backfat change during the entire lactation

period. Also, Knabe et al. (1996) demonstrated that various lysine diets (0.6, 0.75, and 0.9% total lysine) had no influence on BW and backfat loss during lactation. Thus, low-lysine intake did not significantly affect backfat loss, but tended to increase muscle protein degradation, suggesting that dietary protein was insufficient to support milk production (Yang et al., 2000; Jones and Stahly, 1999). Moreover, Prunier et al. (1993) observed that milk output of energy and nitrogen is similar in primiparous sows fed 67.3 or 40.1 kJ ME/d during lactation; however, these low intakes of energy and feed resulted in severe BW and backfat loss of primiparous sows.

In the current study, there was an interaction between energy and lysine effect in the number of piglet birth and alive piglet weight. These results were from the lower number of piglet birth in Lys0.85/1.15 with 3,265 kcal of ME/kg treatment and Lys0.65/0.85 with ME 3,365 kcal of ME/kg treatment. There were some possibilities for these results, one of possibilities was not the result from the dietary factors and it was influenced by the ovulation rate and fetal survival of individual primiparous sows before the experiment started. Cooper et al. (2001) reported that increased lysine intake in the gestation diet had no significant effects on litter size and growth; however, total births and total litter weight were affected by parities. They observed that increased gestation energy intake was related to a higher number of piglets born alive and increased litter weight at farrowing, but not in primiparous sows because primiparous sows were still growing to mature size. The other possibility was estimated by amino acid imbalance. In current study, total lysine level was adjusted on each treatment with same content of limiting amino acids such as methionine, threonine, and tryptophan. This imbalance of amino acids may result in the unexpected number of piglet birth and piglet birth weight. Touchette et al. (1998) demonstrated that different lysine levels with the constant ideal amino acids ratios by adding valine, threonine, and sulfur amino acids to first parity sows, it resulted in a reduced number of total born and born alive piglets on subsequent farrowing. Cooper et al. (2001) reported that different lysine intake (0.44 or 0.55% total lysine) did not affect litter size of the total number born or born

alive, and litter birth weight and piglet birth weight. Thus, different energy and lysine intake during gestation had no significant effect on litter size and litter weight or piglet weight at birth in primiparous sows

Litter growth was improved by greater milk production with high-energy diet (Noblet and Etienne, 1986; Tokach et al., 1992) and greater lactation feed intake (Pattersone et al., 2011). In the current study, the dietary energy effect was observed in piglet weight gain and piglet weight at day 21 of lactation, not in litter weight and gain. According to the results from colostrum content, lactation feed intake, and body weight loss during lactation, 3,365 kcal of ME/kg diet met the energy requirement of sows for milk production and maternal gain and the growth of their progeny rather than 3,265 kcal of ME/kg diet. In addition, these results suggested that the energy effect with litter weight was not observed due to litter size during lactation and feeding *ad libitum*.

In the present study, sows fed 0.7%, 0.85%, 1.0%, or 1.15% lysine with different energy diets (3,265 or 3,365 kcal of ME/kg) consumed, on average, 33.7, 46.3, 52.1, and 56.5 g/d of lysine on the 3265 ME kcal/kg diet, and 36.3, 44.1, 52.1, and 50.8 g/d of lysine on the 3365 ME kcal/kg diet. Previous studies had reported that the maximal response in pig or litter weaning weights occurred at 47g of lysine/d (Stahly et al., 1990; sows consumed 20-47 g/d and weaned 10.5 pigs per litter), 55 g of lysine/d (Johnston et al., 1993; sows consumed 35-55 g/d and waned 11.1 pigs per litter), and 57 g of lysine/d (Richert et al., 1994; sows consumed 36-57 g/d and weaned 10.5 pigs per litter). According to the NRC (1998), total lysine intake during lactation (35.3 or 48.6 g/d) met the lysine requirement of lactating sows. According to the NRC (2012), total lysine intake during lactation for primiparous sows was 48.7-56.5 g/d (the daily weight gain of piglets was 190-270 g) and were weaned 11 pigs per litter. Taken together, lysine intake ranged from 33.7-52.1 g/d met or supported piglet growth with no negative effects. The piglet weaning weight in the present study was similar to that observed by Touchette et al. (1998b), Thaler et al. (1992), and Santos et al. (2006), who reported no improvement in litter performance with greater lysine intake during lactation. In

accordance with Knabe et al. (1996), the 21-d pig weights were not increased by feeding a 0.9% lysine corn-SBM based diet and they concluded that 0.75% lysine diet met the nutrient needs of the sows or nutrient deficiency limited the sow's ability to respond to the higher lysine intake. In addition, the lack of response to increasing levels of lysine on litter performance (even with the addition of DL-methionine, L-threonine, and L-tryptophan to achieve balance in the diets) could be related to a lack of other limiting amino acids (Touchette et al., 1998b; Santos et al., 2006), such as valine and isoleucine (Richert et al., 1997). For these reasons, lysine intake during lactation met the minimum lysine requirement or induced amino acid imbalance of lactating sows and did not show any significant differences in litter growth as a result of the lysine effect.

Piglet birth weight and litter uniformity are important factors affecting pre-weaning piglet survival (Milligan et al., 2002; Quiniou et al., 2002). Because low weight piglets do not consume a sufficient amount of colostrum and have low passive immunity or nutritional status (Wolf et al., 2008), and litters with greater BW variation had more variable weight at weaning and slaughter (Roberts and Deen, 1995; Gondret et al., 2005). There was no significant difference in the SD and CV of piglet birth weight and day 21 of lactation because of pre-mating factors and maternal nutrition during gestation (Campos et al., 2012; Wientjes et al., 2013). Before gilts mate, insufficient restoration of follicle development and increased developmental variation within the preovulatory follicle pool may be reflected in compromised development and uniformity of embryos and placentas and compromised luteal development, thereby ultimately affecting litter uniformity (Wientjes et al., 2013). In addition, Campos et al. (2012) are of the opinion that maternal nutrition during gestation, such as insulin, IGF-1, and dietary protein or amino acid levels, had an effect on piglet uniformity. Although the CV of the mean BW was positively related to the backfat thickness gain of the sow during gestation (Quesnel et al., 2008), dietary effects were not observed in backfat gain during gestation and piglet uniformity in the present study.

Lactating sows required a greater daily lysine intake to maximize nitrogen

(N) balance than to maximize lactational performance (King et al., 1993), and restricted amino acid intake and excessive body protein mobilization during lactation had a negative influence on further reproduction (King and Dunkin, 1986; Brendemuhl et al., 1987; King and Martin, 1989; Jones and Stahly, 1995). The blood urea nitrogen concentration was used as an indicator of protein mobilization, N balance (Coma et al., 1996), and amino acid requirements (Chen et al., 1978; King et al., 1993) in sows. Also, creatinine was an indicator of muscle catabolism (Belstra et al., 1998; Heo et al., 2007). Based on the concentrations of creatinine, 0.65% and 0.75% lysine gestation diets had high efficiency of protein utilization in lactating sows at 24 hrs postpartum. According to the results of blood urea nitrogen, high lysine intake induced excess nitrogen in day 110 of gestation, and 0.75/1.00% lysine group showed high efficiency of N utilization in lactating sows at 24hrs postpartum and day 21 of lactation.

Many previous studies reported that the chemical composition of colostrum and milk was not affected by dietary energy levels during gestation because sows mobilize their internal reserves to compensate for deficient nutrients (Williams et al., 1985; Yang et al., 2008; Jin et al., 2016). Thus, during early lactation, colostrum and body reserves were major determinants of milk yield, but later in lactation, the feed intake of sows becomes important because the body reserves are largely exhausted (Beyer et al., 2007). Body condition of the sow at parturition and during lactation plays a role in milk composition, and the milk fat content is 20% greater in sows with a high body fat content compared to lean sows (Revell et al., 1998a). Thus, the high deposition of protein and fat mass in primiparous sows before lactation resulted in high milk components, except lactose, which was delivered from the dam to their progeny using body reserves. Some researchers reported that a high-lysine diet does not affect milk composition (Revell et al., 1998b; McNamara and Pettigrew, 2002), while others insist that a high-lysine diet increases milk components (Kusina et al., 1999b; Jones and Stahly, 1999; Heo et al., 2007). In current study, the lysine effect was observed only in free fatty acids of colostrum. Milk fat was manufactured in the mammary gland from glycerol and

free fatty acids (Mansbridge and Blake, 1997), and the amount of lysine required to maximize milk production increased as ME intake increased (Tokach et al., 1992). For this reason, the high-energy group had greater free fatty acid content in colostrum compared with the low-energy group, and the 0.75% lysine diet had the highest content of free fatty acids in the colostrum.

Body loss during lactation could delay estrus or decreased subsequent pregnancy rates and litter sizes through insufficient restoration of follicle development, which affects the ovulation rate and embryo quality (Quesnel, 2009). Also, body condition changes during gestation and lactation had an influence on piglet BW and litter uniformity (Wientjes et al., 2013). The calculation of body protein and fat mass was derived from Dourmad et al. (1997), the influence of energy effects on BW and backfat thickness in gestation and the lactation period appeared subsequently in body protein and fat mass. Thus, high energy intake during gestation and the lactation period affects greater body protein and fat mass at the end of the entire period with a similar trend of BW and backfat changes.

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CONCLUSION

Consequently, primipaorus sows fed 3,365 kcal of ME/kg diet had more gain of body weight and backfat compared with sows fed 3,265 kcal of ME/kg diet. Also piglets from sows fed 3,365 kcal of ME/kg diet showed greater piglet weight gain during lactation. Although significant differences were not observed in reproductive performance and piglet uniformity, total lysine 0.75% for gestation and 1.00% for lactation showed higher nitrogen utilization in blood profile of sows. Moreover, WEI was decreased in Lys0.75/1.00% group. Thus, total lysine 0.75% for gestation and 1.00% for lactation in 3,365 kcal of ME/kg showed better performance for sows and growth of their progeny.

REFERENCES

Armstrong, J. D., Britt, J. H., & Kraeling, R. R. 1986. Effect of restriction of energy during lactation on body condition, energy metabolism, endocrine changes and reproductive performance in primiparous sows. Journal of Animal Science, 63(6), 1915-1925.

Belstra, B. A., Richert, B. T., & Frank, J. W. 1998. Effect of gestation dietary crude protein level on the gestation and lactation performance of primiparous sows. Purdue University, 60-64.

Beyer, M., Jentsch, W., Kuhla, S., Wittenburg, H., Kreienbring, F., Scholze, H., Rudolph P. E., Metges, C. C. 2007. Effects of dietary energy intake during gestation and lactation on milk yield and composition of first, second and fourth parity sows. Archives of Animal Nutrition, 61(6), 452-468.

Buitrago, J. A., Maner, J. H., Gallo, J. T., & Pond, W. G. 1974. Effect of dietary energy in gestation on reproductive performance of gilts. Journal of Animal Science, 39(1), 47-52.

Brendemuhl, J. H., Lewis, A. J., & Peo, E. R. 1987. Effect of protein and energy intake by primiparous sows during lactation on sow and litter performance and sow serum thyroxine and urea concentrations. Journal of Animal Science, 64(4), 1060-1069.

Campos, P. H. R. F., Silva, B. A. N., Donzele, J. L., Oliveira, R. F. M., & Knol, E. F. 2012. Effects of sow nutrition during gestation on within-litter birth weight variation: a review. Animal, 6(5), 797-806.

Chen, S. Y., d'Mello, J. P. F., Elsley, F. W. H., & Taylor, A. G. 1978. Effect of dietary lysine levels on performance, nitrogen metabolism and plasma amino acid concentrations of lactating sows. Animal Science, 27(3), 331-344.

Coma, J., Zimmerman, D. R., & Carrion, D. 1996. Lysine requirement of the lactating sow determined by using plasma urea nitrogen as a rapid response criterion. Journal of Animal Science, 74(5), 1056-1062.

Cooper, D. R., Patience, J. F., Zijlstra, R. T., & Rademacher, M. 2001. Effect of energy and lysine intake in gestation on sow performance. Journal of Animal Science, 79(9), 2367-2377.

Cox, N. M., C. R. Barb, J. S. Kesner, R. R. Kraeling, I. A. Matamoros, and G. B. Rampacek. 1989. Effects of intracerebroventricular (ICV) administration of insulin on luteinizing hormone (LH) in gilts. Proc. 3rd Int. Conf. on Pig Reprod., April 11-14, 1989, Univ. of Nottingham, Sutton Bonington, England.

Dourmad, J. Y. 1991. Effect of feeding level in the gilt during pregnancy on voluntary feed intake during lactation and changes in body composition during gestation and lactation. Livestock Production Science, 27(4), 309-319.

Dourmad, J. Y., Etienne, M., Noblet, J., & Causeur, D. 1997. Prédiction de la composition chimique des truies reproductrices à partir du poids vif et de l'épaisseur de lard dorsal. J. Rech. Porcine Fr, 29, 255-262.

Dyck, G. W., & Strain, J. H. 1983. Postmating feeding level effects on conception rate and embryonic survival in gilts. Canadian Journal of Animal Science, 63(3), 579-585.

Flowers, B., Martin, M. J., Cantley, T. C., & Day, B. N. (1989). Endocrine changes associated with a dietary-induced increase in ovulation rate (flushing) in gilts. Journal of Animal Science, 67(3), 771-778.

Fuller, M. F., McWilliam, R., Wang, T. C., & Giles, L. R. 1989. The optimum dietary amino acid pattern for growing pigs. British Journal of Nutrition, 62(2), 255-267.

Gondret, F., Lefaucheur, L., Louveau, I., Lebret, B., Pichodo, X., & Le Cozler, Y. 2005. Influence of piglet birth weight on postnatal growth performance, tissue lipogenic capacity and muscle histological traits at market weight. Livestock Production Science, 93(2), 137-146.

Han, I. K., Bosi, P., Hyun, Y., Kim, J. D., Sohn, K. S., & Kim, S. W. 2000. Recent advances in sow nutrition to improve reproductive performance. Asian-Australasian Journal of Animal Sciences, 13(Special iss.), 335-355.

Heo, S., Yang, Y. X., Jin, Z., Park, M. S., Yang, B. K., & Chae, B. J. 2008. Effects of dietary energy and lysine intake during late gestation and lactation on blood metabolites, hormones, milk compositions and reproductive performance in primiparous sows. Canadian Journal of Animal Science, 88(2), 247-255.

Jin, S. S., Jung, S. W., Jang, J. C., Chung, W. L., Jeong, J. H., & Kim, Y. Y. 2016. Effects of Dietary Energy Levels on the Physiological Parameters and Reproductive Performance of Gestating Gilts. Asian Australasian Journal of Animal Sciences, 29(7), 1004.

Jindal, R., Cosgrove, J. R., Aherne, F. X., & Foxcroft, G. R. 1996. Effect of nutrition on embryonal mortality in gilts: association with progesterone. Journal of Animal Science, 74(3), 620-624.

Jones, D. B., & Stahly, T. S. 1995. Impact of amino acid nutrition during lactation on subsequent reproductive function of sows. Journl of Animal Science 73(Suppl 1), 183.

Jones, D. B., & Stahly, T. S. 1999. Impact of amino acid nutrition during lactation on body

nutrient mobilization and milk nutrient output in primiparous sows. Journal of Animal Science, 77(6), 1513-1522.

Johnston, L. J., Pettigrew, J. E., & Rust, J. W. 1993. Response of maternal-line sows to dietary protein concentration during lactation. Journal of Animal Science, 71(8), 2151-2156.

Kim, S. W., Hurley, W. L., Han, I. K., & Easter, R. A. 1999. Changes in tissue composition associated with mammary gland growth during lactation in sows. Journal of Animal Science, 77(9), 2510-2516.

Kim, S. W., Hurley, W. L., Wu, G., & Ji, F. 2009. Ideal amino acid balance for sows during gestation and lactation. Journal of Animal Science, 87(Suppl 14), E123-E132.

King, R. H., & Martin, G. B. 1989. Relationships between protein intake during lactation, LH levels and oestrous activity in first-litter sows. Animal Reproduction Science, 19(3-4), 283-292.

King, R. H., Toner, M. S., Dove, H., Atwood, C. S., & Brown, W. G. 1993. The response of first-litter sows to dietary protein level during lactation. Journal of Animal Science, 71(9), 2457-2463.

King, R. H., & Dunkin, A. C. (1986). The effect of nutrition on the reproductive performance of first-litter sows 4. The relative effects of energy and protein intakes during lactation on the performance of sows and their piglets. Animal Science, 43(2), 319-325.

Kusina, J., Pettigrew, J. E., Sower, A. F., White, M. E., Crooker, B. A., & Hathaway, M. R. 1999a. Effect of protein intake during gestation and lactation on the lactational performance of primiparous sows. Journal of Animal Science, 77(4), 931-941.

Kusina, J., Pettigrew, J. E., Sower, A. F., Hathaway, M. R., White, M. E., & Crooker, B. A. 1999b. Effect of protein intake during gestation on mammary development of primiparous sows. Journal of Animal Science, 77(4), 925-930.

Knabe, D. A., Brendemuhl, J. H., Chiba, L. I., & Dove, C. R. 1996. Supplemental lysine for sows nursing large litters. Journal of Animal Science, 74(7), 1635-1640.

Lewis, A., & Speer, V. 1973. Lysine requirement of the lactating sow. Journal of Animal Science, 37(1), 104-110.

Liao, C., & Veum, T. L. 1994. Effects of dietary energy intake by gilts and heat stress from days 3 to 24 or 30 after mating on embryo survival and nitrogen and energy balance. Journal of Animal Science, 72(9), 2369-2377.

Libal, G. W., & Wahlstrom, R. C. 1977. Effect of gestation metabolizable energy levels on sow productivity. Journal of Animal Science, 45(2), 286-292.

Long, H. F., Ju, W. S., Piao, L. G., & Kim, Y. Y. 2010. Effect of dietary energy levels of gestating sows on physiological parameters and reproductive performance. Asian Australas Journal of Animal Science. 23:1080–1088.

Mansbridge, R. J., & Blake, J. S. 1997. Nutritional factors affecting the fatty acid composition of bovine milk. British Journal of Nutrition, 78(1), S37-S47.

McNamara, J. P., & Pettigrew, J. E. 2002. Protein and fat utilization in lactating sows: I. Effects on milk production and body composition. Journal of Animal Science, 80(9), 2442-2451.

Milligan, B. N., Fraser, D., & Kramer, D. L. 2002. Within-litter birth weight variation in the domestic pig and its relation to pre-weaning survival, weight gain, and variation in weaning weights. Livestock Production Science, 76(1), 181-191.

Noblet, J., & Etienne, M. 1986. Effect of energy level in lactating sows on yield and composition of milk and nutrient balance of piglets. Journal of Animal Science, 63(6), 1888-1896.

Noblet, J., Dourmad, J. Y., & Etienne, M. 1990. Energy utilization in pregnant and lactating sows: modeling of energy requirements. Journal of Animal Science, 68(2), 562-572.

National Research Council. 1998. Nutrient requirements of swine, 10th ed. National Academy Press, Washington, DC.

National Research Council. 2012. Nutrient requirements of swine, 11th ed. National Academy Press, Washington, DC.

Patterson, J. L., Smit, M. N., Novak, S., Wellen, A. P., & Foxcroft, G. R. (2011). Restricted feed intake in lactating primiparous sows. I. Effects on sow metabolic state and subsequent reproductive performance. Reproduction, Fertility and Development, 23(7), 889-898.

Pharazyn, A., Foxcroft, G. R., Aherne, F. X., & Hartog, L. D. 1991. Dietary energy and protein intake, plasma progesterone and embryo survival in early pregnancy in the gilt. Canadian Journal of Animal Science, 71(3), 949-952.

Prunier, A., Dourmad, J. Y., & Etienne, M. 1993. Feeding level, metabolic parameters and reproductive performance of primiparous sows. Livestock Production Science, 37(1-2), 185-196.

Quesnel, H., Brossard, L., Valancogne, A., & Quiniou, N. 2008. Influence of some sow

characteristics on within-litter variation of piglet birth weight. Animal, 2(12), 1842-1849.

Quesnel, H. 2009. Nutritional and lactational effects on follicular development in pigs. Control of Pig Reproduction VIII, 8, 121-134.

Quiniou, N., Dagorn, J., & Gaudré, D. 2002. Variation of piglets' birth weight and consequences on subsequent performance. Livestock Production Science, 78(1), 63-70.

Reese, D. E., Peo, E. R., & Lewis, A. J. 1984. Relationship of lactation energy intake and occurence of postweaning estrus to body and backfat composition in sows. Journal of Animal Science, 58(5), 1236-1244.

Revell, D. K., Williams, I. H., Mullan, B. P., Ranford, J. L., & Smits, R. J. 1998a. Body composition at farrowing and nutrition during lactation affect the performance of primiparous sows: I. Voluntary feed intake, weight loss, and plasma metabolites. Journal of Animal Science, 76(7), 1729-1737.

Revell, D. K., Williams, I. H., Mullan, B. P., Ranford, J. L., & Smits, R. J. 1998b. Body composition at farrowing and nutrition during lactation affect the performance of primiparous sows: II. Milk composition, milk yield, and pig growth. Journal of Animal Science, 76(7), 1738-1743.

Richert, B. T., R. D. Goodband, M. D. Tokach, J. L. Nelssen, R. G. Campbell, S. Kershaw, and S. A. Blum. 1994. The effect of lysine and valine fed during lactation on sow and litter lactation performance. 1994 Kansas State Univ. Swine Day, Manhattan. p 15-22.

Roberts J, Deen J 1995. Conformance quality in pig production. The Compendium on Continuing Education for the Practicing Veterinarian, 17, 1308–1311

Ruiz, M. E., Speer, V. C., Hays, V. W., & Switzer, W. P. 1968. Effect of feed intake and antibiotic on reproduction in gilts. Journal of Animal Science, 27(6), 1602-1606.

Santos, J. M. G. D., Moreira, I., & Martins, E. N. 2006. Lysine and metabolyzable energy requirements of lactating sows for subsequent reproductive performance. Brazilian Archives of Biology and technology, 49(4), 575-581.

Stahly, T. S., G. L. Cromwell, and H. J. Monegue. 1990. Lactational responses of sows nursing large litters to dietary lysine levels. Journal of Animal Science, 68(Suppl. 1):369

Thaler, R. C., Woerman, R. L., & Britzman, D. B. 1992. Effect of lysine level in lactation diets on sow performance and milk composition. Journal of Animal Science, 70(Suppl

1), 238.

Touchette, K. J., Allee, G. L., Newcomb, M. D., & Boyd, R. D. 1998. The lysine requirement of lactating primiparous sows. Journal of Animal Science, 76(4), 1091-1097.

Tokach, M. D., Pettigrew, J. E., Dial, G. D., Wheaton, J. E., Crooker, B. A., & Johnston, L. J. 1992. Characterization of luteinizing hormone secretion in the primiparous, lactating sow: relationship to blood metabolites and return-to-estrus interval. Journal of Animal Science, 70(7), 2195-2201.

Van den Brand, H., Dieleman, S. J., Soede, N. M., & Kemp, B. 2000. Dietary energy source at two feeding levels during lactation of primiparous sows: I. Effects on glucose, insulin, and luteinizing hormone and on follicle development, weaning-to-estrus interval, and ovulation rate. Journal of Animal Science, 78(2), 396-404.

Whittemore, C. T. 1996. Nutrition reproduction interactions in primiparous sows. Livestock Production Science, 46(2), 65-83.

Wientjes, J. G. M., Soede, N. M., Knol, E. F., Van den Brand, H., & Kemp, B. 2013. Piglet birth weight and litter uniformity: Effects of weaning-to-pregnancy interval and body condition changes in sows of different parities and crossbred lines. Journal of Animal Science, 91(5), 2099-2107.

Williams, I. H., Close, W. H., & Cole, D. J. A. 19851. Strategies for sow nutrition: Predicting the response of pregnant animals to protein and energy intake. Recent Advances in Animal Nutrition, 133-147.

Woerman, R. L., & Speer, V. C. 1976. Lysine requirement for reproduction in swine. Journal of Animal Science, 42(1), 114-120.

Wolf, J., Žáková, E., & Groeneveld, E. 2008. Within-litter variation of birth weight in hyperprolific Czech Large White sows and its relation to litter size traits, stillborn piglets and losses until weaning. Livestock Science, 115(2), 195-205.

Yang, H., Foxcroft, G. R., Pettigrew, J. E., Johnston, L. J., Shurson, G. C., Costa, A. N., & Zak, L. J. 2000b. Impact of dietary lysine intake during lactation on follicular development and oocyte maturation after weaning in primiparous sows. Journal of Animal Science, 78(4), 993-1000.

Yang, Y., Heo, S., Jin, Z., Yun, J., Shinde, P., Choi, J., Yang, B., & Chae, B. 2008. Effects of dietary energy and lysine intake during late gestation and lactation on blood metabolites, hormones, milk composition and reproductive performance in multiparous

sows. Archives of Animal Nutrition, 62(1), 10-21.

Young, L. G., King, G. J., Walton, J. S., McMillan, I., & Klevorick, M. 1990. Age, weight, backfat and time of mating effects on performance of gilts. Canadian Journal of Animal Science, 70(2), 469-481.

Zak, L. J., Cosgrove, J. R., Aherne, F. X., & Foxcroft, G. R. 1997. Pattern of feed intake and associated metabolic and endocrine changes differentially affect postweaning fertility in primiparous lactating sows. Journal of Animal Science, 75(1), 208-216.

Zhang, R. F., Hu, Q., Li, P. F., Xue, L. F., Piao, X. S., & Li, D. F. 2011. Effects of lysine intake during middle to late gestation (day 30 to 110) on reproductive performance, colostrum composition, blood metabolites and hormones of multiparous sows. Asian-Australasian Journal of Animal Sciences, 24(8), 1142-1147.

Table 1. The formulas and chemical composition of experimental gestation diet

Item	ME 3,265 kcal/kg			
	Lys 0.55%[1)]	Lys 0.65%	Lys 0.75%	Lys 0.85%
Ingredients, %				
Corn	77.03	77.17	77.34	77.53
SBM-46	13.12	12.79	12.46	12.13
Wheat bran	1.99	2.05	2.08	2.05
PKM (extraction)	3.00	2.04	2.98	3.02
Tallow	1.54	1.52	1.49	1.46
L-Lysine HCl(78%)	0.00	0.13	0.27	0.40
DL-Methionine(99%)	0.03	0.03	0.04	0.04
L-Threonine(99%)	0.01	0.02	0.02	0.03
L-Tryptophan(10%)	0.09	0.11	0.13	0.15
MDCP	1.44	1.44	1.44	1.44
Limestone	1.15	1.15	1.15	1.15
Vit. Mix[2)]	0.10	0.10	0.10	0.10
Min. Mix[3)]	0.10	0.10	0.10	0.10
Choline-Cl(50%)	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,265.07	3,265.03	3,265.02	3,265.00
Crude protein, %	12.15	12.15	12.15	12.15
Total lysine, %	0.55	0.65	0.75	0.85
Total methionine, %	0.23	0.23	0.23	0.23
Total threonine, %	0.48	0.48	0.48	0.48
Total tryptophan, %	0.13	0.13	0.13	0.13
Calcium, %	0.75	0.75	0.75	0.75
Total phosphorus, %	0.60	0.60	0.60	0.60

[1)] Experimental diet was formulated with corn-soybean meal (SBM) based diet and adjusted lysine content.

[2)] Provided per kg of diet : vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64 g; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; vitamin B_{12}, 12 μg; vitamin K, 2.4 mg

[3)] Provided per kg of diet: mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4)] Calculated value

Table 1. The formulas and chemical composition of experimental gestation diet (continued)

Item	ME 3,365 kcal/kg			
	Lys 0.55%[1)]	Lys 0.65%	Lys 0.75%	Lys 0.85%
Ingredients, %				
Corn	71.96	72.09	72.27	72.53
SBM-46	12.97	12.64	12.31	12.00
Wheat bran	3.90	3.96	3.97	3.93
PKM (extraction)	3.86	3.87	3.87	3.85
Tallow	4.03	4.01	3.98	3.94
L-Lysine HCl(78%)	0.00	0.13	0.27	0.40
DL-Methionine(99%)	0.03	0.04	0.04	0.04
L-Threonine(99%)	0.02	0.02	0.03	0.03
L-Tryptophan(10%)	0.08	0.09	0.11	0.13
MDCP	1.38	1.38	1.38	1.38
Limestone	1.17	1.17	1.17	1.17
Vit. Mix[2)]	0.10	0.10	0.10	0.10
Min. Mix[3)]	0.10	0.10	0.10	0.10
Choline-Cl(50%)	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,365.04	3,365.04	3,365.02	3,365.03
Crude protein, %	12.15	12.15	12.15	12.15
Total lysine, %	0.55	0.65	0.75	0.85
Total methionine, %	0.23	0.23	0.23	0.23
Total threonine, %	0.48	0.48	0.45	0.48
Total tryptophan, %	0.13	0.13	0.11	0.13
Calcium, %	0.75	0.75	0.75	0.75
Total phosphorus, %	0.60	0.60	0.60	0.60

[1)] Experimental diet was formulated with corn-soybean meal (SBM) based diet and adjusted lysine content.

[2)] Provided per kg of diet : vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64 g; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; vitamin B_{12}, 12 μg; vitamin K, 2.4 mg

[3)] Provided per kg of diet: mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4)] Calculated value

Table 2. The formulas and chemical composition of experimental lactation diet

Item	ME 3,265 kcal/kg			
	Lys 0.70%	Lys 0.85%	Lys 1.00%	Lys 1.15%
Ingredients, %				
Corn	71.46	71.87	72.23	72.62
SBM-46	18.02	17.98	17.96	17.92
Wheat bran	2.00	2.00	2.00	2.00
Sesame meal(40%)	4.00	3.49	3.00	2.48
PKM (extraction)	0.00	0.00	0.00	0.00
Tallow	1.39	1.31	1.24	1.16
L-Lysine HCl(78%)	0.00	0.19	0.38	0.58
DL-Methionine(99%)	0.01	0.01	0.01	0.02
L-Threonine(99%)	0.02	0.03	0.03	0.04
L-Tryptophan(10%)	0.22	0.22	0.22	0.22
MDCP	1.20	1.21	1.23	1.25
Limestone	1.08	1.09	1.10	1.11
Vit. Mix[1)]	0.10	0.10	0.10	0.10
Min. Mix[2)]	0.10	0.10	0.10	0.10
Choline-Cl(50%)	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Chemical composition[3)]				
ME, kcal/kg	3,265.02	3,265.03	3,265.04	3,265.07
Crude protein, %	15.20	15.20	15.20	15.20
Total lysine, %	0.70	0.85	1.00	1.15
Total methionine, %	0.25	0.25	0.25	0.25
Total threonine, %	0.62	0.62	0.62	0.62
Total tryptophan, %	0.18	0.18	0.18	0.18
Calcium, %	0.75	0.75	0.75	0.75
Total phosphorus, %	0.60	0.60	0.60	0.60

[1)] Provided per kg of diet : vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64 g; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; vitamin B_{12}, 12 μg; vitamin K, 2.4 mg.

[2)] Provided per kg of diet: mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[3)] Calculated value

Table 2. The formulas and chemical composition of experimental lactation diet (continued)

Item	ME 3,365 kcal/kg			
	Lys 0.70%	Lys 0.85%	Lys 1.00%	Lys 1.15%
Ingredients, %				
Corn	69.22	69.59	69.99	70.39
SBM-46	18.20	18.28	18.37	18.37
Wheat bran	1.88	1.89	1.89	1.89
Sesame meal(40%)	4.22	3.64	2.99	2.40
PKM (extraction)	0.00	0.00	0.00	0.00
Tallow	3.37	3.29	3.21	3.13
L-Lysine HCl(78%)	0.00	0.18	0.37	0.57
DL-Methionine(99%)	0.01	0.01	0.01	0.02
L-Threonine(99%)	0.02	0.02	0.03	0.04
L-Tryptophan(10%)	0.20	0.20	0.20	0.21
MDCP	1.20	1.22	1.25	1.28
Limestone	1.08	1.08	1.09	1.10
Vit. Mix[1)]	0.10	0.10	0.10	0.10
Min. Mix[2)]	0.10	0.10	0.10	0.10
Choline-Cl(50%)	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Chemical composition[3)]				
ME, kcal/kg	3,365.04	3,365.06	3,365.04	3,365.00
Crude protein, %	15.20	15.20	15.20	15.20
Total lysine, %	0.70	0.85	1.00	1.15
Total methionine, %	0.25	0.25	0.25	0.25
Total threonine, %	0.62	0.62	0.62	0.62
Total tryptophan, %	0.18	0.18	0.18	0.18
Calcium, %	0.75	0.75	0.75	0.75
Total phosphorus, %	0.60	0.60	0.60	0.60

[1)] Provided per kg of diet : vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64g; riboflavin, 3.2mg; calcium pantothenic acid, 8 mg; niacin, 16mg; vitamin B_{12}, 12 μg; vitamin K, 2.4 mg.

[2)] Provided per kg of diet: mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[3)] Calculated value

Table 3. Effects of dietary energy and lysine levels on growth performance in primiparous sows during gestation

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %		E	L	I
Body weight, kg												
35d	167.9	167.0	167.8	168.8	169.1	168.1	167.9	162.5	9.91	0.74	0.91	0.77
110d	199.0	196.0	192.6	190.6	200.6	194.8	196.0	202.2	13.15	0.36	0.79	0.72
BW gain (35-110d)	31.1	29.0	24.8	21.8	31.5	26.7	28.1	39.7	10.61	0.07	0.56	0.25
Backfat thickness, mm												
35d	24.9	24.5	25.1	23.7	23.7	25.6	27.1	23.2	4.72	0.80	0.64	0.86
110d	23.9	25.8	24.1	24.2	28.2	26.2	26.8	26.2	4.26	0.10	0.96	0.80
BF gain (35-110d)	-1.0	1.3	-1.0	0.5	4.5	0.6	-0.3	3.0	4.79	0.21	0.64	0.54

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.
[2)] Standard error of mean
[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

Table 4. Effects of dietary energy and lysine levels on growth performance in primiparous sows during lactation

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %		E	L	I
Body weight, kg												
24hrs postpartum	179.5	183.7	167.2	168.2	172.9	173.0	174.7	181.1	12.39	0.85	0.69	0.16
Day 21 of lactation	163.4	177.8	155.1	165.0	168.9	173.3	183.9	178.5	16.06	0.09	0.75	0.36
BW loss (0-21d)	-16.1	-5.9	-12.1	-3.2	-4.0	0.3	9.2	-2.6	12.65	0.05	0.57	0.51
Backfat thickness, mm												
24hrs postpartum	22.6	24.5	23.8	25.0	27.7	26.5	25.9	26.7	3.99	0.04	0.95	0.76
Day 21 of lactation	19.2	20.6	19.3	20.6	23.1	21.4	21.8	23.5	4.17	0.07	0.88	0.88
BF loss (0-21d)	-3.4	-3.9	-4.5	-4.4	-4.6	-5.1	-4.1	-3.2	2.87	0.81	0.96	0.76
ADFI, kg/d	4.81	5.45	5.21	4.91	5.18	5.19	5.21	4.42	0.868	0.74	0.39	0.71
WEI, d	5.20	5.33	5.25	5.33	4.50	6.75	4.33	5.00	0.811	0.70	0.03	0.06

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

Table 5. Effects of dietary energy and lysine levels on reproductive performance in primiparous sows

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %		E	L	I
No. of piglets												
Total born	13.1^{ab}	16.0^{a}	13.5^{ab}	9.6^{bc}	12.4^{bc}	8.2^{c}	13.0^{ab}	12.8^{ab}	3.10	0.17	0.53	<.01
Still birth	1.0	0.8	0.0	0.4	0.4	0.6	0.7	0.3	0.78	0.90	0.72	0.50
Mummy‡	0.1^{b}	2.2^{a}	0.0^{bc}	0.0^{bc}	0.2^{b}	0.6^{b}	0.7^{b}	0.0^{bc}	0.70	0.45	0.01	0.10
Born alive	12.0	13.0	13.5	9.2	11.8	7.0	11.6	12.5	3.10	0.29	0.40	0.04
Litter weight, kg												
Total litter weight	15.40	16.79	16.58	12.98	15.34	10.70	15.10	14.64	3.53	0.24	0.54	0.18
Alive litter weight	14.43	14.63	16.57	12.58	15.00	10.14	14.00	14.31	3.68	0.38	0.46	0.37
Alive piglet weight	1.23	1.13	1.22	1.37	1.29	1.51	1.22	1.16	0.17	0.35	0.79	0.02
Piglet uniformity (parturition)												
SD	222.9	218.5	198.6	232.6	271.5	169.1	247.7	233.3	77.66	0.62	0.51	0.48
CV	19.0	19.5	16.4	17.6	21.7	13.2	20.5	21.1	6.95	0.65	0.64	0.36
Piglets <800g, %	9.5	7.3	3.0	5.6	8.0	12.6	13.2	9.8	12.40	0.31	0.98	0.82
Piglets >1600g, %	12.8	2.0	1.5	19.0	11.8	34.4	9.8	4.5	15.51	0.32	0.60	0.08

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

[abc] Mean with different superscripts in the same row significantly differ (P<0.05).

‡Quadratic response (P=0.08) to dietary lysine levels when significance of lysine effect was detected.

Table 6. Effects of dietary energy and lysine levels on litter performance in primiparous sows

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %		E	L	I
No. of piglets												
After fostering	11.6	11.3	11.5	11.6	11.4	11.2	11.5	11.5	0.65	0.63	0.70	0.97
21d of lactation	10.8	11.2	11.5	10.6	10.6	10.8	10.2	10.2	1.22	0.17	0.77	0.82
Litter weight, kg												
After fostering	13.95	12.65	13.84	15.56	14.42	15.84	14.26	13.69	1.625	0.36	0.90	0.04
Day 21 of lactation	54.16	55.75	61.02	56.44	58.41	60.18	58.12	54.95	9.687	0.74	0.83	0.79
Weight gain (0-21d)	40.21	43.10	47.18	40.88	43.99	44.34	43.86	41.26	8.761	0.86	0.72	0.85
Piglet weight, kg												
After fostering	1.19	1.13	1.21	1.34	1.27	1.41	1.24	1.19	0.159	0.25	0.90	0.07
Day 21 of lactation	4.98	4.98	5.31	5.30	5.54	5.65	5.77	5.35	0.740	0.08	0.85	0.81
Weight gain (0-21d)	3.79	3.85	4.10	3.96	4.27	4.24	4.53	4.16	0.626	0.08	0.73	0.96
Piglet uniformity (21d of lactation)												
SD	1076	925	1204	1144	944	1037	1067	967	370.9	0.48	0.81	0.83
CV	21.8	19.9	22.7	22.0	17.1	18.6	18.8	18.6	7.83	0.19	0.97	0.96

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

Table 7. Effects of dietary energy and lysine levels on blood profiles in primiparous sows

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %		E	L	I
Total protein, g/dL												
35d	----------7.5----------											
110d	7.16	7.15	7.36	6.90	6.46	7.03	7.26	7.16	0.356	0.33	0.23	0.25
24hrs postpartum	6.25	6.30	6.80	6.56	6.66	6.00	6.63	6.50	0.445	0.88	0.25	0.59
Day 21 of lactation	6.30	6.55	6.30	6.10	6.30	6.70	6.43	6.46	0.384	0.39	0.54	0.91
Creatinine, mg/dL												
35d	----------1.90----------											
110d	1.89	2.37	2.22	2.05	1.99	1.96	2.16	2.19	0.195	0.56	0.26	0.18
24hrs postpartum	1.49	2.59	2.58	2.03	2.10	2.19	2.21	2.29	0.319	0.87	0.04	0.09
Day 21 of lactation	1.57	1.64	1.68	1.60	1.89	2.00	1.60	1.45	0.272	0.38	0.42	0.38
Blood urea nitrogen, mg/dL												
35d	----------12.0----------											
110d[†]	6.5	6.70	8.1	7.2	6.8	7.9	8.3	8.5	0.71	0.08	0.09	0.71
24hrs postpartum	11.9	10.1	8.0	10.5	9.4	10.5	9.4	10.7	1.59	0.86	0.33	0.42
Day 21 of lactation[††]	15.7^{ab}	14.4^{b}	12.3^{b}	13.1^{b}	15.7^{ab}	18.1^{a}	14.4^{b}	12.4^{b}	1.88	0.15	0.02	0.27

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

[ab] Mean with different superscripts in the same row significantly differ ($P<0.05$).

[ABC] Mean with different superscripts in the same row significantly differ ($P<0.01$).

[†] Linear response ($P<0.05$) to dietary lysine levels when significance of lysine effect was detected.

[††] Linear response ($P<0.01$) to dietary lysine levels when significance of lysine effect was detected.

Table 8. Effects of dietary energy and lysine levels on blood profiles in nursery pigs

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %		E	L	I
Glucose, mg/dL												
24hrs postpartum	119.5	143.5	133.0	123.0	114.6	126.0	166.0	110.3	24.07	0.96	0.23	0.49
Day 21 of lactation	129.0	123.5	126.6	118.0	133.3	127.6	122.0	128.6	10.77	0.47	0.68	0.74
Total protein, g/dL												
24hrs postpartum	5.1	5.2	5.1	6.2	5.6	4.2	6.5	6.2	0.98	0.59	0.19	0.37
Day 21 of lactation	5.1	5.2	5.0	5.1	4.9	5.1	5.5	5.2	0.21	0.39	0.30	0.05
Creatinine, mg/dL												
24hrs postpartum	0.58	0.57	1.02	0.81	0.74	0.78	0.77	0.79	0.179	0.78	0.20	0.25
Day 21 of lactation	0.87	0.90	0.92	0.93	0.93	0.79	0.81	0.90	0.091	0.21	0.56	0.40
Blood urea nitrogen, mg/dL												
24hrs postpartum	13.8	14.1	11.6	15.5	15.3	14.7	19.3	19.8	4.85	0.17	0.77	0.74
Day 21 of lactation	6.0	6.8	6.6	5.8	7.0	6.6	8.8	6.9	1.77	0.21	0.61	0.74
IGF-1, ng/mL												
24hrs postpartum	86.9	70.5	73.1	91.2	77.0	108.4	98.6	80.7	19.65	0.34	0.97	0.32
Day 21 of lactation	153.6	135.0	158.7	135.1	160.4	177.1	154.6	150.1	31.30	0.34	0.88	0.74

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

[abc] Mean with different superscripts in the same row significantly differ ($P<0.05$).

Table 9. Effects of dietary energy and lysine levels on milk composition in primiparous sows

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %		E	L	I
Casein, %												
Colostrum	5.25	4.52	7.06	6.08	7.34	7.70	9.38	6.53	1.929	0.03	0.31	0.74
Milk (21d)	4.57	4.51	4.65	4.41	4.54	4.36	4.71	4.51	0.251	0.95	0.48	0.89
Fat, %												
Colostrum	9.45	7.89	7.56	8.11	7.87	10.19	6.21	7.07	1.371	0.54	0.12	0.17
Milk (21d)	6.13	6.93	7.80	6.66	7.87	6.33	8.3.1	6.82	0.930	0.35	0.16	0.38
Protein, %												
Colostrum	6.50	5.61	9.18	7.76	9.57	9.98	12.40	8.45	2.644	0.03	0.29	0.74
Milk (21d)	5.04	4.91	5.02	4.76	4.83	4.82	5.37	5.05	0.308	0.61	0.50	0.56
Lactose, %												
Colostrum	4.48	4.83	4.10	4.32	4.04	4.09	3.57	4.21	0.374	0.02	0.13	0.67
Milk (21d)	5.95	6.04	6.03	6.08	5.78	5.83	5.28	5.95	0.220	0.04	0.34	0.39
Total solid, %												
Colostrum	22.44	20.06	23.54	22.54	24.49	27.44	25.70	22.13	2.671	0.03	0.62	0.18
Milk (21d)	18.60	19.10	20.17	18.67	19.95	18.28	20.61	19.13	1.108	0.51	0.16	0.58
Solid not fat, %												
Colostrum	11.17	10.58	13.54	12.35	14.00	14.16	16.51	12.91	2.398	0.03	0.31	0.78
Milk (21d)	11.37	11.17	11.19	11.03	10.93	10.96	10.95	11.08	0.306	0.23	0.97	0.78
Free fatty acid, %												
Colostrum	3.44[B]	3.35[B]	4.17[A]	3.40[B]	4.23[A]	3.53[B]	4.35[A]	4.62[A]	0.319	<.01	0.01	0.06
Milk (21d)	5.54	5.49	4.65	6.16	6.37	5.25	5.43	4.85	0.848	0.96	0.44	0.21

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.
[2)] Standard error of mean
[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.
[AB] Mean with different superscripts in the same row significantly differ (P<0.01).

Table 10. Effects of dietary energy and lysine levels on body composition in primiparous sows

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %		E	L	I
Body protein mass, kg												
35d	44.45	43.68	44.84	43.10	43.17	45.49	47.33	41.00	7.328	0.92	0.64	0.86
110d	50.20	52.11	49.68	48.73	56.33	52.28	53.39	54.04	7.406	0.10	0.92	0.83
Changes (35-110d)	5.75	8.43	4.84	5.63	13.16	6.79	6.06	13.04	7.337	0.10	0.53	0.55
24hrs postpartum	43.98	47.48	44.16	44.62	49.30	47.71	47.32	49.89	6.844	0.11	0.94	0.83
Day 21 of lactation	35.89	40.98	35.50	38.06	42.25	40.99	43.99	44.97	8.657	0.05	0.91	0.74
Changes (0-21d)	-8.09	-6.50	-8.66	-6.56	-7.05	-6.73	-3.33	-4.92	5.821	0.32	0.90	0.78
Body fat mass, kg												
35d	40.93	40.62	41.12	40.71	40.76	41.22	41.64	39.38	2.739	0.91	0.71	0.83
110d	46.31	46.40	45.76	44.87	48.04	46.29	46.71	47.67	3.258	0.18	0.88	0.78
Changes (35-110d)	5.38	5.78	4.64	4.16	7.28	5.07	5.07	8.29	2.840	0.06	0.49	0.41
24hrs postpartum	42.28	43.68	41.47	41.01	42.78	42.40	42.50	43.96	3.017	0.41	0.90	0.50
Day 21 of lactation	38.23	41.31	37.82	38.98	40.51	40.74	42.84	42.40	4.377	0.08	0.85	0.59
Changes (0-21d)	-4.05	-2.37	-3.65	-2.03	-2.27	-1.66	0.34	-1.56	3.093	0.09	0.69	0.61

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy lysine effect.

[ab] Mean with different superscripts in the same row significantly differ ($P<0.05$).

Chapter V : Effects of Dietary Energy and Lysine Levels on Physiological Responses, Reproductive Performance, Piglet Uniformity, and Longevity in Sows during 1 to 3 Parities

ABSTRACT: This study was conducted to evaluate the effects of dietary energy and lysine levels on physiological responses, reproductive performance, piglet uniformity, and longevity in sows during 1 to 3 parities. A total of 48 F1 gilts (Yorkshire x Landrace) were allocated to one of eight dietary treatments in a completely randomized design (CRD). Experimental diets were composed with different energy levels (3,265 versus 3,365 kcal of ME/kg) and lysine levels (gestation 0.55, 0.65, 0.75, 0.85%, lactation: 0.70, 0.85, 1.00, 1.15%, respectively). Third parity sows fed high energy diet had a greater body weight at day 110 of gestation, 24hrs postpartum, and more body weight loss (Energy, P=0.01, P=0.02, and P<0.01, respectively). Increasing dietary energy level induced a greater backfat thickness during day 35 and 110 of gestation in parity 2 (Energy, P=0.01, and P<0.01, respectively) and parity 3 (Energy, P<0.01, and P<0.01, respectively). Also, high energy group showed a greater backfat thickness at 24hrs postpartum in parities 1, 2, and 3, respectively (Energy, P=0.04, P<0.01, and P<0.01, respectively) and the end of lactation in parity 3 (Energy, P=0.01). High energy group had a greater protein mass or fat mass in day 35 and 110 of gestation in parity 2 (Energy, P=0.01, P<0.01, P=0.04, and P=0.02, respectively) and parity 3 (Energy, P<0.01, and P<0.01, respectively). Although there were no significant energy and lysine effects on the number of piglets as total born, born alive, total litter weight and alive litter weight, Lys0.55/0.70 with 3,265 kcal of ME/kg group showed greater reproductive performance over three consecutive parities. There were no significant differences in litter weight and litter weight gain, however, final piglet weight and piglet weight gain were showed a tendency to increase by energy effect in first

parity (Energy, P=0.08, and P=0.08, respectively) and same interaction effects were detected in final piglet weight and piglet weight gain in third parity (Interaction, P=0.02, and P=0.04, respectively). High energy group in second parity had a tendency of increasing standard deviation of piglet birth weight (Energy, P=0.06). Lactation feed intake was greater in 3,265 kcal of ME/kg group at parity 3 and weaning to esturs interval was not affect by dietary energy and lysine levels. Considering the number of sows along parity and culling rate, Lys0.55/0.75 with 3,265 kcal of ME/kg showed the lowest culling rate in numerically among treatments. Consequently, total lysine 0.55 % in gestation diet and 0.70% in lactation diet with 3,265 kcal of ME/kg showed the better reproductive performance and longevity in parities 2 and 3.

Key words: Energy, Lysine, Reproductive Performance, Longevity, Sow

INTRODUCTION

Sow longevity had an important economic impact on pork operation (Kroes and van Male, 1979; Sehested, 1996) and poor sow longevity could lead to economic inefficiency and animal wellbeing concerns (Stalder et al., 2004). The sow performance at first and second parity is important for culling decisions in the breeding herd (Iida and Koketsu, 2015; Andersson et al., 2016). Additionally, the first and second parity performance based on number of offspring born alive can be used effectively to predict subsequent performance (Sasaki and Koketsu, 2008; Hoving et al., 2011; Gruhot et al., 2017).

Newton and Mahan (1993) found no relationship between breeding weights of 120, 135, or 150 kg and the reproductive ability of gilts over three parities. Deficient energy intake during gestation is associated with lower body fat reserves at farrowing or weaning and WEI is delayed and conception rate is decreeased (King, 1987; Young et al., 1990), but over energy feeding during gestation increased body weight and body condition of the sow at the end of pregnancy and it could affect poor lactation performance or locomotion problems (Castaing et al., 1983). Thus, it is necessary to provide the adequate nutrition to sows during 1 to 3 parities to maintain the optimal body reserves for high reproductive performance and to maximize the longevity (Dourmad et al., 1994). Because modern primiparous sows have a increased growth rate, a larger mature size, a reduced body fat levels and greater prolificacy, they need the new nutritional requirements (Whittemore, 1996). Moreover, sows of second parity had a high risk of getting second parity syndrome with the inadequate nutrition to first parity (Clowes et al., 2003; Thaker and Bilkei, 2005; Saito et al., 2010). Although there have been several studies on dietary energy and lysine levels in first (Tokach et al., 1992; Zak et al., 1997; Eissen et al., 2003; Heo et al., 2008) or second parity sows (Kirkwood et al., 1990; Beyer et al., 2007; Hoving et al., 2012), few have studied the nutritional effects on reproductive performance in sows during 1 to 3 consecutive parities.

KFS (2017) suggested the total lysine requirement for 12.35, 11.81, 9.95 g/d in gestation sows of parity 1, 2, and 3, and 44.28 g/d and 45.93 g/d in lactation of parity 1 and 2+. NRC (2012) recommended the total lysine requirement 12.4/19.3, 11.0/17.5, 9.4/15.4 g/d (<90d, and >90d of gestation) for gestating sows as parity 1, 2, and 3, respectively. Also, NRC (2012) suggested total lysine requirement 52.6-56.5 g/d and 56.4-60.5 g/d for lactating sows as parity 1 and 2+. Considering the difference of NRC (2012) and KFS (2017), we need to verifty the adequate requirement of lysine for gestating and lactating sows.

Therefore, the objective of current study was to evaluate the effects of dietary energy and lysine levels in gestation and lactation diet on the optimal body condition, reproductive performance, and longevity in sows during 1 to 3 consecutive parities.

MATERIALS AND METHODS

The experiment was designed in accordance with Seoul National University Institutional Animal Care and Use Committee (SNU-IACUC) and the use of animals for scientific purposes. All procedures were followed by the animal experimental guidelines approved by the SNU-IACUC (SNU-160819-9).

Dietary treatments

All sows were allocated to dietary treatments at the experimental farm of Seoul National University, Eumseong-gun, Chungcheongbuk-do, Korea. Eight diets, two energy levels (3,265 and 3,365 kcal of ME/kg) and four lysine levels (gestation 0.55, 0.65, 0.75, 0.85%; lactation: 0.70, 0.85, 1.00, 1.15%, respectively) were formulated from corn-soybean meal based (Table 1 and 2). Dietary energy was altered through the combination of cereal grains and tallow while lysine was adjusted so that all experimental diets were formulated with same crude protein content. The content of metabolizable energy, crude protein, calcium, total phosphorus, amino acids, vitimins, and minerals were met or exceeded the recommendations of NRC (1998) and limiting amino acids (lysine, methionine, threonine, tryptophan).

Sow management, housing and feeding procedures

Forty-eight gilts (Yorkshire x Landrace F1 cross, Darby, Korea) were allocated to one of eight dietary treatments in a completely randomized design (CRD) over first to third parity sows. Pregnant gilts on day 35 of gestation allocated to treatment by body weight (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea) and backfat thickness (Anyscan BF, Songkang GLC Co. LTD, Seongnam-si, Gyeonggi-do, Korea) at P_2 position (65mm from the midline over the last rib). During gestation period, gilts and sows were housed in gestation stall (2.20 × 0.64 m) with concrete slatted floor. Each gestation stall was equipped with a feeder and a waterer for sows. From prefarrowing through to weaning, sows were housed in farrowing crates (2.50 ×

1.80 m) on steel and plastic slatted floors in auto-ventilation system. The room temperature for gestating and lactating sows was maintained average 20 ± 3℃ and 28 ± 2℃, respectively. The temperature of piglet creep zones were heated with a heat lamp set at 32± 2℃. All sowss were fed 2 kg, 2.2 kg, 2.4 kg once a day at 08:00 hours in parity 1, 2, and 3. End of farrowing, litter size, live litter birthweight, and each piglet weight at birth were recorded for each sow within 24 hour of farrowing. Within 24 hour of farrowing, each sow was weighed (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea) and backfat thickness measured by ultrasound meter (Anyscan BF, Songkang GLC Co. LTD, Seongnam-si, Gyeonggi-do, Korea) at the P_2 position. Within 24 hour, piglets were fostered within treatments and litters standardized to piglets per sow. Fe-dextran 150 ppm (Gleptosil®, Alstoe, UK) injection, tail docking, and castration (for male piglets) were practiced to all piglets. All piglets were fed breast milk only and creep feed were not provided until weaning. After farrowing, lactating sows were fed the lactation diet which increased gradually from 1.0 kg/d to 5 kg/d during 5 days postpartum and fed diet *ad libitum* until weaning. Feed that was spilled by the sow and wasted was recorded every day during lactation period. Litters were weighed after cross-fostering and the day 21 day of lactation. Sows were weighed and backfat P_2 measured on the 24hrs postpartum and the day 21 of lactation. Following weaning, sows were moved to individual stalls (2.20 × 0.65 m) and fed 3 kg of common sow diet (moisture 11.4%, crude protein 12.6%, ether extract 5.8%, and crude ash 4.9%) twice a day (08:00 and 16:00 h). Sows were mated on their first postweaning oestrus by artificial insemination twice on 12 hours interval with fresh diluted semen (Dary AI center, Chunju-si, Chungcheongbuk-do, Korea). Following mating, sows were moved into gestation barn with individual stall. Confirmation of pregnany was practiced at day 21 of gestation by re-estrus check and at day 35 of gestation by ultrasound pregnancy diagnostic device (Easyscan, Dongjin BLS Co. Ltd., Gwangju-si, Gyeonggi-do, Korea).

Sample collection and analysis

The body weight and backfat thicknes (P_2 position), body length of sows were measured at day 35, 110 of gestation, 24hrs postpartum, and day 21 of lactation, respectively. Body weight was measured by electric scale (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea) and backfat thickness was measured by ultrasound lean meter (Anyscan BF, Songkang GLC Co. LTD, Seongnam-si, Gyeonggi-do, Korea). The weaning to estrus interval (WEI) of sows was checked from weaning to first estrus period. Voluntary feed intake of lactating sows was examined by record of feed supply and wastage during lactation period.

Within 12hrs postpartum, the number of piglets in total born, born alive, stillborn, mummy, and their weight were measured (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea), respectively. In day 21 of lactation, body weight of piglets was measured for litter weight, piglet weight, and both weight gain. Also, the piglet body weight at birth and 21 day of lactation for each litter was used for calculating piglet uniformity such as coefficient of variation (CV), and standard deviation (SD).

The protein and fat mass of sows were calculated using the equations of Dourmad et al. (1997).

$$EBW\ (kg) = 0.905 \times BW^{1.013}$$

$$Fat\ (kg) = -26.4 + 0.221 \times EBW + 1.331 \times backfat\ (mm)$$

$$Protein\ (kg) = 2.28 + 0.178 \times EBW + 0.333 \times backfat\ (mm)$$

Statistical analysis

All of collected data were carried out by least squares mean comparisons and were evaluated with the General Linear Model (GLM) procedure of SAS (SAS Institute, 2004). Individual sows and their litters were used as the experimental unit and were analyzed as a two-way ANOVA. Orthogonal polynomial contrasts were used to detect linear and quadratic responses to lysine levels when significance of lysine effect detected. The differences were declared significant at $P<0.05$ or highly significant at $P<0.01$ and the determination of tendency for all analysis was $0.05 \geq P$ and $P<0.10$.

RESULTS

The effects of dietary energy and lysine levels on body weight of sows over three consecutive parities was presented in Table 3. Third parity sows fed high energy diet had a greater body weight at day 110 of gestation (Energy, P=0.01). There was significant interaction in body weight gain during gestation in parities 2 and 3 (Interaction, P=0.03, and P=0.03, respectively). Body weight gain was increased as dietary lysine levels increased in high energy group, and it was decreased as dietary lysine levels increased in low energy group. Body weight of 24hrs postpartum in parity 3 was higher and more body weight loss observed in high energy group (Energy, P=0.02, and P<0.01, respectively). Body weight gain during whole period was greater in high energy group (Energy, P=0.01).

Dietary energy intake had significant influence to backfat thickness of gestation and lactation period (Table 4). Increasing dietary energy level induced greater backfat thickness at the day 35 and 110 of gestation in parity 2 (Energy, P=0.01, and P<0.01, respectively) and in parity 3 (Energy, P<0.01, and P<0.01, respectively). Also, in lactation, high energy group showed greater backfat thickness of 24hrs postpartum in parities 1, 2, and 3 (Energy, P=0.04, P<0.01, and P<0.01, respectively). In the end of lactation, parity 3 sows fed high energy diet showed a greater backfat thickenss than sows fed low energy diet (Energy, P=0.01).

Estimated protein mass of gestating and lactating sows (Table 5) were affected by energy levels, not lysine levels. High energy group had a greater protein mass at the day 35 and 110 of gestation in parity 2 (Energy, P=0.01, and P<0.01, respecitvely) and parity 3 (Energy, P<0.01, and P<0.01, respectively). Also, increasing energy content in diet increased protein mass on 24hrs postpartum in parities 2 and 3 (Energy, P<0.01, P<0.01) and on day 21 of lactation in parity 3 (Energy, P=0.01). There was a significant interaction in protein mass gain during gestation period in parity 3 (Interaction, P=0.03) and overall period (Interaction, P<0.03) between energy and lysine levels. Similar to estimated protein mass, estimated fat mass of gestating and lactating sows was influenced by energy effect

only (Table 6). Sows fed high energy diet had greater fat mass at the day 35 and 110 of gestation in parity 2 (Energy, P=0.04, and P=0.02, respecitvely) and parity 3 (Energy, P<0.01, and P<0.01, respectively), and at 24hrs postpartum in parities 2 and 3 (Energy, P<0.01, and P<0.01, respectively). Also, interaction with energy and lysine was observed in body fat mass gain during gestation at parity 3 (Interaction, P=0.02), and during lactation at parity 2 (Interaction, P=0.02). Although lactation fat mass gain tended to increase in parity 1 (Energy, P=0.09), lactation fat mass gain tended to decreased in parity 3 (Energy, P=0.05) when sows fed high energy diet. Overall changes of fat mass in first parity had a significant difference by energy levels (Energy, P=0.01), and interaction with energy and lysine effect was observed in parities 2 and 3 (Interaction, P<0.01, and P=0.04, respectively).

The effects of dietary energy and lysine levels on reproductive performance were present in Table 7. There were no significant energy and lysine effects on the number of piglets as total born, born alive. However, significant interactions were detected in the number of total born piglets in parity 1 and 2 (Interaction, P<0.01, and P=0.02, respectively), and born alive in parity 1 and 2 (Interaction, P=0.04, and P=0.02, respectively). The effect of lysine level was shown in the number of mummy in parity 1 (lysine, P=0.01) and the number of piglets total born and born alive in parity 2 (lysine, P=0.08, P=0.06, respectively).

There were no significant differences in total litter weight and alive litter weight during 1 to 3 parities by energy and lysine levels (Table 8), but interaction effects were observed in total litter weight and alive litter weight in parity 2 (Interaction, P=0.02, and P=0.01, respectively), and alive piglet weight in parities 1 and 3 (Interaction, P=0.02, and P=0.02, respectively). Otherwise, there were no significant difference in final litter weight and litter weight gain. In final piglet weight and piglet weight gain of first parity showed a tendency to increase by energy levels (Energy, P=0.08, and P=0.08, respectively) and interaction effects were detected in final piglet weight and piglet weight gain in third parity (Interaction, P=0.02, and P=0.04, respectively).

Piglet uniformity in first and third parity was not influenced by energy and lysine levels (Table 9). However, high energy group in second parity had a tendency of increasing standard deviation of piglet birth weight (Energy, P=0.06). Lys0.75/1.0 and Lys0.65/0.85 treatments showed a lower standard deviation of piglet birth weight in second parity (Lysine, P=0.03). Also, standard deviation and coefficient variation of piglet birth weight in second parity were decreased in high energy level, and increased in low energy level according to lysine level (Interaction, P=0.02, P=0.09, respectively).

Measuring the number of culled sows in the end of pairty, low energy group showed high culling rate in parity 1 and higher energy group showed high culling rate in parities 2 and 3. One of sows in Lys0.65/0.85 with 3,265 kcal of ME/kg and 3,365 kcal of ME/kg culled with postparturient dysgalactia and one sow in Lys0.65/0.85 with 3,265 kcal of ME/kg culled with fetal dystocia at parity 1. The other sows were culled by reproductive problem like re-estrus and infertility. There were no culled sows in Lys0.55/0.70% with 3,265 kcal of ME/kg during1 to 3 consecutive parities.

DISCUSSION

The previous trials (Gatlin et al., 2002; Long et al., 2010; Jin et al., 2016) supported the results of the current experiment, in which sows fed high energy diet had a greater BW and a thicker backfat compared with sows fed low energy diet. In contrast to the energy effects, dietary lysine levels did not influence on BW and backfat thickenss in the present study. Dietary lysine levels in gestation did not showed any effects on BW and backfat thickness (Cooper et al., 2001; Santos et al., 2006). In other hands, Dourmad et al. (1998) used isoenergetic lactation diets with two crude protein levels and L-lysine-HCl supplementation; they did not find any difference in backfat thickness and reported that that sows fed the lowest lysine level (0.66%) lost more weight during lactation. Lysine effects did not cause a significant difference in body weight or backfat thickness; however, the dietary energy effects on body weight were significantly noticeable from end of first parity to the third parity. Body protein mass and fat mass in sows showed the same trend of body weight and backfat thickness of sows during 1 to 3 parities. Sows fed high energy diet showed a greater body protein mass and fat mass on day 21 of lactation in parity 1 to parity 3 sows. It was necessary to provide adequate energy levels for sows, in order to ensure for each sow an adequate body weight and backfat thickness at farrowing (Dourmad et al., 1994). Gill (2007) insisted that modern genotypes on the long-term benefits of nutritionally enhancing fatness in gilts and young sows, however, they had some problems that longevity could be reduced due to culling for lameness and reproductive failure with body condition extrmes (Danielsen et al., 1993).

Sows were often in a catabolic state during lactation, resulting in tissue mobilization due to the high demand for nutrients required in milk production (Mullan & Williams, 1990); further, excess tissue mobilization often affects WEI and sow productivity (Reese et al., 1982; Mullan & Williams, 1989; Jones & Stahly, 1995). Dietary energy and lysine levels caused no significant difference in body weight loss and backfat loss during lactation in parities 2 and 3. However, backfat

loss of lactation at third parity increased when sows were fed 3,365 kcal of ME/kg diet; this increase resulted from low lactation feed intake. The current result of parity 3 was in accordance with the result of Coffey et al. (1994), who demonstrated that sows fed higher dietary energy during gestation had low feed intake and lost more weight during lactation. Young et al. (2004) reported that an increased body weight at farrowing would accompany decreased feed intake during the lactation period and several common reproductive problems, such as prolonged weaning-to-estrus transition (Baidoo et al., 1992), higher incidence of anestrus after weaning, and a decreased conception rate (Kirkwood & Thacker, 1988). Also, sows fed low energy diet had greater feed intake rather than sows fed high energy diet for meeting their energy requirement in *ad libitum* situation (O′Grady et al., 1985). In accordance with previous studies, sows fed 3,365 kcal of ME/kg diet in parity 3 had greater farrowing body weight and lower lactation feed intake, although the weaning-to-estrus interval was not negatively affected.

Considering longevity of sow, sows with lower feed intake and greater backfat loss during lactation had a shorter productive lifetime (Serenius et al., 2006). Also, body condition was very important factors to deterimine culled sows and thin sow problem or degree of body composition adversely contributes to poor reproductive performance and sow longevity (Stadler et al., 2004). Consequiently, sows fed 3,265 kcal of ME/kg diet showed positive influcenced on maintaining an adequate body weight and backfat thickenss, lactation feed intake, and backfat loss of lactation in parity 3 for sow longevity.

Although there were no dietary effects on the number of piglets as total born, stillbirth, and born alive, there were lysine effect on mummy and interaction of total born and born alive. However, this result was derived only from a small number of investigated sows per treatment, and thus, its applicability at a larger scale is questionable. Some researchers reported fewer live births because of increased dietary energy intake in the gestation diet (Frobish et al., 1973; Buitrago et al., 1974; Libal & Wahlstrom, 1977). Santos et al. (2006) demonstrated that

dietary ME and lysine levels do not affect the reproductive performance in the subsequent farrowing, and they suggested that supplementation levels >0.75% for lysine and >3,250 kcal/kg for overall dietary energy are not necessary requirements for lactating sows. Consequently, 0.55% and 0.70% total lysine with 3,265 or 3,365 ME of kcal/kg in the gestation and lactation diet met the requirement of sows regardless of parities 2 and 3 for optimal reproductive performance in terms of the number of total born and born alive. In total litter weight and alive litter weight, there were no significant effects by energy and lysine levels, however, total litter weight and alive litter weight during overall period were higher in Lys0.55/0.70 with 3,265 kcal of ME/kg, numerically. Increased energy intake in gestation diet resulted in increased pig birth weights (Henry & Etienne, 1978), which subsequently increased pig survival and weaning weights (Cromwell et al., 1989). Although Coffey et al. (1994) insisted that feeding high-energy diets (5,900 vs. 7,400 kcal/d) during gestation increased pig birth weight and piglet weight gain to weaning, the current study did not show any such effects. Cooper et al. (2001) reported that increased lysine intake in the gestation diet had no significant effects on litter size and growth; however, total births and total litter weight were affected by parities 1, 2, and 3+. The reason was explained that The increasing intake of lysine and other synthetic amino acids resulted in a reduced number of total born and born alive piglets on subsequent farrowing by Touchette et al. (1998) who fed different lysine levels to first parity sows and kept the ideal amino acids ratios constant by adding valine, threonine, and sulfur amino acids. In current study, different total lysine levels with same content of other amino acids showed no significant effects on the number of piglet birth, and its litter weight, respectively.

Park et al. (2008) demonstrated that compared with low energy treatment (3,265 kcal of ME/kg), high dietary energy treatment (3,365 kcal/kg) during lactation increased the number of piglets and litter weight at weaning and improved piglet growth rate. In addition, Noblet et al. (1998) reported that the variation of energy levels from 27 to 63 MJ DE/d significantly influenced piglet growth during lactation. Matzat et al. (1990) observed a linear correlation between piglet growth

and energy intake levels. In agreement with previous studies, different energy values in lactation diets had effects on piglet growth in parity 1. However, sows with parities 2 and 3 did not showed any energy effect on piglet growth during the lactation period. Pluske et al. (1995) reported no effect of litter weight gain on increasing the metabolizable energy intake from 18,000 to 25,000 kcal/d. In agreement with the result of Pluske et al. (1995), herein, different energy levels in lactation diet had no influence on litter weight gain in sows in parities 2 and 3. Because they provided the lactation diet with *ad libitum* after day 5 of lactation, thus it can be met energy requirement for piglet growth during lactation period. Therefore, it was necessary to provide 3,365 kcal of ME/kg for primiparous sows during lactation, however, 3,265 kcal of ME/kg was suffient energy requirement for sows with parity 2 and parity 3 during lactation. In terms of lysine effects, Mahan (1998) demonstrated that different gestation protein levels with same lysine content did not affect litter weight and litter weight gain at day 21 of lactation in parities 1 and 2–5. In addition, Stahly et al. (1990) and Johnston et al. (1993) reported a positive effect of not only lysine but also protein intake on litter weight gain during lactation. However, the piglet weight and litter weight at day 21 of lactation in the current study were similar to the values reported by Touchette et al. (1998), Thaler et al. (1992), and Santos et al. (2006) who reported no improvement on litter performance with greater lysine intake. Consequently, different lysine content in lactation diet had no significant influence on litter performance after cross-fostering, and the total lysine content of over 0.70% of lactation diet met the requirement of lactating sows for litter growth during 1 to 3 consecutive parities. Nevertheless, increasing total lysine level in 3,265 kcal of ME/kg diet could maximize piglet growth in parity 3.

In piglet uniformity, sow BW and backfat increase during gestation were negatively related with litter uniformity (Quesnel et al., 2008; Wientjes et al., 2013). Because sow body development and litter development were competing nutritional demands during gestation, particularly in parities 1 and 2, It was possible that

compared with sows gestating small litters, those gestating more litters got inadequate energy to utilize for their own body development (Lewis & Bunter, 2011). Litter uniformity was compromised by severe body condition loss during previous lactation by carry over effects from body condition increase during gestation and sow body condition loss during lactation (Wientjes et al., 2013). In the current study, standard deviation of piglet birth weight at parity 2 was showed lysine effect; lysine 0.75/1.0% led to the better piglet uniformity in parity 2. Despite there being no lysine effects on body weight and backfat thickness during gestation in parities 1 and 2, 0.75/1.0% lysine-supplemented with 3,265 kcal of ME/kg diet met the requirement of gestating sows in 2 for maternal requirements and piglet growth; further, the balance of lysine and other amino acids prevented body condition decline associated with follicle development and next reproduction. In the current study, parity effects on litter characteristics at birth were in accordance with previous studies (Damgaard et al., 2003; Quesnel et al., 2008; Wientjes et al., 2013), and they indicated that in terms of the parity effect on litter size, the mean piglet birth weight was the highest in parity 3 and 4 sows, and litter uniformity decreased with parity as a result of an increase in the percentage of both small and large piglets in older sows. In addition, Wientjes et al. (2012) reported that the 1.4% to 1.8% increase in birth weight CV may correspond to an estimated 1.5% to 1.9% increase in piglet mortality, respectively. Considering the interaction of heavy weight piglets and CV in parity 3, higher total lysine level within 3,265 kcal of ME/kg diet did not affect CV of piglet birth weight significantly, and resulted in increasing the ratio of heavy weight piglets in litter.

Insufficient nutrient intake during lactation caused severe body weight loss, delayed WEI, and reduced conception rate, ovulation rate, and fetal survival rate (Kirkwood et al., 1987a, b; Baidoo et al., 1992; Zak et al., 1997). Reese et al. (1982) noted a significantly delayed WEI in sows fed 8-Mcal ME/d than those fed 16-Mcal ME/d. Coffey et al. (1994) also observed prolonged WEI in sows provided with normal energy diet (ME 3,240 kcal/kg) compared with those provided high energy diet (ME 3,600 kcal/kg). Park et al. (2008) demonstrated a higher incidence

of delayed estrus after weaning in sows with greater body weight and backfat losses than those with less body weight and backfat losses during lactation. In the current study, significant body weight loss of lactating sows was observed by energy effect in parities 1 and 3; however, it did not have any negative effect on WEI. King and Martin (1989) suggested that the effect of inadequate nutrient intake during lactation on subsequent reproduction was mediated through decreased secretion of LH pulses before weaning. Tokach et al. (1992) insisted that insulin related with energy intake had an influence on LH and GnRH secretion for WEI and follicle development. Dietary lysine effects did not significantly affect WEI after parities 2 and 3. However, the higher requirement of lysine for maternal growth in primiparous sows resulted in shortened WEI with 0.75/1.0% total lysine treatment because of amino acid balance. Thus, 0.75/1.0% of total lysine content in gestation and lactation diets reduced weaning-to-estrus interval in first parity sow, and dietary energy and lysine levels in these diets had no signficiant effects on WEI in second or third parity sows.

In culling rate of sows, sows fed 3,265 kcal of ME/kg diet showed highly culling rate in parity 1 with thin body problems, and sows fed 3,365 kcal of ME/kg diet resulted in higly culltine rate in parities 2 and 3 with reproductive problems. The thin sow problem or degree of body composition adversely contributes to poor reproductive performance and sow longevity (King, 1987). Young et al. (1990) observed that significantly fewer sows receiving the lowest energy level during gestation (22.2 MJ ME/d) completed three parities and many of the sows which were discarded had 10 mm or less P2 backfat thickness when removed. Moreover, in the study of Dourmad et al. (1994), energy levels lower than 25 MJ ME/d during gestation were then associated with delayed return to oestrus after weaning and reduced longevity, suggesting that the increased lactation feed intake was not sufficient to compensate for the low pregnancy supply. Thus insufficient energy supply may result in inadequate maternal gain of sows with parity 1 for next reproduction. Some minimum level of backfat was needed on replacement sows so that they maximize lifetime number of piglets born alive (Young et al., 1990;

Dourmad et al., 1994). Also, improving body condition at weaning is likely to have potential benefits that include decreased sow mortality, lower weaning to oestrus intervals, and better reproductive performance in the next litter (Stalder et al., 2004). Followed with Frobish et al. (1973), long term effects of four levels of energy levels (from 12.5 to 31.4 MJ ME/d) during gestation with ad libitum feeding during lactation in over three reproductive cycles, the number of sows completing three reproductive cycles tended to be lower for both the lowest and the highest level of energy supply. In that study, lower energy intake was dominant reason of conceive failure and leg abnormalities were the major factor causing removal of sows receiving the highest energy intake. Castaing et al. (1983) compared the long term effects of three levels of energy allowance during gestation (29.9, 33.1, 36.6 MJ DE/d). The proportion of sows completing 4 reproductive cycles was lower with the higher energy level. Culling for reproductive failure tended to be lower for the medium level, whereas significantly more sows fed the higher energy supply were discarded because of locomotion problems. There was no lysine effect on culling rate of sows as parity. Santos et al. (2006) demonstrated that the reproductive performance in the subsequent farrowing was not affected by the lysine levels (0.75, 0.90, 1.05 and 1.20%). In the result of Yang et al. (2000), low lysine (0.4% lysine) intake in primiparous lactating sows impaired follicular development and reduced the ability of follicles to support oocyte maturation. However, high (1.6% lysine) compared with medium lysine (1.0% lysine) intake had no further positive effects on ovarian function. Supplemented total lysine 0.55/0.70% was sufficient for requirement of sows for next reproduction in parities 1, 2, and 3. Consequently, total lysine 0.55% and 0.70% for gestation and lacation, respectively, with 3,265 kcal or ME/kg had the postivie influence on culling rate for sows during 1 to 3 consecutive parities.

CONCLUSION

In conclusion, sows fed 3,365 kcal of ME/kg diet had greater body weight and backfat thickness during parities 2 and 3. It had a possibility to cause high culling rate with excessive body condition easily. Considering reproductive performance and longevity, Lys0.55/0.70% with 3,265 kcal of ME/kg had positive influence on the number of piglet birth and culled sows during 1 to 3 parity. Consequently, total lysine 0.55 % in gestation diet and 0.70% in lactation diet with 3,265 kcal of ME/kg had the better productivity and longevity in parities 2 and 3.

REFERENCES

Andersson, E., Frössling, J., Engblom, L., Algers, B., & Gunnarsson, S. 2016. Impact of litter size on sow stayability in Swedish commercial piglet producing herds. Acta Veterinaria Scandinavica, 58(1), 31.

Baidoo, S. K., Aherne, F. X., Kirkwood, R. N., & Foxcroft, G. R. 1992. Effect of feed intake during lactation and after weaning on sow reproductive performance. Canadian Journal of Animal Science, 72(4), 911-917.

Beyer, M., Jentsch, W., Kuhla, S., Wittenburg, H., Kreienbring, F., Scholze, H., Rudolph P. E., Metges, C. C. 2007. Effects of dietary energy intake during gestation and lactation on milk yield and composition of first, second and fourth parity sows. Archives of Animal Nutrition, 61(6), 452-468.

Buitrago, J. A., Maner, J. H., Gallo, J. T., & Pond, W. G. 1974. Effect of dietary energy in gestation on reproductive performance of gilts. Journal of Animal Science, 39(1), 47-52.

Clowes, E. J., Williams, I. H., Baracos, V. E., Pluske, J. R., Cegielski, A. C., Zak, L. J., & Aherne, F. X. 1998. Feeding lactating primiparous sows to establish three divergent metabolic states: II. Effect on nitrogen partitioning and skeletal muscle composition. Journal of Animal Science, 76(4), 1154-1164.

Clowes, E. J., Aherne, F. X., Schaefer, A. L., Foxcroft, G. R., & Baracos, V. E. 2003. Parturition body size and body protein loss during lactation influence performance during lactation and ovarian function at weaning in first-parity sows. Journal of Animal Science, 81(6), 1517-1528.

Cunninghan, J. G. 1999. Digestão e absorção: os processos não-fermentativos. In: Tratado de Fisiologia Veterinária. 2. ed. Rio de Janeiro: Guanabara Koogan. pp. 242-265.

Cooper, D. R., Patience, J. F., Zijlstra, R. T., & Rademacher, M. 2001. Effect of energy and lysine intake in gestation on sow performance. Journal of Animal Science, 79(9), 2367-2377.

Coffey, M. T., Diggs, B. G., Handlin, D. L., Knabe, D. A., Maxwell, C. V., Noland, P. R., ... & Gromwell, G. L. 1994. Effects of dietary energy during gestation and lactation on

reproductive performance of sows: a cooperative study. S-145 Committee on Nutritional Systems for Swine to Increase Reproductive Efficiency. Journal of Animal Science, 72(1), 4-9.

Cromwell, G. L., Hall, D. D., Clawson, A. J., Combs, G. E., Knabe, D. A., Maxwell, C. V., ... & Prince, T. J. 1989. Effects of additional feed during late gestation on reproductive performance of sows: a cooperative study. Journal of Animal Science, 67(1), 3-14.

Damgaard, L. H., Rydhmer, L., Løvendahl, P., & Grandinson, K. 2003. Genetic parameters for within-litter variation in piglet birth weight and change in within-litter variation during suckling. Journal of Animal Science, 81(3), 604-610.

Dourmad, J. Y., Etienne, M., Prunier, A., & Noblet, J. 1994. The effect of energy and protein intake of sows on their longevity: a review. Livestock Production Science, 40(2), 87-97.

Dourmad, J. Y., Etienne, M., Noblet, J., & Causeur, D. 1997. Prédiction de la composition chimique des truies reproductrices à partir du poids vif et de l'épaisseur de lard dorsal. J. Rech. Porcine Fr, 29, 255-262.

Dourmad, J. Y., Noblet, J., & Etienne, M. 1998. Effect of protein and lysine supply on performance, nitrogen balance, and body composition changes of sows during lactation. Journal of Animal Science, 76(2), 542-550.

Eissen, J. J., Apeldoorn, E. J., Kanis, E., Verstegen, M. W. A., & De Greef, K. H. 2003. The importance of a high feed intake during lactation of primiparous sows nursing large litters. Journal of Animal Science, 81(3), 594-603.

Frobish, L. T., Steele, N. C., & Davey, R. J. 1973. Long term effect of energy intake on reproductive performance of swine. Journal of Animal Science, 36(2), 293-297.

Flowers, B., Martin, M. J., Cantley, T. C., & Day, B. N. (1989). Endocrine changes associated with a dietary-induced increase in ovulation rate (flushing) in gilts. Journal of Animal Science, 67(3), 771-778.

Gatlin, L. A., Odle, J., Soede, J., & Hansent, J. A. 2002. Dietary medium-or long-chain

triglycerides improve body condition of lean-genotype sows and increase suckling pig growth. Journal of Animal Science, 80(1), 38-44.

Gruhot, T. R., Díaz, J. A. C., Baas, T. J., & Stalder, K. J. 2017. Using first and second parity number born alive information to estimate later reproductive performance in sows. Livestock Science, 196, 22-27.

Heo, S., Yang, Y. X., Jin, Z., Park, M. S., Yang, B. K., & Chae, B. J. 2008. Effects of dietary energy and lysine intake during late gestation and lactation on blood metabolites, hormones, milk compositions and reproductive performance in primiparous sows. Canadian Journal of Animal Science, 88(2), 247-255.

Henry, Y., & Etienne, M. 1978. Alimentation énergétique du porc. Journées Rech. Porcine en France, 10, 119-166.

Hoving, L. L., Soede, N. M., Graat, E. A. M., Feitsma, H., & Kemp, B. 2011. Reproductive performance of second parity sows: Relations with subsequent reproduction. Livestock Science, 140(1), 124-130.

Hoving, L. L., Soede, N. M., Feitsma, H., & Kemp, B. 2012. Lactation weight loss in primiparous sows: consequences for embryo survival and progesterone and relations with metabolic profiles. Reproduction in Domestic Animals, 47(6), 1009-1016.

Iida, R., & Koketsu, Y. 2015. Number of pigs born alive in parity 1 sows associated with lifetime performance and removal hazard in high-or low-performing herds in Japan. Preventive Veterinary Medicine, 121(1), 108-114.

Jin, S. S., Jin, Y. H., Jang, J. C., Hong, J. S., Jung, S. W., & Kim, Y. Y. 2017. Effects of dietary energy levels on physiological parameters and reproductive performance in gestating sows over three consecutive parities. Asian-Australasian Journal of Animal Sciences.

Johnston, L. J., Pettigrew, J. E., & Rust, J. W. 1993. Response of maternal-line sows to dietary protein concentration during lactation. Journal of Animal Science, 71(8), 2151-2156.

Jones, D. B., & Stahly, T. S. 1995. Impact of amino acid nutrition during lactation on subsequent reproductive function of sows. Journal of Animal Science, 73(Suppl 1), 183.

King, R. H., & Martin, G. B. 1989. Relationships between protein intake during lactation, LH levels and oestrous activity in first-litter sows. Animal Reproduction Science, 19(3-4), 283-292.

Kirkwood, R. N., Baidoo, S. K., Aherne, F. X., & Sather, A. P. 1987a. The influence of feeding level during lactation on the occurrence and endocrinology of the postweaning estrus in sows. Canadian Journal of Animal Science, 67(2), 405-415.

Kirkwood, R. N., Lythgoe, E. S., & Aherne, F. X. 1987b. Effect of lactation feed intake and gonadotrophin-releasing hormone on the reproductive performance of sows. Canadian Journal of Animal Science, 67(3), 715-719.

Kirkwood, R. N., & Thacker, P. A. 1988. Nutritional factors affecting embryo survival in pigs (results and speculations). Pig News and Information.

Kirkwood, R. N., Baidoo, S. K., & Aherne, F. X. 1990. The influence of feeding level during lactation and gestation on the endocrine status and reproductive performance of second parity sows. Canadian Journal of Animal Science, 70(4), 1119-1126.

Kroes, Y., & Van Male, J. P. 1979. Reproductive lifetime of sows in relation to economy of production. Livestock Production Science, 6(2), 179-183.

Lewis, C. R. G., & Bunter, K. L. (2011). Body development in sows, feed intake and maternal capacity. Part 2: gilt body condition before and after lactation, reproductive performance and correlations with lactation feed intake. Animal, 5(12), 1855-1867.

Libal, G. W., & Wahlstrom, R. C. 1977. Effect of gestation metabolizable energy levels on sow productivity. Journal of Animal Science, 45(2), 286-292.

Long, H. F., Ju, W. S., Piao, L. G., & Kim, Y. Y. 2010. Effect of dietary energy levels of gestating sows on physiological parameters and reproductive performance. Asian-Australas Journal of Animal Science, 23:1080–1088.

Mahan, D. C. 1998. Relationship of gestation protein and feed intake level over a five-parity period using a high-producing sow genotype. Journal of Animal Science, 76(2), 533-541.

Matzat, P. D., M. G. Hogberg, R. L. Fogwell, and E. R. Miller. 1990. Lactation performance in high producing gilts fed in excess of ad libitum. In: Report of Swine Research, AS-

SW-8904. Pp 36-40. Michigan State University, East Lansing

McNamara, J. P., & Pettigrew, J. E. 2002. Protein and fat utilization in lactating sows: I. Effects on milk production and body composition. Journal of Animal Science, 80(9), 2442-2451.

Morrow, W. E. M., Leman, A. D., Williamson, N. B., Moser, R., & Pijoan, C. 1989. Improving parity-two litter size in swine. Journal of Animal Science, 67(7), 1707-1713.

Mullan, B. P., & Williams, I. H. 1989. The effect of body reserves at farrowing on the reproductive performance of first-litter sows. Animal Science, 48(2), 449-457.

Mullan, B. P., & Williams, I. H. 1990. The chemical composition of sows during their first lactation. Animal Science, 51(2), 375-387.

Newton, E. A., & Mahan, D. C. 1993. Effect of initial breeding weight and management system using a high-producing sow genotype on resulting reproductive performance over three parities. Journal of Animal Science, 71(5), 1177-1186.

Noblet, J., M. Etienne, and J. Y. Dourmad. 1998. Energetic efficiency of milk production. Pages 113–130 in The Lactating Sow. M. W. A. Verstegen,, P. J. Moughan, and J. W. Schrama, ed. Wageningen Pers, Wageningen, The Netherlands

National Research Council. 1998. Nutrient requirements of swine, 10th ed. National Academy Press, Washington, DC.

National Research Council. 2012. Nutrient requirements of swine, 11th ed. National Academy Press, Washington, DC.

Park, M. S., Yang, Y. X., Choi, J. Y., Yoon, S. Y., Ahn, S. S., Lee, S. H., Yang, B. K., Lee, K. J, Chae, B. J. 2008. Effects of dietary fat inclusion at two energy levels on reproductive performance, milk compositions and blood profiles in lactating sows. Acta Agriculturae Scand Section A, 58(3), 121-128.

Pluske, J. R., Williams, I. H., & Aherne, F. X. 1995. Nutrition of the neonatal pig. The neonatal pig: development and survival, 187-235.

Quesnel, H., Brossard, L., Valancogne, A., & Quiniou, N. 2008. Influence of some sow characteristics on within-litter variation of piglet birth weight. Animal, 2(12), 1842-1849.

Quesnel, H. 2009. Nutritional and lactational effects on follicular development in pigs. Control of Pig Reproduction VIII, 8, 121-134.

Reese, D. E., Moser, B. D., Peo, E. R., Lewis, A. J., Zimmerman, D. R., Kinder, J. E., & Stroup, W. W. 1982. Influence of energy intake during lactation on subsequent gestation, lactation and postweaning performance of sows. Journal of Animal Science, 55(4), 867-872.

Saito, H., Sasaki, Y., Hoshino, Y., & Koketsu, Y. 2010. The occurrence of decreased numbers of pigs born alive in parity 2 sows does not negatively affect herd productivity in Japan. Livestock Science, 128(1), 189-192.

Santos, J. M. G. D., Moreira, I., & Martins, E. N. 2006. Lysine and metabolyzable energy requirements of lactating sows for subsequent reproductive performance. Brazilian Archives of Biology and Technology, 49(4), 575-581.

Sasaki, Y., & Koketsu, Y. 2008. Sows having high lifetime efficiency and high longevity associated with herd productivity in commercial herds. Livestock Science, 118(1), 140-146.

Sauber, T. E., Stahly, T. S., Williams, N. H., & Ewan, R. C. 1998. Effect of lean growth genotype and dietary amino acid regimen on the lactational performance of sows. Journal of Animal Science, 76(4), 1098-1111.

Sehested, E. 1996. Economy of sow longevity. NJF-utredning/rapport (Finland).

Shaw, H. J., & Foxcroft, G. R. 1985. Relationships between LH, FSH and prolactin secretion and reproductive activity in the weaned sow. Journal of Reproduction and Fertility, 75(1), 17-28.

Stalder, K. J., Knauer, M., Baas, T. J., Rothschild, M. F., & Mabry, J. W. 2004. Sow longevity. Pig News and Information, 25(2), 53N.

Stahly, T. S., G. L. Cromwell, and H. J. Monegue. 1990. Lactational responses of sows nursing large litters to dietary lysine levels. Journal of Animal Science, 68(Suppl. 1):369.

Thaler, R. C., Woerman, R. L., & Britzman, D. B. 1992. Effect of lysine level in lactation diets on sow performance and milk composition. Journal of Animal Science, 70(Suppl

1), 238.

Thaker, M. Y. C., & Bilkei, G. 2005. Lactation weight loss influences subsequent reproductive performance of sows. Animal Reproduction Science, 88(3), 309-318.

Tokach, M. D., Pettigrew, J. E., Dial, G. D., Wheaton, J. E., Crooker, B. A., & Johnston, L. J. 1992. Characterization of luteinizing hormone secretion in the primiparous, lactating sow: relationship to blood metabolites and return-to-estrus interval. Journal of Animal Science, 70(7), 2195-2201.

Touchette, K. J., Allee, G. L., Newcomb, M. D., & Boyd, R. D. 1998. The lysine requirement of lactating primiparous sows. Journal of Animal Science, 76(4), 1091-1097.

Whittemore, C. T. 1996. Nutrition reproduction interactions in primiparous sows. Livestock Production Science, 46(2), 65-83.

Wientjes, J. G. M., Soede, N. M., Van der Peet-Schwering, C. M. C., Van Den Brand, H., & Kemp, B. 2012. Piglet uniformity and mortality in large organic litters: Effects of parity and pre-mating diet composition. Livestock Science, 144(3), 218-229.

Wientjes, J. G. M., Soede, N. M., Knol, E. F., Van den Brand, H., & Kemp, B. 2013. Piglet birth weight and litter uniformity: Effects of weaning-to-pregnancy interval and body condition changes in sows of different parities and crossbred lines. Journal of Animal Science, 91(5), 2099-2107.

Young, M. G., Tokach, M. D., Aherne, F. X., Main, R. G., Dritz, S. S., Goodband, R. D., & Nelssen, J. L. 2004. Comparison of three methods of feeding sows in gestation and the subsequent effects on lactation performance. Journal of Animal Science, 82(10), 3058-3070.

Zak, L. J., Cosgrove, J. R., Aherne, F. X., & Foxcroft, G. R. 1997. Pattern of feed intake and associated metabolic and endocrine changes differentially affect postweaning fertility in primiparous lactating sows. Journal of Animal Science, 75(1), 208-216.

Table 1. The formulas and chemical composition of experimental gestation diet

Item	ME 3,265 kcal/kg			
	Lys 0.55%[1)]	Lys 0.65%	Lys 0.75%	Lys 0.85%
Ingredients, %				
Corn	77.03	77.17	77.34	77.53
SBM-46	13.12	12.79	12.46	12.13
Wheat bran	1.99	2.05	2.08	2.05
PKM (extraction)	3.00	2.04	2.98	3.02
Tallow	1.54	1.52	1.49	1.46
L-lysine HCl(78%)	0.00	0.13	0.27	0.40
DL-methionine(99%)	0.03	0.03	0.04	0.04
Threonine(99%)	0.01	0.02	0.02	0.03
Tryptophan(10%)	0.09	0.11	0.13	0.15
MDCP	1.44	1.44	1.44	1.44
Limestone	1.15	1.15	1.15	1.15
Vit. Mix[2)]	0.10	0.10	0.10	0.10
Min. Mix[3)]	0.10	0.10	0.10	0.10
Choline-Cl(50%)	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,265.07	3,265.03	3,265.02	3,265.00
Crude protein, %	12.15	12.15	12.15	12.15
Total lysine, %	0.55	0.65	0.75	0.85
Total methionine, %	0.23	0.23	0.23	0.23
Total threonine, %	0.48	0.48	0.48	0.48
Total tryptophan, %	0.13	0.13	0.13	0.13
Calcium, %	0.75	0.75	0.75	0.75
Total phosphorus, %	0.60	0.60	0.60	0.60

[1)] Experimental diet was formulated with corn-soybean meal (SBM) based diet and adjusted lysine content.

[2)] Provided per kg of diet : vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64 g; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; vitamin B_{12}, 12 μg; vitamin K, 2.4 mg

[3)] Provided per kg of diet: mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4)] Calculated value

Table 1. The formulas and chemical composition of experimental gestation diet (continued)

Item	ME 3,365 kcal/kg			
	Lys 0.55%[1)]	Lys 0.65%	Lys 0.75%	Lys 0.85%
Ingredients, %				
Corn	71.96	72.09	72.27	72.53
SBM-46	12.97	12.64	12.31	12.00
Wheat bran	3.90	3.96	3.97	3.93
PKM (extraction)	3.86	3.87	3.87	3.85
Tallow	4.03	4.01	3.98	3.94
L-lysine HCl(78%)	0.00	0.13	0.27	0.40
DL-methionine(99%)	0.03	0.04	0.04	0.04
Threonine(99%)	0.02	0.02	0.03	0.03
Tryptophan(10%)	0.08	0.09	0.11	0.13
MDCP	1.38	1.38	1.38	1.38
Limestone	1.17	1.17	1.17	1.17
Vit. Mix[2)]	0.10	0.10	0.10	0.10
Min. Mix[3)]	0.10	0.10	0.10	0.10
Choline-Cl(50%)	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,365.04	3,365.04	3,365.02	3,365.03
Crude protein, %	12.15	12.15	12.15	12.15
Total lysine, %	0.55	0.65	0.75	0.85
Total methionine, %	0.23	0.23	0.23	0.23
Total threonine, %	0.48	0.48	0.45	0.48
Total tryptophan, %	0.13	0.13	0.11	0.13
Calcium, %	0.75	0.75	0.75	0.75
Total phosphorus, %	0.60	0.60	0.60	0.60

[1)] Experimental diet was formulated with corn-soybean meal (SBM) based diet and adjusted lysine content.

[2)] Provided per kg of diet : vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64 g; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; vitamin B_{12}, 12 μg; vitamin K, 2.4 mg

[3)] Provided per kg of diet: mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4)] Calculated value

Table 2. The formulas and chemical composition of experimental lactation diet

Item	ME 3,265 kcal/kg			
	Lys 0.70%[1)]	Lys 0.85%	Lys 1.00%	Lys 1.15%
Ingredients, %				
Corn	71.46	71.87	72.23	72.62
SBM-46	18.02	17.98	17.96	17.92
Wheat bran	2.00	2.00	2.00	2.00
Sesame meal(40%)	4.00	3.49	3.00	2.48
PKM (extraction)	0.00	0.00	0.00	0.00
Tallow	1.39	1.31	1.24	1.16
L-lysine HCl(78%)	0.00	0.19	0.38	0.58
DL-methionine(99%)	0.01	0.01	0.01	0.02
Threonine(99%)	0.02	0.03	0.03	0.04
Tryptophan(10%)	0.22	0.22	0.22	0.22
MDCP	1.20	1.21	1.23	1.25
Limestone	1.08	1.09	1.10	1.11
Vit. Mix[2)]	0.10	0.10	0.10	0.10
Min. Mix[3)]	0.10	0.10	0.10	0.10
Choline-Cl(50%)	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,265.02	3,265.03	3,265.04	3,265.07
Crude protein, %	15.20	15.20	15.20	15.20
Total lysine, %	0.70	0.85	1.00	1.15
Total methionine, %	0.25	0.25	0.25	0.25
Total threonine, %	0.62	0.62	0.62	0.62
Total tryptophan, %	0.18	0.18	0.18	0.18
Calcium, %	0.75	0.75	0.75	0.75
Total phosphorus, %	0.60	0.60	0.60	0.60

[1)] Lys 0.70%: corn-soybean meal (SBM) based diet met for 0.70% total lysine, Lys 0.85%: corn-SBM based diet met for 0.85% total lysine. Lys 1.00%: corn-SBM based diet met for 1.00% total lysine. Lys 1.15%: corn-SBM based diet met for 1.15% total lysine.

[2)] Provided per kg of diet : vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64 g; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; vitamin B_{12}, 12 μg; vitamin K, 2.4 mg

[3)] Provided per kg of diet: mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4)] Calculated value

Table 2. The formulas and chemical composition of experimental lactation diet (continued)

Item	ME 3,365 kcal/kg			
	Lys 0.70%[1)]	Lys 0.85%	Lys 1.00%	Lys 1.15%
Ingredients, %				
Corn	69.22	69.59	69.99	70.39
SBM-46	18.20	18.28	18.37	18.37
Wheat bran	1.88	1.89	1.89	1.89
Sesame meal(40%)	4.22	3.64	2.99	2.40
PKM (extraction)	0.00	0.00	0.00	0.00
Tallow	3.37	3.29	3.21	3.13
L-lysine HCl(78%)	0.00	0.18	0.37	0.57
DL-methionine(99%)	0.01	0.01	0.01	0.02
Threonine(99%)	0.02	0.02	0.03	0.04
Tryptophan(10%)	0.20	0.20	0.20	0.21
MDCP	1.20	1.22	1.25	1.28
Limestone	1.08	1.08	1.09	1.10
Vit. Mix[2)]	0.10	0.10	0.10	0.10
Min. Mix[3)]	0.10	0.10	0.10	0.10
Choline-Cl(50%)	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,365.04	3,365.06	3,365.04	3,365.00
Crude protein, %	15.20	15.20	15.20	15.20
Total lysine, %	0.70	0.85	1.00	1.15
Total methionine, %	0.25	0.25	0.25	0.25
Total threonine, %	0.62	0.62	0.62	0.62
Total tryptophan, %	0.18	0.18	0.18	0.18
Calcium, %	0.75	0.75	0.75	0.75
Total phosphorus, %	0.60	0.60	0.60	0.60

[1)] Lys 0.70%: corn-soybean meal(SBM) based diet met for 0.70% total lysine, Lys 0.85%: corn-SBM based diet met for 0.85% total lysine. Lys 1.00%: corn-SBM based diet met for 1.00% total lysine. Lys 1.15%: corn-SBM based diet met for 1.15% total lysine.

[2)] Provided per kg of diet : vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,600 IU; vitamin E, 32 IU; d-biotin, 64 g; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; vitamin B_{12}, 12 μg; vitamin K, 2.4 mg

[3)] Provided per kg of diet: mineral per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu, 54.1 mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4)] Calculated value

Table 3. Effects of dietary energy and lysine levels on body weight of gestating and lactating sows during 1 to 3 consecutive parities

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %		E	L	I
Gestation body weight, kg												
D 35												
Parity 1	167.9	167.0	167.8	168.8	169.1	168.1	167.9	162.5	9.91	0.74	0.91	0.77
Parity 2	186.6	185.7	182.7	197.6	195.1	186.1	194.4	198.7	12.48	0.23	0.29	0.76
Parity 3	202.5	195.5	205.8	205.2	213.6	212.2	207.8	218.6	14.49	0.06	0.80	0.81
D 110												
Parity 1	199.0	196.0	192.6	190.6	200.6	194.8	196.0	202.2	13.15	0.36	0.79	0.72
Parity 2	233.2	233.9	220.2	236.9	233.8	231.1	240.2	247.9	13.70	0.14	0.30	0.34
Parity 3	240.2	232.8	241.8	232.9	243.2	242.6	253.5	270.6	15.89	0.01	0.36	0.17
Total body weight gain (d 35 to d 110)												
Parity 1	31.1	29.0	24.8	21.8	31.5	26.7	28.1	39.7	10.61	0.07	0.56	0.25
Parity 2	46.6	48.2	37.5	39.3	38.7	45.0	45.8	49.2	6.82	0.39	0.70	0.03
Parity 3	37.7	37.3	36.0	27.7	29.6	30.4	45.7	52.0	12.50	0.26	0.47	0.03
Lactation body weight, kg												
24hrs postpartum												
Parity 1	179.5	183.7	167.2	168.2	172.9	173.0	174.7	181.1	12.39	0.85	0.69	0.16
Parity 2	209.0	209.0	202.5	206.8	211.0	213.1	217.3	221.8	12.06	0.06	0.89	0.63
Parity 3	216.8	219.1	226.4	213.1	222.2	231.9	230.9	242.8	16.29	0.02	0.59	0.35
Day 21 of lactation												
Parity 1	163.4	177.8	155.1	165.0	168.9	173.3	183.9	178.5	16.06	0.09	0.75	0.36
Parity 2	185.7	182.5	189.5	191.7	188.1	196.3	190.8	206.0	11.97	0.09	0.29	0.63
Parity 3	219.7	228.0	226.7	211.7	215.3	217.6	225.5	233.6	19.25	0.83	0.82	0.41
Total body weight gain (0-21d lactation)												
Parity 1	-16.1	-5.9	-12.1	-3.2	-4.0	0.3	9.2	-2.6	12.65	0.05	0.57	0.51
Parity 2	-23.3	-26.5	-13.0	-15.1	-22.9	-16.8	-26.5	-15.8	7.86	0.91	0.12	0.05
Parity 3	2.9	8.9	0.3	-1.4	-6.9	-14.3	-5.4	-9.2	12.09	<.01	0.94	0.50
Overall body weight gain (35d of gestation to 21d of lactation)												
Parity 1	-4.5	10.8	-12.7	-3.8	-0.2	5.2	16.0	16.0	15.93	0.01	0.85	0.42
Parity 2	-0.9 [ab]	-3.2 [b]	6.8 [ab]	-5.9 [c]	-7.0 [c]	10.2 [a]	-3.6 [b]	7.3 [a]	8.47	0.18	0.17	<.01
Parity 3	17.2	32.5	20.9	6.5	1.7	5.4	17.7	15.0	11.55	0.14	0.53	0.05

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

[abc] Mean with different superscripts in the same row significantly differ (P<0.05).

Table 4. Effects of dietary energy and lysine levels on backfat thickenss of gestating and lactating sows during 1 to 3 consecutive parities

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70%	Lys 0.65 0.85%	Lys 0.75 1.00%	Lys 0.85 1.15%	Lys 0.55 0.70%	Lys 0.65 0.85%	Lys 0.75 1.00%	Lys 0.85 1.15 %		E	L	I
Gestation backfat thickness, mm												
D 35												
Parity 1	24.9	24.5	25.1	23.7	23.7	25.6	27.1	23.2	4.72	0.80	0.64	0.86
Parity 2	19.8	20.1	19.9	20.1	23.3	22.2	23.0	24.0	3.74	0.01	0.97	0.96
Parity 3	18.3^{B}	16.8^{B}	17.3^{B}	18.7^{B}	23.1^{A}	24.9^{A}	20.3^{AB}	25.3^{A}	3.32	<.01	0.28	0.45
D 110												
Parity 1	23.9	25.8	24.1	24.2	28.2	26.2	26.8	26.2	4.26	0.10	0.96	0.80
Parity 2	22.1	21.2	23.3	23.6	25.2	26.0	26.6	28.4	4.22	<.01	0.58	0.95
Parity 3	20.1^{BC}	20.4^{BC}	19.4^{C}	20.7^{BC}	25.0^{B}	27.4^{A}	25.7^{A}	31.4^{A}	4.10	<.01	0.24	0.48
Total backfat gain (d 35 to d 110)												
Parity 1	-1.0	1.3	-1.0	0.5	4.5	0.6	-0.3	3.0	4.79	0.21	0.64	0.54
Parity 2	2.3	1.1	3.4	3.5	1.9	3.8	2.4	4.4	3.51	0.62	0.66	0.73
Parity 3	1.8	3.6	2.1	2.0	1.9	2.5	5.4	6.1	3.83	0.10	0.97	0.62
Lactation backfat thickness, mm												
24hrs postpartum												
Parity 1	22.6	24.5	23.8	25.0	27.7	26.5	25.9	26.7	3.99	0.04	0.95	0.76
Parity 2	21.7	20.4	22.8	20.6	25.2	25.0	25.7	27.3	4.16	<.01	0.88	0.76
Parity 3	19.6^{B}	19.9^{B}	19.6^{B}	20.1^{B}	23.7^{AB}	27.5^{A}	24.3^{AB}	28.4^{A}	4.17	<.01	0.45	0.62
Day 21 of lactation												
Parity 1	19.2	20.6	19.3	20.6	23.1	21.4	21.8	23.5	4.17	0.07	0.88	0.88
Parity 2	18.6	16.2	20.9	19.0	20.3	22.0	19.8	22.4	4.80	0.16	0.91	0.56
Parity 3	19.3^{bc}	19.0^{bc}	19.6^{bc}	15.7^{c}	20.3^{bc}	24.6^{ab}	21.7^{ab}	27.5^{a}	5.00	0.01	0.28	0.02
Total backfat gain (0-21d lactation)												
Parity 1	-3.4	-3.9	-4.5	-4.4	-4.6	-5.1	-4.1	-3.2	2.87	0.81	0.96	0.76
Parity 2	-3.1	-4.2	-1.9	-1.6	-4.9	-3.0	-5.9	-4.9	3.08	0.10	0.88	0.45
Parity 3	-0.3	-0.9	0	-4.4	-3.4	-2.9	-2.6	-0.9	3.25	0.39	0.88	0.20
Overall backfat gain (35d of gestation to 21d of lactation)												
Parity 1	-5.7	-3.9	-5.8	-3.1	-0.6	-4.2	-5.3	0.3	4.22	0.14	0.41	0.20
Parity 2	-1.2	-3.9	1.0	-1.1	-3.0	-0.2	-3.2	-1.6	3.26	0.37	0.96	0.07
Parity 3	1.0	2.2	2.3	-3.0	-2.8	-0.3	1.4	2.2	3.82	0.91	0.75	0.14

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

[abc] Mean with different superscripts in the same row significantly differ (P<0.05).

[ABC] Mean with different superscripts in the same row significantly differ (P<0.05).

Table 5. Effects of dietary energy and lysine levels on the estimated protein mass of gestating and lactating sows during 1 to 3 consecutive parities

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70%	Lys 0.65 0.85%	Lys 0.75 1.00%	Lys 0.85 1.15%	Lys 0.55 0.70%	Lys 0.65 0.85%	Lys 0.75 1.00%	Lys 0.85 1.15%		E	L	I
Estimated protein mass on gestation, kg												
D 35												
Parity 1	44.45	43.68	44.84	43.10	43.17	45.49	47.33	41.00	7.328	0.92	0.64	0.86
Parity 2	41.94	42.13	41.13	44.79	48.53	45.03	47.92	50.23	6.352	0.01	0.62	0.92
Parity 3	43.45^{BC}	39.84^{C}	42.93^{BC}	44.65^{BC}	48.30^{B}	54.47^{AB}	47.37^{B}	56.42^{A}	5.685	<.01	0.22	0.18
D 110												
Parity 1	50.20	52.11	49.68	48.73	56.33	52.28	53.39	54.04	7.406	0.10	0.92	0.83
Parity 2	55.56	54.61	54.21	58.42	59.91	60.27	63.16	67.31	7.319	<.01	0.38	0.86
Parity 3	54.47^{C}	53.17^{C}	53.94^{C}	53.65^{C}	61.72^{BC}	64.74^{AB}	64.99^{AB}	76.45^{A}	7.705	<.01	0.27	0.21
Gain (d 35 to d 110)												
Parity 1	5.75	8.43	4.84	5.63	13.16	6.79	6.06	13.04	7.337	0.10	0.53	0.55
Parity 2	13.62	12.48	13.08	13.63	11.38	15.24	15.24	17.08	5.163	0.47	0.69	0.64
Parity 3	11.02^{bc}	13.33^{ab}	11.01^{bc}	9.00^{c}	13.42^{ab}	10.37^{c}	17.62^{ab}	20.03^{a}	5.024	0.06	0.32	0.03
Estimated protein mass on lactation, kg												
24hrs postpartum												
Parity 1	43.98	47.48	44.16	44.62	49.30	47.71	47.32	49.89	6.844	0.11	0.94	0.83
Parity 2	49.59	47.76	49.50	47.56	54.60	54.85	56.73	59.88	7.051	<.01	0.90	0.71
Parity 3	48.48^{b}	49.39^{b}	49.32^{b}	48.33^{b}	53.59^{ab}	62.46^{a}	57.98^{ab}	61.70^{a}	7.939	<.01	0.55	0.62
Day 21 of lactation												
Parity 1	35.89	40.98	35.50	38.06	42.25	40.99	43.99	44.97	8.657	0.05	0.91	0.74
Parity 2	40.19	36.24	44.00	41.99	42.93	47.03	42.86	49.73	7.590	0.07	0.64	0.43
Parity 3	48.69	50.26	47.41	42.14	50.01	55.38	53.27	60.00	8.475	0.01	0.86	0.28
Gain (0-21d lactation)												
Parity 1	-8.09	-6.50	-8.66	-6.56	-7.05	-6.73	-3.33	-4.92	5.821	0.32	0.90	0.78
Parity 2	-9.40	-11.52	-5.50	-5.57	-11.67	-7.82	-13.87	-10.11	4.644	0.12	0.41	0.09
Parity 3	0.21	0.87	-1.91	-6.19	-3.58	-7.08	-4.71	-1.70	6.198	0.24	0.88	0.30
Overall protein mass deposition, kg (35d of gestation to 21d of lactation)												
Parity 1	-8.56	-2.70	-9.34	-5.04	-0.92	-4.50	-3.34	3.97	7.992	0.03	0.70	0.40
Parity 2	-1.75	-5.9	2.87	-2.80	-5.60	2.00	-5.06	-0.50	4.821	0.77	0.72	<.01
Parity 3	5.24	10.42	4.48	-2.51	1.71	0.91	5.90	3.58	6.613	0.48	0.46	0.06

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

[abc] Mean with different superscripts in the same row significantly differ (P<0.05).

[ABC] Mean with different superscripts in the same row significantly differ (P<0.05).

Table 6. Effects of dietary energy and lysine levels on the estimated fat mass of gestating and lactating sows during 1 to 3 consecutive parities

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70%	Lys 0.65 0.85%	Lys 0.75 1.00%	Lys 0.85 1.15%	Lys 0.55 0.70%	Lys 0.65 0.85%	Lys 0.75 1.00%	Lys 0.85 1.15%		E	L	I
Estimated fat mass on gestation, kg												
D 35												
Parity 1	40.93	40.62	41.12	40.71	40.76	41.22	41.64	39.38	2.739	0.91	0.71	0.83
Parity 2	42.67	42.60	41.97	44.76	45.38	43.37	45.14	46.26	2.838	0.04	0.36	0.83
Parity 3	45.05	43.25	45.33	45.68	46.78	49.03	46.69	50.32	2.966	<.01	0.47	0.39
D 110												
Parity 1	46.31	46.40	45.76	44.87	48.04	46.29	46.71	47.67	3.258	0.18	0.88	0.78
Parity 2	51.97	51.83	49.99	53.15	53.13	52.87	54.76	56.77	3.297	0.02	0.29	0.57
Parity 3	52.57^{B}	51.31^{B}	52.65^{B}	51.45^{B}	54.78^{B}	55.64^{B}	56.98^{B}	61.93^{A}	3.654	<.01	0.31	0.15
Gain (d 35 to d 110)												
Parity 1	5.38	5.78	4.64	4.16	7.28	5.07	5.07	8.29	2.840	0.06	0.49	0.41
Parity 2	9.30	9.23	8.02	8.39	7.75	9.50	9.62	10.51	1.77	0.38	0.72	0.20
Parity 3	7.52^{bc}	8.06^{ab}	7.32^{bc}	5.77^{c}	8.00^{bc}	6.61^{bc}	10.29^{a}	11.61^{a}	2.549	0.09	0.36	0.02
Estimated fat mass on lactation, kg												
24hrs postpartum												
Parity 1	42.28	43.68	41.47	41.01	42.78	42.40	42.50	43.96	3.017	0.41	0.90	0.50
Parity 2	47.41	46.95	46.56	46.62	48.92	49.24	50.24	51.60	3.041	<.01	0.90	0.66
Parity 3	48.12^{c}	48.64^{bc}	49.16^{bc}	47.61^{c}	50.08^{b}	53.52^{ab}	52.28^{ab}	55.82^{a}	3.831	<.01	0.51	0.36
Day 21 of lactation												
Parity 1	38.23	41.31	37.82	38.98	40.51	40.74	42.84	42.40	4.377	0.08	0.85	0.59
Parity 2	42.11	40.72	43.54	43.32	43.10	45.16	43.43	47.07	3.032	0.05	0.38	0.44
Parity 3	48.53	49.98	48.35	45.88	48.30	49.95	50.41	52.78	4.003	0.16	0.90	0.38
Gain (0-21d lactation)												
Parity 1	-4.05	-2.37	-3.65	-2.03	-2.27	-1.66	0.34	-1.56	3.093	0.09	0.69	0.61
Parity 2	-5.30^{abc}	-6.23^{b}	-3.02^{a}	-3.30^{a}	-5.82^{b}	-4.08^{b}	-6.81^{c}	-4.53^{b}	1.811	0.30	0.12	0.02
Parity 3	0.41	1.34	-0.81	-1.73	-1.78	-3.57	-1.87	-3.04	2.794	0.05	0.92	0.32
Overall fat mass deposition, kg (35d of gestation to 21d of lactation)												
Parity 1	-2.70	0.69	-3.30	-1.73	-0.25	-0.48	1.20	3.02	3.765	0.01	0.88	0.51
Parity 2	-0.56^{ab}	-1.88^{c}	1.57^{a}	-1.44^{b}	-2.28^{c}	1.79^{a}	-1.71^{c}	0.81^{ab}	2.026	0.60	0.32	<.01
Parity 3	3.48	6.73	3.02	0.20	1.52	0.92	3.72	2.46	2.808	0.25	0.45	0.04

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

[abc] Mean with different superscripts in the same row significantly differ (P<0.05).

[AB] Mean with different superscripts in the same row significantly differ (P<0.05).

Table 7. Effects of dietary energy and lysine levels on reproductive performance of sows during 1 to 3 consecutive parities

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70%	Lys 0.65 0.85%	Lys 0.75 1.00 %	Lys 0.85 1.15 %	Lys 0.55 0.70%	Lys 0.65 0.85%	Lys 0.75 1.00 %	Lys 0.85 1.15 %		E	L	I
Total born/litter												
Parity 1	13.1^{ab}	16.0^{a}	13.5^{ab}	9.6^{bc}	12.4^{ab}	8.2^{bc}	13.0^{ab}	12.8^{ab}	3.10	0.17	0.53	<.01
Parity 2	14.8^{a}	13.6^{ab}	9.8^{b}	13.8^{a}	14.2^{a}	8.5^{c}	14.4^{a}	14.4^{a}	3.07	0.89	0.08	0.02
Parity 3	16.2	11.5	10.0	10.4	11.4	7.0	14.4	13.5	4.47	0.76	0.22	0.05
Total	44.1	41.1	33.3	33.8	38.0	23.7	41.8	40.7	7.78	0.61	0.22	<.01
Average	14.7	13.7	11.1	11.3	12.7	7.9	13.9	13.6	2.59	0.62	0.22	<.01
Still birth/litter												
Parity 1	1.0	0.8	0	0.4	0.4	0.6	0.7	0.3	0.78	0.90	0.72	0.50
Parity 2	0.1	0.4	0	0.4	0.1	0.7	0.8	0.8	0.72	0.14	0.59	0.73
Parity 3	0.7	0.3	0	0.8	0.2	0	0.6	0.3	0.45	0.36	0.48	0.09
Total	1.8	1.5	0	1.6	0.7	1.3	2.1	1.4	1.06	0.79	0.71	0.07
Average	0.6	0.5	0	0.5	0.2	0.4	0.7	0.5	0.37	0.84	0.68	0.09
Mummy/litter												
Parity 1	0.1^{b}	2.2^{a}	0^{b}	0^{b}	0.2^{b}	0.6^{b}	0.7^{b}	0^{b}	0.70	0.45	0.01	0.10
Parity 2	0.5	0	0.2	0.2	0.3	0	0	0	0.28	0.31	0.15	0.95
Parity 3	0.5	0	0	0.2	0	0	0	0	0.16	0.15	0.38	0.38
Total	1.1	2.2	0.2	0.4	.5	0.6	0.7	0	1.04	0.26	0.18	0.37
Average	0.4	0.7	0.1	0.1	0.2	0.2	0.2	0	0.35	0.24	0.18	0.37
Born alive/litter												
Parity 1	12.0	13.0	13.5	9.2	11.8	7.0	11.6	12.5	3.10	0.29	0.40	0.04
Parity 2	14.2^{a}	13.2^{ab}	9.6^{bc}	13.2^{ab}	13.8^{a}	7.8^{c}	13.6^{a}	13.6^{a}	2.88	0.69	0.06	0.02
Parity 3	15.0	11.2	10.0	9.4	11.2	7.0	13.8	13.2	4.34	0.94	0.29	0.07
Total	41.2	37.4	33.1	31.8	36.8	21.8	39.0	39.3	7.26	0.70	0.12	<.01
Average	13.7	12.5	11.0	10.6	12.3	7.3	13.0	13.1	2.42	0.70	0.12	<.01
Total litter weight, kg												
Parity 1	15.40	16.79	16.58	12.98	15.34	10.70	15.10	14.64	3.530	0.24	0.54	0.18
Parity 2	20.37	18.90	12.82	18.69	18.46	13.36	20.00	19.95	4.447	0.86	0.20	0.02
Parity 3	20.26	14.84	15.15	15.98	16.51	11.60	18.93	19.77	5.940	0.94	0.29	0.32
Total	56.03	50.53	44.55	47.65	50.31	35.66	54.03	54.36	11.10	0.90	0.33	0.11
Average	18.68	16.84	14.85	15.88	16.77	11.89	18.01	18.12	3.702	0.90	0.33	0.11
Alive litter weight, kg												
Parity 1	14.43	14.63	16.57	12.58	15.00	10.14	14.00	14.31	3.68	0.38	0.46	0.37
Parity 2	20.04^{a}	18.34^{ab}	12.79^{c}	18.04^{ab}	18.30^{ab}	12.13^{c}	18.87^{ab}	18.80^{ab}	3.998	0.82	0.09	0.01
Parity 3	19.56	14.70	15.15	14.78	16.25	11.60	11.83	19.63	5.760	0.82	0.35	0.31
Total	54.03	47.67	44.51	45.40	49.55	33.87	44.70	52.74	10.49	0.92	0.22	0.17
Average	18.01	15.89	14.84	15.13	16.52	11.29	14.90	17.58	3.499	0.92	0.22	0.17
Alive piglet weight, kg												
Parity 1	1.23	1.13	1.22	1.37	1.29	1.51	1.22	1.16	0.17	0.35	0.79	0.02
Parity 2	1.43	1.41	1.42	1.37	1.37	1.57	1.40	1.44	0.241	0.60	0.83	0.76
Parity 3	1.31	1.33	1.52	1.65	1.61	1.69	1.33	1.56	0.214	0.20	0.37	0.02
Total	3.97	3.87	4.16	4.39	4.27	4.77	3.95	4.16	0.639	0.83	0.88	0.24
Average	1.32	1.29	1.39	1.46	1.42	1.59	1.32	1.39	0.213	0.83	0.88	0.24

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.
[2)] Standard error of mean
[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.
[abc] Mean with different superscripts in the same row significantly differ (P<0.05).

Table 8. Effects of dietary energy and lysine levels on litter performance of sows during 1 to 3 consecutive parities

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %		E	L	I
After-fostering (no. of piglets/litter)												
Parity 1	11.6	11.3	11.5	11.6	11.4	11.2	11.5	11.5	0.65	0.63	0.70	0.97
Parity 2	11.6	11.8	11.8	12.0	11.8	12.0	11.7	11.6	0.49	0.90	0.93	0.60
Parity 3	11.0	10.7	10.5	11.2	10.4	10.5	11.4	10.7	0.87	0.72	0.76	0.19
21d of lactation (no. of piglets/litter)												
Parity 1	10.8	11.2	11.5	10.6	10.6	10.8	10.2	10.2	1.22	0.17	0.77	0.82
Parity 2	11.0	11.3	10.2	10.8	11.3	11.0	11.3	9.8	1.40	0.96	0.54	0.50
Parity 3	10.5	9.2	9.3	10.7	10.4	9.5	10.6	10.2	1.21	0.59	0.26	0.48
Initial litter weight (24hrs postpartum)												
Parity 1	13.95	12.65	13.84	15.56	14.42	15.84	14.26	13.69	1.625	0.36	0.9	0.04
Parity 2	17.00	17.26	15.58	16.60	15.97	18.88	17.63	15.82	2.126	0.51	0.27	0.28
Parity 3	15.48	14.23	16.40	18.27	15.95	16.04	16.14	16.70	2.474	0.89	0.26	0.57
Final litter weight (day 21 of lactation)												
Parity 1	54.16	55.75	61.02	56.44	58.41	60.18	58.12	54.95	9.687	0.74	0.83	0.79
Parity 2	60.66	55.14	54.04	55.35	58.91	56.77	63.67	53.16	9.305	0.57	0.58	0.54
Parity 3	60.83	56.10	62.14	73.52	70.06	60.05	61.27	65.27	9.372	0.76	0.15	0.32
Litter weight gain (0-21d)												
Parity 1	40.21	43.10	47.18	40.88	43.99	44.34	43.86	41.26	8.761	0.86	0.72	0.85
Parity 2	43.66	37.88	38.46	38.75	42.94	37.89	46.04	37.34	7.938	0.61	0.39	0.65
Parity 3	45.35	41.87	45.74	55.25	54.11	44.01	45.13	48.57	8.482	0.72	0.22	0.39
Average piglet weight, kg												
Initial piglet weight (24hrs postpartum)												
Parity 1	1.19	1.13	1.21	1.34	1.27	1.41	1.24	1.19	0.159	0.25	0.90	0.07
Parity 2	1.45	1.47	1.32	1.39	1.35	1.57	1.51	1.36	0.196	0.55	0.42	0.37
Parity 3	1.40	1.33	1.56	1.62	1.53	1.52	1.41	1.55	0.181	0.70	0.35	0.17
Final piglet weight (day 21 of lactation)												
Parity 1	4.98	4.98	5.31	5.30	5.54	5.65	5.77	5.35	0.740	0.08	0.85	0.81
Parity 2	5.57	4.94	5.29	5.09	5.20	5.21	5.71	5.45	0.777	0.52	0.71	0.62
Parity 3[†]	5.78	6.08	6.65	6.87	6.77	6.21	5.79	6.37	0.685	0.79	0.51	0.02
Piglet weight gain (0-21d)												
Parity 1	3.79	3.85	4.10	3.96	4.27	4.24	4.53	4.16	0.626	0.08	0.73	0.96
Parity 2	4.12	3.47	3.97	3.70	3.85	3.64	4.20	4.09	0.687	0.58	0.44	0.72
Parity 3	4.38	4.75	5.09	5.25	5.24	4.69	4.38	4.82	0.636	0.75	0.78	0.04

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

[abc] Mean with different superscripts in the same row significantly differ (P<0.05).

Table 9. Effects of dietary energy and lysine levels on piglet uniformity in sows during 1 to 3 consecutive parities

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70%	Lys 0.65 0.85%	Lys 0.75 1.00%	Lys 0.85 1.15%	Lys 0.55 0.70%	Lys 0.65 0.85%	Lys 0.75 1.00%	Lys 0.85 1.15%		E	L	I
Piglet uniformity (parturition)												
SD												
Parity 1	222.9	218.5	198.6	232.6	271.5	169.1	247.7	233.3	77.66	0.62	0.51	0.48
Parity 2‡	283.0^{B}	238.0^{C}	202.7^{C}	322.2^{AB}	367.4^{A}	290.4^{B}	288.5^{B}	250.3^{BC}	62.64	0.06	0.03	0.02
Parity 3	306.9	274.9	294.2	268.2	272.8	358.6	292.2	236.5	121.55	0.92	0.81	0.78
CV												
Parity 1	19.0	19.5	16.4	17.6	21.7	13.2	20.5	21.1	6.95	0.65	0.64	0.36
Parity 2	20.5	16.9	15.4	24.0	27.7	19.5	21.7	17.9	6.33	0.22	0.14	0.09
Parity 3	23.9	21.0	19.4	17.2	18.4	21.3	23.2	15.0	9.01	0.76	0.61	0.69
Piglets <800g, %												
Parity 1	9.5	7.3	3.0	5.6	8.0	12.6	13.2	9.8	12.4	0.31	0.98	0.82
Parity 2	4.6	2.2	4.8	8.5	14.2	2.5	7.5	5.7	7.70	0.36	0.32	0.37
Parity 3	8.8	7.7	6.3	1.5	4.5	6.3	12.5	0	6.34	0.90	0.11	0.40
Piglets >1600g, %												
Parity 1	12.8	2.0	1.5	19.0	11.8	34.4	9.8	4.5	15.51	0.32	0.60	0.08
Parity 2	31.3	23.6	34.3	32.9	32.4	53.7	30.9	29.8	26.36	0.48	0.93	0.51
Parity 3	8.9^{c}	17.0^{bc}	61.8^{a}	60.1^{a}	50.3^{ab}	67.8^{a}	26.6^{bc}	52.2^{ab}	22.54	0.14	0.16	<.01
Piglet uniformity (21d of lactation)												
SD												
Parity 1	1076	925	1204	1144	944	1037	1067	967	370.9	0.48	0.81	0.83
Parity 2	930	777	1169	1028	1030	1158	1022	984	315.4	0.52	0.84	0.43
Parity 3	1106	903	1174	759	1009	1044	1291	915	327.9	0.53	0.17	0.86
CV												
Parity 1	21.8	19.9	22.7	22.0	17.1	18.6	18.8	18.6	7.83	0.19	0.97	0.96
Parity 2	16.9	16.2	22.1	21.0	19.6	23.9	18.9	18.1	7.11	0.66	0.91	0.40
Parity 3	19.9	15.8	17.8	11.2	14.8	17.0	22.6	14.6	6.15	0.65	0.21	0.42

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

[ABC] Mean with different superscripts in the same row significantly differ (P<0.01).

‡ Quadratic response (P<0.05) to dietary lysine levels when significance of lysine effect was detected.

Table 10. Effects of dietary energy and lysine levels on WEI, lactation feed intake, culling rate of sows during 1 to 3 consecutive parities

Item[1)]	ME 3,265 kcal/kg				ME 3,365 kcal/kg				SEM[2)]	P-value[3)]		
	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %	Lys 0.55 0.70 %	Lys 0.65 0.85 %	Lys 0.75 1.00 %	Lys 0.85 1.15 %		E	L	I
Weaning to estrus interval, day												
Parity 1	5.20	5.33	5.25	5.33	4.50	6.75	4.33	5.00	0.811	0.70	0.03	0.06
Parity 2	5.00	5.25	5.75	5.25	5.60	5.33	5.25	5.20	0.710	0.90	0.90	0.52
Parity 3	4.40	4.67	5.20	4.75	4.50	5.33	5.00	4.80	0.504	0.47	0.13	0.62
Lactation feed intake, g/d												
Parity 1	4.81	5.45	5.21	4.91	5.18	5.19	5.21	4.42	0.868	0.74	0.39	0.71
Parity 2	4.02	3.43	3.86	3.61	3.46	3.76	3.54	3.71	0.822	0.70	0.98	0.66
Parity 3	6.54	6.59	5.52	6.22	5.79	4.49	5.61	5.75	1.228	0.07	0.64	0.36
No. of sows												
Initial	6	6	6	6	6	6	6	6				
Parity 1	6	4	5	5	6	5	6	6				
Parity 2	6	4	5	5	6	4	5	5				
Parity 3	6	4	5	5	5	4	5	4				
Sow removal, head												
Parity 1	0	2	1	1	0	1	0	0				
Parity 2	0	0	0	0	0	1	1	1				
Parity 3	0	0	0	0	1	0	0	1				
Culled rate, %												
1-3 parity	0	33	16	16	16	33	16	33				

[1)] Factors : energy level (3,265 or 3,365 kcal of ME/kg) and lysine level (total lysine 0.55/0.70, 0.65/0.85, 0.75/1.00, 0.85/1.15%) in gestation/lactation diet.

[2)] Standard error of mean

[3)] E: energy effect, L: lysine effect, I: interaction between energy and lysine effect.

[abc] Mean with different superscripts in the same row significantly differ ($P<0.05$).

Chapter VI. Overall Conclusion

This study was carried out to investigate the dietary arginine, lysine, and energy levels on physiological responses and reproductive performance in sows and growth of their progeny. Therefore, three experiments were conducted to investigate 1) the effects of arginine supplementation levels compared with increased feeding on reproductive performance and piglet uniformity in late gestating sows, 2) the effects of dietary energy and lysine levels on physiological responses, reproductive performance, blood profiles, and milk composition in primiparous sows, 3) the effects of dietary energy and lysine levels on physiological responses, reproductive performance, piglet uniformity and longevity in sows during 1 to 3 parities.

In experiment 1, addition of arginine 1.5% level on late-gestating sows improved total litter weight and alive litter weight, but no effects on piglet growth during lactation and piglet uniformity of piglet birth weight. Based upon the previous results, second trial was conducted for comparing increased feeding during late-gestation period. Additional arginine supplementation had no difference in reproductive performance and piglet uniformity among treatment. Although additional arginine up to 1.5% improved litter weight and its gain linearly, there were no difference with increased feeding. Consequently, addition of dietary arginine 1.5% in late gestation showed equivalent effects on piglet birth weight and uniformity compared with increased feeding.

In experiment 2, high energy diet (3,365 kcal of ME/kg) increased body weight and backfat gain during gestation and lactation. Different lysine and energy levels had no significant influence on reproductive performance and piglet uniformity. High energy group showed higher milk content in colostrum and greater piglet wegith at day 21 of lactation and piglet weight gain. Total lysine 0.75/1.00% showed higher nitrogen utilization in blood profile of sows during lactation and shorten weaning to estrus interval. Considering litter weight and litter weight gain, lysine 0.75% for gestation and lysine 1.00% for lactation with 3,365 kcal of ME/kg had the better performance for primiparous sows and growth of their progeny.

In experiment 3, high energy intake with 3,365 kcal of ME/kg increased body weight, backfat thickness, protein mass, and fat mass during gestation and lactation. There were no significant energy and lysine effect on the reproductive performance, Lys0.65/0.85 and Lys0.75/1.00 treatment with 3,265 kcal of ME/kg had positive influence on piglet uniformity at parity 2. Sows fed 3,265 kcal of ME/kg diet showed a greater lactation feed intake in parity 3. Lys0.55/0.70 with 3,265 kcal of ME/kg showed the lower number of culled sows during 1 to 3 consecutive parities. Consequently, total lysine 0.55% in gestation diet and total lysine 0.70% in lactation diet with 3,265 kcal of ME/kg had the better productivity and longevity in sows with parities 2 and 3.

Consequently, these results implied that additional 1.5% L-arginine on late gestating sows, and total lysine 0.75% and 1.0% for gestation and lactation with 3,365 kcal of ME/kg in primiparous sows, and total lysine 0.55% and 0.70% for gestation and lactation with 3,265 kcal of ME/kg in sows for parities 2 and 3 had the better productivity of sows and growth of their progeny.

Chapter VII. Summary in Korean

본 실험은 사료내 아지닌, 라이신, 에너지 수준이 모돈의 생리학적 변화와 번식성적 및 자돈의 성장에 미치는 영향을 알아보기 위하여 수행되었다. 총 3개의 실험으로 구성되어 있으며, 1) 임신후기 아르지닌의 급여가 증량급여 대비 모돈의 번식성적과 자돈 균일도에 미치는 영향, 2) 사료내 에너지와 라이신의 급여수준이 초산돈의 생리학적 변화, 번식성적, 혈액성상, 유성분 등에 미치는 영향, 3) 사료내 에너지와 라이신의 급여수준이 1산차부터 3산차까지의 생리학적 변화, 번식성적, 자돈 균일도, 연산성에 미치는 영향을 평가하기 위해 수행되었다.

실험 1. 임신후기 사료내 아지닌 급여가 증량급여 대비 모돈의 번식성적 및 자돈균일도에 미치는 영향

본 연구는 임신후기 아지닌의 급여가 증량급여와 비교하여 모돈의 번식성적과 자돈 균일도에 미치는 영향을 규명하기 위해서 수행되었다. 실험1은 아지닌의 수준별 첨가효과를 조사하기 위해 수행되었으며, 총 40두의 F1 경산모돈(Yorkshire × Landrace)을 공시하여, 4처리 5반복, 반복당 1두씩 체중과 산차에 따라 완전임의배치법으로 구배치 하였다. 실험처리구는 아지닌의 첨가수준(0.72%, 1.0%, 1.5%, 2.0%)에 따라 구분하였다. 포유기에는 동일한 포유돈 사료를 급여하였다. 전체 실험기간동안의 모돈의 체중 및 등지방 두께 변화에는 처리구에 따른 유의적인 영향이 나타나지 않았으며, 총산자수, 사산수, 생시산자수와 같은 번식성적에서도 아지닌의 첨가수준에 따른 영향이 나타나지 않았다. 그렇지만 복당체중

(Linear, P=0.08)과 복당생시체중 (Quadratic, P=0.07)에서 아지닌의 첨가수준이 1.5%일 때 가장 높은 결과가 나타났으며, 자돈의 균일도에서는 통계적 유의차가 발견되지 않았다. 임신기 혈액성상에서는 처리구간의 유의차가 나타나지 않았으나, 포유기 혈중요소태질소(BUN)에서 아지닌의 첨가수준이 증가함에 따라 유의적으로 증가하는 결과가 나타났다 (Linear, P<0.05). 초유 및 상유(21일령)의 유성분에서는 임신후기 아지닌의 첨가수준에 따른 유의적인 영향이 나타나지 않았다. 실험2는 임신후기 증량급여 효과와 아지닌의 첨가효과를 비교하기 위하여 수행되었으며, 총 44두의 F1 경산모돈(Yorkshire × Landrace)을 공시하여, 4처리 11반복, 반복당 1두씩 체중과 산차에 따라 완전임의배치법으로 구배치 하였다. 실험처리구는 아지닌 첨가(0.72%, 1.0%, 1.5%) 처리구 (2.4kg/일)와 증량급여 (3kg/일) 처리구로 구성하였다. 모돈의 체중 및 등지방 두께 변화에는 처리구간의 유의적인 차이가 나타나지 않았으며, 번식성적, 자돈 균일도, 혈액성상, 유성분에서도 통계적인 유의차는 발견되지 않았다. 하지만, 아지닌 첨가수준이 1.5%로 증가시 3주차 복당체중과 복당증체량이 증가하는 유의적 경향이 나타났다 (Linear, P=0.06, P=0.05). 결론적으로, 임신후기 사료에 아지닌을 1.5%까지 첨가시 복당체중 및 복당생시체중이 향상되는 효과를 기대할 수 있으며, 임신후기 증량급여 방식과 비교하여 대등한 생시자돈체중과 자돈균일도 효과를 가지는 것으로 보인다.

실험 2. 사료내 에너지와 라이신의 수준이 초산돈의 생리학적 변화, 번식성적, 혈액성상 및 유성분에 미치는 영향

본 연구는 사료 내 에너지와 라이신의 수준이 초산돈의 체형변화, 번식성적, 혈액성상 및 유성분에 미치는 영향을 알아보기 위해 수행되었다. 임신이 확인된 평균체중 168.1 ± 9.71 kg, F1 모돈(Yorkshire × Landrace) 48 두를 공시하여, 8 처리 6 반복 반복당 1 두씩, 체중과 등지방 두께에 따라 완전임의배치법 (CRD; completely randomized design)로 구배치하여 실험을 수행하였다. 실험설계는 2×4 factorial design 으로 구성하였으며, 요인 1 은 사료 내 에너지 함량 3,265 kcal or ME/kg 와 3,365 kcal of ME/kg 으로 설정하였으며 요인 2 는 총 라이신 함량 (임신기 0.55, 0.65, 0.75, 0.85%, 포유기 0.70, 0.85, 1.00, 1.15%)으로 설정하였다. 임신기에 사료는 일일 2kg 을 급여하였으며, 포유기에는 분만후 5 일부터 무제한 급여하였다. 고에너지 사료를 급여한 모돈들의 임신기 증체량과 등지방두께가 더 높았으며 (Energy, P=0.07, P=0.09), 포유기 체중과 등지방두께는 높고 (Energy, P=0.09, P=0.07) 체중감소량은 낮은 결과가 나타났다 (Energy, P=0.05). 번식성적에서는 총산자수, 생시자돈수, 복당체중, 자돈균일도에서 에너지와 라이신수준에 따른 유의적인 영향이 나타나지 않았으며, 총산자수와 생시산자수에서 요인간 상호작용이 나타났다 (Interaction, P<0.01, P=0.04). 또한 고에너지 사료를 급여한 모돈의 포유 21 일령 자돈들의 체중 및 증체량이 더 높게 나타나는 유의적 경향이 나타났다 (Energy, P=0.08, P=0.08). 재귀발정일에서는 라이신 0.75/1.0% 처리구가 가장 짧은 재귀발정일을 나타내었다 (Lysine, P=0.03). 모돈의 혈중요소태질소 농도를 분석한 결과 Lys0.75/1.00 처리구에서 분만직후 (Quadratic, P=0.02) 와 포유 21 일령

(Lysine, P=0.02)에 가장 낮은 농도를 보이는 결과가 나타났다. 유성분에서는 고에너지 사료를 급여한 모돈들의 초유내 카제인, 유단백, 고형분, 무지고형분, 유리지방산의 농도가 높게 나타났으며 (Energy, P=0.03, P=0.03, P=0.03, P=0.03, P<0.01), 초유내 유리지방산의 농도는 Lys0.75/1.00 과 Lys0.85/1.15 에서 높게 나타났다 (Lysine, P=0.01). 고에너지 처리구의 임신 110 일령과 포유 21 일령의 단백질 축적이 유의적으로 높게 나타났으며 (Energy, P=0.10, P=0.05), 지방 축적에서는 임신기 전체와 포유 21 일령에서 높게 나타났다 (Energy, P=0.06, P=0.08). 결론적으로, 초산돈의 3,365 kcal of ME/kg 사료 섭취는 체중과 등지방두께를 높여주고, 포유자돈의 증체량을 높여주는 효과를 가진다. 비록 초산돈의 번식성적과 자돈 균일도에 에너지와 라이신 함량에 따른 효과가 나타나지 않았지만, 혈중요소태질소 농도, 재귀발정일, 복당체중 및 복당증체량을 고려해볼 때, 임신기 0.75% 포유기 1.0% 총 라이신 함량에 3,365 ME kcal/kg 의 에너지함량을 급여시 초산돈의 생산성 및 자돈의 성장에 가장 좋을 것으로 판단된다.

실험 3. 사료내 에너지와 라이신 수준이 1산차부터 3산까지의 모돈의 생리학적 변화, 번식성적, 자돈 균일도 및 연산성에 미치는 영향

본 연구는 사료 내 에너지와 라이신 수준이 1 산차부터 3 산차까지의 연속적인 모돈의 체형변화, 번식성적, 자돈 균일도 및 연산성에 미치는 영향을 알아보기 위해 수행되었다. F1 모돈(Yorkshire × Landrace) 48 두를 공시하여, 8 처리 6 반복 반복당 1 두씩, 체중과 등지방 두께에 따라 완전임의배치법 (CRD; completely randomized design)로 구배치하여 실험을 수행하였다. 실험설계는 2×4 factorial design 으로 구성하였으며, 요인 1 은 사료 내 에너지 함량 3,265 kcal of ME/kg 과 3,365 kcal of ME/kg 으로 설정하였으며 요인 2 는 총라이신 함량 (임신기 0.55%, 0.65%, 0.75%, 0.85%, 포유기 0.70%, 0.85%, 1.00%, 1.15%)으로 설정하였다. 임신기에 사료는 초산돈은 일일 2kg, 2 산차 모돈은 일일 2.2kg, 3 산차 모돈은 일일 2.4kg 을 급여하였으며, 포유기에는 분만후 5 일부터 무제한 급여하였다. 고에너지 급여시 3 산차 모돈의 임신말기, 분만후 24 시간의 체중과, 포유기 체중손실이 높게 나타났다 (Energy, P=0.01, P=0.02, P<0.01), 고에너지의 급여는 2 산차와 3 산차 임신기의 등지방두께를 높이며 (Energy, P<0.01, P<0.01) 포유기 등지방 두께도 높이는 것으로 나타났다 (Energy, P<0.05). 고에너지 급여 모돈들은 2 산차와 3 산차 임신기에 더 높은 단백질량과 (Energy, P<0.01, P<0.01) 체지방량(Energy, P<0.05, P<0.01), 3 산차 포유기에 높은 단백질량을 보였다 (Energy, P<0.01). 총산자수, 생시자돈수, 복당체중에서는 1-3 산차에서 에너지와 라이신 요인 효과가 나타나지 않았지만, 수치적으로 보았을 때 3,265 kcal of ME/kg 사료를 급여한 Lys0.55/0.70% 그룹의 모돈의 총산자수 및 복당체중이 가장 높게

나타났다. 포유기 자돈의 성적은 1 산차에서는 3,365 kcal of ME/kg 사료를 급여한 모돈군에서 높은 3 주차 자돈체중과 증체량을 보였지만 (Energy, P=0.08), 2 산차와 3 산차에서는 에너지 및 라이신에 의한 영향은 나타나지 않았다. 자돈의 균일도에서는 1 산차와 3 산차에서는 요인효과가 나타나지 않았지만, 2 산차의 생시자돈의 체중의 표준분포가 고에너지 그룹에서 높아지고 (Energy, P=0.06), 라이신 0.75/1.00%와 0.65/0.85% 처리구에서 낮아지는 결과가 나타났다 (Lysine, P=0.03). 포유기 사료섭취량은 3 산차에 3,265 kcal of ME/kg 사료를 급여한 모돈의 사료섭취량이 3,365 kcal of ME/kg 사료를 급여한 모돈보다 높게 나타났다 (Energy, P=0.07). 산차별 두수 현황 및 도태율에서는 3,265 kcal of ME/kg 사료를 급여한 Lys0.55/0.70% 그룹의 모돈들이 가장 낮은 도태율을 가지며, 재귀발정일에서는 에너지 및 라이신 요인에 의한 차이는 나타나지 않았다. 결론적으로, 임신기 0.55% 총 라이신함량과 포유기 0.70% 총 라이신 함량에 3,265 kcal of ME/kg 에너지 함량의 사료를 급여하는 것이 2 산차와 3 산차 모돈의 생산성 및 연산성을 향상시키기 위해 가장 좋을 것으로 사료된다.