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Effects of Dietary Energy and Crude Protein Levels in Weaning Pigs, Growing-finishing Pigs and Gestating Sows

사료 내 에너지-단백질 수준이 이유자돈, 육성비육돈 및 임신모돈에 미치는 영향

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Overall Summary

Effects of Dietary Energy and Crude Protein Levels in Weaning Pigs, Growing–finishing Pigs and Gestating Sows

It is well known that animal physiology, nutrition, genetics, animal behavior, environment and housing were developed over the last 15 years. And the swine productivity has significantly increased efficiently in the breeding herd, resulted in improvement of weaning piglets per sow per year (PSY) and market pigs per sow per year (MSY). As the swine productivity improved, nutrients requirements of swine had continually changed in NRC (NRC, 1988, 1998 and 2012) such as metabolic energy (ME), amino acids and crude protein (CP) concentration. To maintain improved swine productivity, adequate nutrients should be supplemented efficiently in their diet. Consequently three experiments were conducted: 1) to investigate the effect of dietary energy and crude protein levels on growth performance, blood profiles, nutrient digestibility and economic analysis in weaning pigs 2) to investigate the effect of dietary energy and crude protein levels on growth performance, blood profiles, carcass traits and economic analysis in growing–finishing pigs; and 3) to investigate the effect of dietary energy and crude protein levels on reproductive performance, litter performance, milk quality and blood profiles in gestating sows.

Experiment Ⅰ. Effects of Dietary Energy and Crude Protein Levels on Growth Performance, Blood Profiles, Nutrient Digestibility, and Economic Analysis in Weaning Pigs

This experiment was conducted to investigate the effect of reducing dietary metabolizable energy (ME) and crude protein (CP) levels on growth performance, blood profiles, nutrient digestibility, and economic analysis in weaning pigs. A total of 240 crossbred pigs ([Yorkshire × Landrace] × Duroc) with an average body weight (BW) of 8.67±1.13 kg were used for 6 weeks feeding trial. Experimental pigs were allotted to a 2 × 3 factorial arrangement using a randomized complete block design. The first factor was two levels of dietary ME level (3,200 or 3,300 kcal of ME/kg) and the second factor was three dietary CP levels based on subdivision of early and late weaning phases (low CP level: 19.7%/16.9%; middle CP level: 21.7%/18.9%; or high CP level: 23.7%/20.9%). Over the entire experimental period, there was no significant difference in BW among groups, but average daily feed intake (ADFI) was increased ($P=0.02$) and gain to feed ratio (G:F ratio) was decreased by decreasing ME level in diet ($P<0.01$). Decreasing CP levels in the diet, average daily gain (ADG) was increased linearly ($P<0.05$) and G:F ratio was increased quadratically ($P<0.05$). In the early weaning period, blood urea nitrogen (BUN) concentration tended to increase when dietary ME decreased but it was decreased when CP level in the diet decreased ($P=0.09$ and $P<0.01$, respectively). Total protein concentration tended to increase when CP level was reduced

(P=0.08). In the late weaning period, BUN concentration was decreased linearly as CP level decreased (P<0.01). Digestibility of crude protein and crude fat was decreased when ME was decreased by 100 kcal/kg (P=0.05 and P=0.01, respectively). Crude protein digestibility increased linearly as CP level decreased (P=0.01). In the late weaning period and during whole experimental period, feed cost per weight gain showed increased when ME decreased by 100 kcal/kg (P<0.01 and P=0.02, respectively), and increased linearly when CP level in the diet decreased (P<0.01 and P<0.01, respectively). Total feed cost per pig (get to 25 kg) was increased when dietary ME was high with low CP level (P<0.05). A weaning pig diet containing high ME level (3,300 kcal/kg) and low CP level (19.7%/16.9%) can improve growth performance and nutrient digestibility of pig and reduce the cost of production.

Experiment Ⅱ. Effects of Dietary Energy and Crude Protein Levels on Growth Performance, Blood Profiles, Carcass Traits, and Economic Analysis in Growing-finishing Pigs

This experiment was conducted to determine the effect of dietary energy and crude protein levels on growth performance, blood profiles, carcass traits, and economic analysis in growing-finishing pigs. A total of 180 crossbred pigs ([Yorkshire × Landrace] × Duroc) with an average body weight of 30.96±3.07 kg were used for a 12-week feeding trial. Experimental pigs were allotted to a 2 × 3 factorial arrangement

using a randomized complete block design. The first factor was two levels of dietary metabolizable energy (ME) level (3,200 or 3,300 kcal/kg), and the second factor was three dietary crude protein (CP) levels based on subdivision of growing-finishing phases (low CP level: 16%/14.3%/14.3%/11.2; middle CP level: 17.0%/15.3%/15.3%12.2% or high CP level: 18.0%/16.3%/16.3%/13.2%). Average daily gain and G:F ratio were decreased linearly as dietary CP level decreased (linear, P=0.04 and P=0.03, respectively) in the early growing phase and G:F ratio was decreased linearly as dietary CP levels decreased (P=0.02) over the whole growing phase. Over the entire experimental phase, G:F ratio was decreased as dietary ME level decreased (P=0.01). There were no significant differences in glucose and total protein concentration in the blood when pigs were fed different dietary ME and CP levels during the growing period, but blood urea nitrogen (BUN) concentration increased when dietary ME decreased (P<0.01). There were no significant differences in glucose or BUN concentration in the blood when different dietary ME and CP were provided during the finishing period, but total protein concentration was decreased as dietary ME decreased (P=0.04). In this study, there were no significant differences in proximate analysis, physiochemical properties, muscle TBARS assay, pH changes or colors of longissimus muscles. However, saturated fatty acid (SFA) was increased (P<0.01) and polyunsaturated fatty acid (PUFA) was decreased (P=0.03) when ME decreased by 100 kcal/kg in growing-finishing pig diets. In addition, monounsaturated fatty acid (MUFA) tented to increase when CP level was decreased in growing-finishing pig diets

(P=0.06). On economic analysis, there were no significant difference in total growing days from 30kg to 115kg and feed cost per weight gain of pig, but in total feed cost per pig and total feed cost per weight gain tended to increase when ME level in growing−finishing pig diet decreased (P=0.08 and P=0.07, respectively). A growing−finishing diet of high energy diet with the high level of CP can improve growth performance, pork quality, and reduce the cost of production.

Experiment Ⅲ. Effects of Dietary Energy and Crude Protein Levels on Reproductive Performance, Litter Performance, Milk Quality, and Blood Profiles in Gestating Sows

This experiment was conducted to evaluate the effect of dietary energy and crude protein levels on reproductive performance, litter performance, milk quality and blood profiles in gestating sows. A total of 59 multiparous sows (Yorkshire × Landrace) with similar body weight (BW), backfat thickness (BF) and parity were assigned to one of six treatments with 9 or 10 sows per treatment using a 2 × 3 factorial arrangement and completely randomized design. The first factor was two levels of dietary energy (3,200 or 3,300 kcal/kg) and the second factor was three dietary crude protein (CP) levels based from 35 day in gestating phases (low CP level: 10.5%; middle CP level: 12% or high CP level: 13.5%). There were no significant differences in BW, BW change in sows from gestation 35 day to 21 day of lactation, ADFI during lactation, and weaning to estrus interval (WEI). Backfat thickness change in lactating sows decreased linearly as CP level increased (P=0.03). Increased energy level in the gestating sow diet tended to increase the total number of piglet born (P=0.07), but piglet weight decreased (P=0.02). Litter weight gain was not affected by dietary energy and CP level in the diet of gestating sows. There was no significant differences in milk quality on day 21 of lactation according to dietary energy level (ME: 3,200−3,300 kcal/kg) or CP level (10.5%−13.5%), but casein (P=0.03), protein (P=0.04), total solids (P=0.03) and solids−not−fat (P=0.03) concentration increased linearly and lactose (P=0.06) level tends to decreased linearly in colostrum when decreasing CP level in gestating sow diets. There were no significant differences in blood glucose concentration in gestating sows when sows were fed different levels of energy during gestation, but blood glucose increased at 21 day of lactation when energy increased by 100 kcal/kg (P=0.04). Blood urea nitrogen concentration increased linearly when dietary CP levels increased at 110 day in gestation , 24−hours postpartum, and 21 days of lactation (linear, P<0.05, P<0.05, and P<0.05, respectively), and it also increased when dietary energy increased at 110 days of gestation and 24−hours postpartum (P<0.01, and P<0.01, respectively). A gestating sow diet containing high ME level and low CP level can improve reproductive performance, litter performance and colostrum quality.

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List of Abbreviation

ADG	Average daily gain
ADFI	Average daily feed intake
BF	Backfat thickness
BUN	Blood urea nitrogen
BW	Body weight
CP	Crude protein
DE	Digestible energy
G:F ratio	Gain-feed ratio
ME	Metabolizable energy
MSY	Market pigs per sow per year
MUFA	Monounsaturated fatty acids
NE	Net energy
NSP	Non-starch polysaccharides
NRC	National research council
PSY	Weaning piglets per sow per year
PUFA	Polyunsaturated fatty acid
SAS	Statistical analysis system
SBM	Soybean meal
SFA	Saturated fatty acids
WEI	Weaning to estrus interval

Chapter I. Introduction

It is well known that through physiology, nutrition, genetics, animal behavior, environment and housing development over the last 15 years, the swine performance have significantly increased efficiency of reproduction in the breeding herd, weaning piglets per sow per year (PSY) and market pigs per sow per year (MSY). As the swine production efficiency improved, nutrition requirements of swine had changed in NRC (NRC, 1998; NRC, 2012) in terms of metabolizable energy (ME) and amino acid levels and crude protein (CP) concentration.

Number of low birth weight piglet born and light pigs at weaning were increase when increasing the number of piglets born and number of weaning pigs. In Ribeiro et al. (2015) study, average daily gain (ADG) was decreased 70g by weaning weight (4.0kg to 6.3kg). So nutrition requirements should change, such as ME requirement in NRC was increased from 1998 (3,265kcal/kg) to 2012 (3,400-3,350 kcal/kg), but CP levels was decreased from 23.7%-20.6% to 20.9%-18.9% (the value of CP is calculated from N by multiplying by 100/16). Using low CP level in weaning pig diet is because higher of CP intake than needed can have an adverse effect on the environment, and increased fecal nitrogen content, and decreased the diarrhea of weaning pigs (Lewis and Southern, 2001; Nyachoti et al., 2006; Wellock et al., 2008a).

Feed always accounts for about two thirds of the cost of producing market-weight swine. Growing-finishing period in commercial pigs had the biggest average daily feed intake (ADFI), longest feeding days and largest total feed cost (NRC, 1988; Korea Feed Association, 2016). Growth of growing-finishing pig is whole body protein and lipid deposition (Nieto et al., 2012). In Jongbloed and Lenis (1992), Paik et al. (1996) and Jeong et al. (2010) studies showed that insufficient nutrients limit the potential growth and production of animal and excessive nutrients reduce the economic profitability and pollutes the environment. On the other hand, Lee et al. (2000a) reported that feeding four diets with CP sequence (16%-14.7%-13.4%-12%) and one diet with CP 16% had no significant difference on growth performance in finishing pig diets. Given all this, energy and CP concentration of diets are playing a major role on growth performance and cost of production in growing-finishing pig diets.

PigCHAMP (2016) reported that most of swine performances in USA were increased from 2004 to 2016, such as farrowing rate: 77.72% to 82.51%; total piglets born per sow: 12.51 to 13.95; average piglets born alive per sow: 10.34 to 12.58; weaning piglets per sow: 9.10 to 11.03; PSY: 20.27 to 23.05. As improved sow performance, require more nutrients to carry on normal reproductive cycle and body maturation (Boyd et al., 2000). Sow nutrition plays a role in fetal growth and development as well as postnatal performance and sow health (Cerisuelo et al., 2009). So the feeding of gestating sows is not only getting optimal fetal growth, but also maintaining appropriate maternal protein and fat gain (Ji et al., 2005). So energy and CP intake are important in gestation sows.

Consequently, to meet the higher swine production efficiency and to supplement the option protein and energy requirement, three experiments were conducted: 1) to investigate the effect of dietary energy and crude protein levels on growth performance, blood profiles, nutrient digestibility and economic analysis in weaning pigs; 2) to investigate the effect of dietary energy and crude protein levels on growth performance, blood profiles, carcass traits and economic analysis in growing–finishing pigs; and 3) to investigate the effect of dietary energy and crude protein levels on reproductive performance, litter performance, milk quality and blood profiles in gestating sows.

Chapter Ⅱ. Literature Review

1. The Strategies for Improving Productivity and Saving Feed Cost

1.1 Nutrient Requirement of Pigs

To make maximum pig production, fast growth rate and save the feed cost were important in swine industry. Pigs and pork production are to convert nutrients supplied by a range of feedstuffs into more pigs and pork products. Several nutrients are essential for the synthesis of muscle, adipose tissue, bone, hair, skin and other body components and for body maintenance, growth, reproduction and lactation, such as energy, protein, amino acid, minerals, vitamins, water and so on.

On the other hand, Wilson and Bayer (2000) reported that feed accounts for about 60% of the cost of producing market-weight pigs. As we all know, nutrient concentrations are not only affecting the swine performance, but also have connection with cost of production. Feeding excess nutrients to animals can have an adverse impact on the environment (Swine Nutrition 2nd Edition, 2001). On the contrary, some of studies reported that insufficient nutrients effect on the reproductive, lactating and growth performance (Baker et al., 1970; Svajgr et al., 1972; Head and Williams, 1991; Jongbloed and Lenis, 1992; Paik et al., 1996; Messias de Bragança et al., 1998; Revell et al., 1998; Kusina et al., 1999b; Jeong et al., 2010). Therefore, in order to improve swine productivity and decrease feed cost, the experiments to evaluate changed requirements of some nutrients have to be conducted, along with those to evaluate the interactive response between nutrients concentrations and swine performance.

1.2 Feed Ingredients

Corn and soybean meal (SBM) are two of the main feed ingredients for the swine industry in Asia, which usually use more than 60% in swine diet as an energy and protein sources for a long time in South Korea. However, prices of corn and SBM are always change with kinds of facts, such as increasing development of the animal industry, biofuel production, severe drought and so on. Consequently, feed companies tried to find a way to reduce the price of feed through use some alternative feed ingredient in animal diet. Among many feed ingredients, cassava meal, sugar beet pulp, rapeseed meal and palm kernel meal have been used in swine industry (Longland and Low, 1990; Oke, 1990; Thacker, 1990b; Wu, 1991; Rantanen et al., 1995), because of alternatives to corn and SBM with a competitive price, steady supply and similar growth performance of animals. However, these materials are consist of a complex matrix granule that contains many types of non-starch polysaccharides (NSP), resulting in lower digestion and absorption of nutrients. It means that high level of NSP intake is negative effects on growth performance and health. So, using levels of alternative feed ingredient are limited in animal diet.

1.3 Animal Management Techniques

There have lots of studies reported that swine productivity was effected by animal management techniques. Creep feed has been used in pre-weaning pigs to improve body condition of lactating sows and growth performance of their progeny (Bruinins et al., 2002; Klindt, 2003; Pluske et al., 2007). However, there were also opposite results that there had no effects on growth performance of piglets after weaning when their eat creep feed (Sulabo et al., 2010). Therefore, the additional studies to determine the duration of creep feeding and the response of nursery piglets and lactating sows on this management technique were needed to solve the confusion of farmers.

Phases feeding can prevent nutrition waste and reduce cost of production. In Lee et al. (2000a) study, when phases increased in finishing pig diets, had no effects on growth performance, and total feed cost per pig and feed cost per weight gain were decreased. Similar to this observation, some studies indicated that number of phases had no effect on the growth performance of growing-finishing pig (Lee et al., 2001b; Ko et al., 2003, Choi et al., 2010). Consequently, limitation some of nutrition levels in the diet had no negative effects on growth performance during the finishing period.

Determining optimal time of insemination after the onset of estrus is one of the most important factors to improve sow productivity. There had lots of studies showed different results when used different time of insemination. Sows inseminated between 0 and 24 hours before ovulation showed high fertility consistently (Soede et al., 1995; Kemp et al., 1996). In addition, Weltze et al. (1994) reported that the interval from the onset of estrus to first artificial insemination should be decreased as weaning to estrus interval increased. And in Steverink et al. (1999) study showed that the best reproductive performances were depended on the time of insemination relative to ovulation. So each farm should determine individual insemination strategy.

2. Nutritions in Swine Feed Industry

2.1 Feed Intake

Weaning, growing and finishing pigs are feed on an *ad libitum* basis. Consequently, feed intake and nutrition digestibility are determining their growth performance. Some of studies reported that voluntary feed intake as the total weight of feed ingested in a given period of free access to feed, and the potential feed intakes as the weight of feed required to fulfill all of the pig nutrient requirements (Forbes, 1995; Curtis, 1996). But in practice, voluntary feed intake is usually lower than the potential intake because of a range of internal animal constraints, environmental limitations or nutritional factors.

In addition, controlling feed intake of pigs had been concentrated on sows. Body et al. (2000) and Trottier and Johnston (2001) reported that feeding strategies for gestating sows have been applied to accomplish maximum total piglet born and body condition of sows. However, their feeding strategies showed different results, and mechanisms involved in physiological parameters and reproductive performance were not clearly understood (Piao et al., 2010). Gilts fed increased in early gestating period showed decreased survival rate of embryo in day 28 of gestation (Dyck et al., 1980), and feeding of 1.8 to 2.0 kg/day during early gestation had no effects on reproductive performance and saved feed cost (Pharazyn et al., 1991). In Whittemore et al. (1984) study reported that there had no effects of increased feeding level during late gestation on litter size, but Kirkwood (1988), Noblet et al. (1990) and Miller (1996) reported that piglets birth weight and milk production was increased by sows feeding levels increased in late gestation. However, the responses were varied by the parity of sows, the number of piglets born alive, dietary nutrition concentration and it is definite that the constant feeding ration is efficient way in the aspect of manpower management. Consequently, additional studies were needed to determine optimal feeding strategies for gestating sows.

2.2 Energy

Feed accounts for about 60−70% of the cost of producing market−weight swine. People always made to optimize gain: feed ratio (G:F ratio) and made feed costs might be minimized. There are depend on knowledge of nutrient availability in feed ingredients and the requirements of pigs. Total digestible nutrient system allows comparisons, roughly equivalent to digestible energy level between feed ingredients. However, energy concentration in diets, had effects on voluntary feed intake, the intake of other nutrients, reproductive performance, G:F ratio and immunity in pigs. In addition, energy level was closely associated with the feed cost due to the high price of fat sources. Carbohydrates are the single most abundant feed energy in diets for swine comprising 60−70% of the total energy intake, and the use of fats and oils in diets for pigs is of great importance due to the high energy value, which is approx 2.25 times that of carbohydrates (Swine Nutrition 2nd Edition, 2001).

In South Korea, increasing ADFI and energy concentration in feed companies have been usually used to compensate heat loss during winter season, because of the temperature of facilities for pigs is difficult to control. However, excess energy intake may result in decreased ADFI and increased BW loss in lactation (Long et al., 2010; Ribeiro et al., 2016).

2.3 Protein and Amino Acid

Improving the efficiency of feed utilization and reducing feed cost are important for successful pig production. Protein as one of the main factor which accounts for a major cost in feed (SCA, 1987). However, feeding excess protein to animals can have an adverse impact on the environment, increase the cost of production in swine enterprise and improve the diarrhea rate (Nyachoti et al., 2006; Wellock et al., 2008a). The management of wastes and odors has become a problem in the swine industry. Therefore, it is important to use efficient protein and amino acid utilization.

Baker (1997) reported that because the availability of amino acids and the ratio between the essential amino acids and non-essential amino acids differ from supplement to supplement, protein supplements have different nutritional values individually. Then, the ideal pattern and profiles of amino acids are variable depending on change when pigs weight change (Mahan and Shields, 1998). Protein turnover is important to determine energy and protein requirement of pigs, because of it is related to lean growth rate, and these requirements by a mathematical model derived from several findings (NRC, 2012).

2.4 Fat and Fiber

Usually, it is necessary to add fat to increase dietary energy levels, but cannot use too much because of the cost. With the addition of fat in swine diets, effects of energy sources including fat and starch sources have been found to decrease the feed cost and improve swine productivity. In Tilton et al. (1999) study, they found that addition of fat in lactating sow diets had influences on increasing fat content of milk, piglet growth performance and litter weight. However, van den Brand et al. (2000) reported that adding carbohydrate sources had improving milk quality, and sow ADFI, and Nelssen et al. (1985) and Kemp et al. (1995) also reported that litter size, energy digestibility, body conditions and litter weight were improved when adding high level of starch sources in lactating sow diets.

Fiber sources always used in ruminant animals diets, because the rumen microbes could digest fiber fractions, but these ingredients were not used in mono-gastric animal diets because endogenous digestive enzyme of mono-gastric animals could not digest fiber fractions without exogenous enzyme derived from diet mannanase, cellulase, xylanase, glucanase and so on (Noblet and Etienne, 1989; Black et al., 1993). However, there were some studies reported positive effects on swine performance when fed high fiber diets. Total born, stereotypic behaviors and physical activity, energy digestibility, embryo development and maternal energy balance of gestating sows had positive effects by high fiber diets (Lee and Close, 1987; Grieshop et al., 2001). In addition, some of studies reported that growth performance and gut health were increased and diarrhea rate was reduced when improved fiber concentration in weaning pig diets (Cherbut 1990; Schneeman 1990; Longland et al., 1994; Spiller 1994; McDonald et al., 1999). So high fiber diets could improve swine productivity and to decrease production cost.

2.5 Feed Additives

Many feed additives have been used to improve the growth performance, reproductive performance, feed efficiency, immunity and productivity in Korean swine industry, such as probiotics, prebiotics, acidifier, emulsifier, enzymes and plant extracts.

There had some studies reported that probiotics had positive effects on pigs. In Stamati et al. (2006) and Kim et al. (2008) studies showed that adding probiotics in pig diets can provide substrates for beneficial microbes, and improved growth performance, body conditions of lactating sows, fertility, milk fat and protein contents, and piglet survival rate. Then, O' Quinn et al. (2001) and Maxwell et al. (2003) showed prebiotics in pig diets also can provide substrates for beneficial microbes, resulting in increased pre-weaning growth, reduced return to estrus interval and pre-weaning mortality.

For over ten years in the past, lots of new feed ingredients replaced the corn and soybean meal in swine feed because of the price of these feed ingredients are highly increased. So, enzymes always use in swine feed to improve fiber digestibility. Bach-Knudsen et al. (1988) and O' Doherty and McKeon (2000) reported that high fiber diet could reduce nutrient digestibility. Then, Araki and Kitamikado (1988) presented that supplementation carbohydrate enzymes such as mannanase and cellulase could be solved that problem.

In addition, acidifier, emulsifier and plant extracts were also used to reduce gut pH of piglets after weaning, and to improve fat digestibility of pigs.

3. Energy Requirements in Swine Diet

3.1 Energy Requirements of Swine

3.1.1 Weaning Pigs

The NRC (1998) reported that nutrient requirement of weaning pigs (3 to 20kg) should contain 3,265 kcal ME/kg. Estimated daily ME requirements for 3−5, 5−10, and 10−20kg pig are 820, 1,620, and 3,265 kcal/day, respectively. Then, the NRC (2012) publication on nutrient requirements of swine indicates that diets fed to pig weight 5 to 25 kg should contain 3,400 and 3,350 kcal ME/kg. And estimated daily ME requirements for 5−7, 7−11, and 11−25kg pig are 904, 1,592, and 3,033 kcal/day, respectively. Accompany by change ME concentration in diet and weaning pig weight change, weaning pig daily ME intake was decreased from NRC 1998 to 2012 requirement.

It is challenging that weaning pig maintains feed intake. Thus, health weaning pigs have no consume enough energy to meet their need for rapid protein deposition, especially the first few days after weaning. So, weaning pig should eat high nutrient and high digestible dense complex diet composed of ingredients for grow well. Unfortunately, adding high levels of fat is not beneficial, because of pigs development do not utilize fat very well in this period. Therefore, supplied by providing part of the energy as readily available carbohydrates such as lactose, glucose or sucrose in weaning pig diets, could find weaning pigs suitable energy for optimum performance.

3.1.2 Growing-finishing Pigs

Energy concentration in feed determines voluntary feed intake of growing-finishing pigs. When pigs feed high concentration energy diet and lipid accumulation increase, feed intake, weight gain, and lean percentage will decrease. The daily energy requirement is the total of the requirements for maintenance, for protein and fat deposition and for thermo-regulation. Growing-finishing pig needs energy intake for growth and maintenance. The NRC (1998) used a value of $110W^{0.75}$ kcal/ of daily or $106W^{0.75}$ kcal of ME daily as the maintenance requirement for all weight of growing-finishing pigs.

Energy requirement for pig growth is used to synthesis of tissue, organ, bone and muscle and fat by protein and lipid deposition. Synthesis of 1g protein need 10.6 kcal of ME and 1g of fat need 12.5 kcal of ME (Verstegen et al., 1987). And 1kg muscle tissue contained 23% of protein, and 1kg fat tissue contained 80-95% of fat. According to this, energy requirement for fat deposition is higher than that of muscle synthesis (Wenk et al., 1980).

NRC and other feeding standards have been reported the energy requirement of growing-finishing pigs and showed in

Table 1. During the growing-finishing period, NRC suggested that 3,265 ME kcal/kg (NRC, 1998) and 3,300 ME kcal/kg (NRC, 2012) for energy requirement, respectively. Also, KFSS (2007) showed 3,265 ME kcal/kg in feed, but 3,350 kcal of ME, 3,300 kcal of ME, 3,300 kcal of ME and 3,300 kcal of ME is suggested on 25-45 kg, 45-65 kg, 65-85 kg and 85-120 kg pigs, respectively in KFSS (2012). NRC (1998; 2012), SCA (1987), JRC (1993) and KFSS (2007; 2012) had similar energy requirement in growing-finishing pigs, but ARC (1981) showed a lower energy requirement than others.

Table 1. Energy requirements for growing-finishing pigs.

Item	Body weight (kg)			
NRC, 1998	**20 - 50**	**50 - 80**	**80 - 120**	
ME, kcal/kg	3,265	3,265	3,265	
NRC, 2012	**25 - 50**	**50 - 75**	**75 - 100**	**100 - 135**
ME, kcal/kg	3,300	3,300	3,300	3,300
KFSS, 2007	**25 - 50**	**50 - 80**	**80 - 120**	
DE, kcal/kg	3,400	3,400	3,400	
Estimated ME[1)], kcal/kg	3,265	3,265	3,265	
KFSS, 2012	**25 - 45**	**45 - 65**	**65 - 85**	**85 - 120**
ME, kcal/kg	3,350	3,300	3,300	3,300
ARC, 1981	**15 - 50**		**50 - 90**	
DE, kcal/kg	3,107		3,107	
Estimated ME[1)], kcal/kg	2983		2983	
SCA, 1987	**20 - 50**		**50 - 90**	
DE, kcal/kg	3,346		3,346	
Estimated ME[1)], kcal/kg	3,212		3,212	
JRC, 1993	**30 - 70**		**70 - 110**	
DE, kcal/kg	3,300		3,300	
Estimated ME[1)], kcal/kg	3,168		3,168	

[1)] The value of ME is approximately 94~97 % of DE in swine feed and average 96% (ARC, 1981).

3.1.3 Gestating Sows

Energy intake during gestation is generally limited to control weight gain and body condition of sow. NRC (1998) uses a desired gestation weight gain and the expected number of piglets born to determine the desired energy intake. The gain of weight, energy, and protein in the products of gestation is considered as constants per pig in the litter. Weight gain of sows can be determined from the desired sow weight gain and weight gain from the products of gestation. Weight gain of gestating sows is fat and protein, and the energy intake required is from the total of the energy required for maintenance, the products of conception, and the sow gain of fat and protein.

Several experiments have been conducted on the application of net energy (NE) prediction equations for diets and feedstuff in gestating sows. NRC (2012) recommended 2,518 kcal/kg of NE for all of gestation sows, and it is regardless of parity, BW, backfat thickness (BF) and litter size of sows. And this requirement was same in all day of gestation and the ME and digestible energy (DE) requirements for gestating sows were 3,300 and 3,388 kcal/kg in diet in NRC (2012), respectively. The prediction equations are determined from completed diets, and the experiments to apply predictions in individual ingredients are essential in the NE system. But there were just few studies to determine NE requirement for individual ingredients, and measured heat production can be varied because of limited experimental environment and challenges quantifying fasting heat production (Birkett and de Lange, 2001). So, it needs more experiment to verify the prediction equations of the NE system.

3.2 Effect of Dietary Energy Levels in Swine Diet

3.2.1 Weaning Pigs

Bikker et al. (1995), Quiniou et al. (1995), and Weis et al. (2004) studied the effect of different energy concentration, achieved by controlling daily feed intake, on body composition of growing pigs. But we could find no references in the literature of similar studies in the weanling pig. In contrast, there have been lots of studies on the effect of energy level on the growth performance of weaning pigs. But the effect of dietary energy levels on weanling pig performance is conflicting. In Hastad et al. (2001a) study, weight gain was improved when increasing the dietary energy level. However, some of studies reported that there was no significant difference on growth performance when weaning pig fed different levels of energy (Tokach et al., 1995; Hastad et al., 2001b).

It has long been recognized that dietary energy level is an important determinant of voluntary feed intake of pigs (NRC, 1987; Lewis, 2001), feed intake could decrease when energy level increase in pig diet. Tokach et al. (1995), Reis de Souza et al. (2000), and Levesque (2002) evaluated there had no significant different on ADFI and growth performance when increasing ME (3.27 to 3.61 Mcal/kg), DE (3.24 to 3.50 Mcal/kg) or DE (3.18 to 3.59 Mcal/kg) in weaning pig diet, respectively.

Similar to ADFI, G:F ratio was not affected when dietary NE concentration (2.21 to 2.42 Mcal/kg) increased (Oresanya et al., 2008). However, Levesque (2002) and Oresanya et al. (2007)

evaluated G:F ratio was improved with increasing DE concentration. Other, G:F ratio was decreased when improved feed intake occurs without changes in growth rate (Pettigrew and Moser, 1991; Xing et al., 2004).

3.2.2 Growing-finishing Pigs

Among feed effects, dietary energy level plays a major role in the variation in feed intake, regulation of feed intake depends on energy density. In general, high dietary energy levels for growing-finishing pigs reduced ADFI and improved ADG and G:F ratio (Pettigrew and Moser, 1991). In addition, some researches showed had no significant difference on body weight and ADG, but improved G:F ratio by adding energy in growing-finishing diets (Baird et al., 1958; Clawson et al., 1962; Wagner et al., 1963). However, too low of energy level showed low energy intake and growth performance in pigs (Chadd and Cole, 1999; Smith et al., 1999; De la Llata et al., 2001). And too high of dietary energy concentration showed reduced ADG, ADFI and G:F ratio (Stahly et al., 1981; Southern et al., 1989; Williams et al., 1994; Dunshea et al., 1998). Unlike previous experiments, some studies reported that there had no significant difference no growth rate and ADFI when fed different concentration of energy in growing-finishing pigs (Cromwell et al. 1978; Matthews et al., 2003)

Furthermore, fat is important ingredients in growing-finishing pig diets because of it high energy level (Stahly, 1984). In Young et al. (2003) study showed that there had similar ADG and G:F ratio when adding 2.5% and 5% of fat in growing-finishing pig diets. Similar to this result, Haydon et al. (1989) reported that they had no effect on growth performance when growing pigs were fed 5 % added fat. But feeding 4.5% or 10% of fat in growing–finishing pig diets had been showed increased G:F ratio and decreased ADFI (Southern et al., 1989; Azain et al., 1991; Williams et al., 1994; Matthews et al., 2003). Moreover, some studies used 5% fat in growing–finishing diet in summer to improve ADG and G:F ratio (Stahly and Cromwell, 1979; Stahly et al., 1981). Adding dietary fat 0%–6% with 3.31–3.61 Mcal improved ADG and G:F ratio and reducing ADFI (De la Llata et al., 2001).

3.2.3 Gestating Sows

Energy is required for the maintenance and growth of the sow, and conceptus development. If nutrient intake is severely restricted, it will develop at the expense of maternal tissue to development of the conceptus takes priority (Walach–Janiak et al., 1986). Beyer et al. (1994) reported sows were fed three energy levels during three reproductive cycles that the total weight gain of the uterus, uterine fluids, products of conception, and mammary tissue was 22.8 kg and was not affected by energy level or parity, but Maternal weight gain was dependent on the amount of energy consumed. Therefore, energy intake of the sow during gestation is limited to prevent excessive growth and fattening (Verstegen et al., 1987).

There had some studies reported that increased BW of sows by high energy intake during gestation (Buitrago et al., 1974; Libal and Wahlstrom, 1977; Dourmad, 1991; Van den Brand et al., 2000). Dourmad et al. (1999) showed excess energy intake results in increased BW and BF, and impaired body conditions of gestating sows could be a main reason of reproductive problems (Young et al., 1990). In addition, King and Young, (1957), Clawson et al. (1963) and Ruiz et al. (1968) reported that litter size was decreased when increased BW of gestating sows. Feeding high energy diets in gestation decreased voluntary feed intake of sows during lactation (Baker et al., 1968; Dourmad, 1991). However, low feed intake in lactation can reduce amounts of maternal tissue and increase losses of BW and BF (Williams, 1995), reduce of ovulation rate, conception rate and embryo survival in next parity (Hughes et al., 1984; Zak et al., 1997; Han et al., 2000).

Jindal et al. (1996) reported that the gilts fed diets containing constant dietary energy showed decreased embryonic survival rate during early gestation period. However, other experiments showed there had no detectable effects of dietary energy levels on the number of embryo and the rate of embryo survival (Pharazyn et al., 1991; Liao and Veum, 1994). In addition, gilts fed diets containing moderate energy levels compared to those fed diets containing low energy levels showed increased embryonic mortality and reduced number of embryo and ovulation rate from mating to day 10 of gestation (Dyck and Strain, 1983; Toplis et al., 1983). There had negative effects on the number of embryo survival (Kirkwood et al., 1990) and had no effects on farrowing rate (Dyck and Cole, 1986) when increasing dietary energy levels in early day of gestating sows. However, too low energy intake during early day of gestation showed reduced litter size (Sorensen and Thorup, 2003) and pregnancy rate (Virolainen et al., 2004). Moderate energy levels of diets during the early day of gestation had negative effect on embryo survival in relatively low prolific sows, whereas high energy diets (above 37 MJ ME per day) in early pregnancy did not effect on litter size in highly prolific gilts or sows (Kongsted, 2005).

Merk and Kirchgessner (1984) and Einarsson and Rojkittikhun (1993) reported that increased energy level in during mid and late pregnancy had no detectable effects on litter size, but Gatel et al. (1987) found a slightly higher culling rate of sows (anoestrus after weaning and leg problems) when they fed high level of energy during mid and late pregnancy. Kongsted et al. (2005) reported that feeding high energy diets and low−energy−high−fiber diets during the first 4 weeks of gestation have no effect on reproductive performance and litter size. However, sows fed high energy diets showed improved culling rate because sows were not pregnant repeatedly (Kongsted et al., 2005).

4. Protein Requirements in Swine Diet

4.1 Crude Protein Requirements of Swine

4.1.1 Weaning Pigs

The NRC (1998) reported that CP requirement of weaning pigs (3−5kg, 5−10kg, 10−20kg) are 26%, 23.7% and 20.9%, respectively. Also, estimated daily CP requirements for 3−5, 5−10, and 10−20kg pig are 65, 118.5 and 209 g/day, respectively. Then, the NRC (2012) publication on nutrient requirements of swine indicates that diets fed to pig weight 5−7kg, 7−11kg and 11−25 kg should contain 22.7%, 20.6% and

18.9%. And estimated daily CP requirements for 5−7, 7−11, and 11−25 kg pig are 63.6, 101.6 and 180.1 g/day, respectively. Accompany by change CP concentration in diet and weaning pig weight change, weaning pig daily CP intake was decreased from NRC 1998 to 2012 requirement.

Many weaning pigs have a poor and variable growth rate associated with a low and variable ADFI after weaning. Furthermore, weaning pigs have an increased susceptibility to enteric pathogens that may cause diarrhea. Also the optimal level of dietary CP at weaning period is somewhat controversial. Low−protein diets are usually used to reduce diarrhea of weaning pigs (Callesen, 2004), and have been shown to reduce the ratio of diarrhea, however, may be the result at the expense of growth performance (Eggum et al., 1987). Some of studies reported that reducing CP in weaning pig diets, reduced the ammonia in the small intestine (Nyachoti et al., 2006; Htoo et al., 2007; Pierce et al., 2007), but also reduced growth performance of weaning pigs (Nyachoti et al., 2006).

4.1.2 Growing−finishing Pigs

Dietary protein level is one of the important source for the synthesis of body tissue, organ, hair, bone, skin, blood and other tissues. Furthermore, some amino acids contained in protein are required for the synthesis of non−protein compounds, such as hormones, neurotransmitters, immunoglobulins and other bioactive peptides.

Phase feeding is one of the methods to supply adequate nutrients to meet growing−finishing pig' s needs. Generally, nutrient requirements have been decreased as pig growth, and apropos of phase feeding is preventing the waste of nutrition and save the cost of feeding. Moreover, phase feeding reduces excreted with excessive nitrogen. Thus, NRC indicated that there was one more phase in growing-finishing pig from 1998 to 2012. Also, CP requirements in NRC 2012 was less than NRC 1998 when growing-finishing pig in the same weight. In addition, the CP requirement for growing-finishing pigs in NRC 1998 and 2012 is presented in Table 2. In fact, many experiments reported that providing the adequate amino acids balance is more efficient and productive than protein contents in pig' s growth.

Table 2. Crude protein requirements for growing-finishing pigs in NRC 1998 and 2012.

Item	Body weight (kg)			
NRC, 1998	20 - 50	50 - 80		80 - 120
CP, %	18.0	15.5		13.2
NRC, 2012	25 - 50	50 - 75	75 - 100	100 - 135
CP[1)], %	15.8	13.8	12.2	10.5

[1)]Calculated from total nitrogen × 6.25.

4.1.3 Gestating Sows

Generally, sows have been selected and bred with attempting to improve total litter born which leads to higher demand of nutrients. The body reserves and accumulation during gestation are important to maintain reproductive performance, milk production and sow BW and BF. Protein supply in gestation is important for fetal growth and mammary development. Shields et al. (1980) reported that sows fed too less of protein intake had no effect on total litter born, but the ovary function, milk production and litter growth is depressed, so it was need increased protein intake of lactation to compensate for the previous gestation inadequacy. In gilts, protein losses is more difficult to recover by lactation feeding than fat due to the muscle and visceral organ. In addition, weaning to estrval interval (WEI) was increased when the sows lose more than 16% protein during lactation (Clowes et al., 2003). High level of dietary protein in gestation showed increased litter weight gain and litter weaning weight (Mahan, 1998; Kusina et al., 1999b) and increased milk production (Kusina et al., 1999b). However, high protein level in gestation diets resulted in reduction of BF (Mahan, 1998). Consequently, high protein level in gestation sow diets, has effect on better litter performance and reproductive performance.

Noblet et al. (1985) reported that the requirement of protein for reproduction increased from 7 to 41% of sow dietary protein intake in early (50 days) and late (110 days) gestation. Sows use protein largely for maintaining their body in early gestation, and in late gestation sows need a greater protein and amino acids because the mammary gland is rapidly increased and the growth of fetus (McPherson et al., 2004; Ji et al., 2006). Kim et al. (2009a) demonstrated that the protein requirement during gestation is determined by the amino acids composition in sow tissue and fetuses as well as amino acid ratio for protein deposition and maintenance. Because of these factors are changed by different periods of gestation and the protein need for maintenance and accretion is increased at late gestation. The protein requirement of gestating sows is also increased. NRC (1998) suggested one phase of CP requirement in gestating sow diets were from 12% to 12.9%. However, NRC (2012) suggested two phases (<90 days and >90 days) of dietary CP requirement in gestation are (total nitrogen × 6.25) 7.13% to 10.13% and 10.13% to 13.44%, respectively.

4.2 Effects of Dietary Crude Protein Levels in Swine Diet

4.2.1 Weaning Pigs

Generally, feeding low protein with amino acid supplemented diets may be a means of managing diarrhea in weaning pigs (Proha' szka and Baron 1980; Nyachoti et al. 2006). According to Wellock et al. (2007), Opapeju et al. (2008) and Heo et al. (2008), toxic intestinal protein fermentation products was decreased when feeding weaning pig a low protein with amino acid supplemented diets. Although previous studies have measured feeding a low CP with amino acid supplemented diet to weaning pigs showed to promote indicators of enteric health and to reduce incidences of diarrhea compared with feeding a high CP diet (Nagy and Fekete 1999; Opapeju et al. 2008; Heo et al. 2008).

Le Bellego and Noblet, (2002) showed the possibility of decreasing CP level in weaning pig diets in association with an adequate amino acid supplementation had no effect on BW gain and protein deposition, and N excretion had reduced when CP was reduced from 22.4% to 20.4%. In addition, Nyachoti et al. (2006) demonstrated that a significant reduction on the ADG and ADFI of weaning pig when received diets containing 19% or less CP. However, some experiment reported that growth performance was increased when increased CP levels in weaning pig diets (Bikker et al., 2006; Wellock et al., 2006).

4.2.2 Growing-finishing Pigs

Usually, growing-finishing pigs showed higher growth ADG, G:F ratio and carcass leanness compared when pigs fed adequate CP level in the diet (Gilster and Wahlstrom, 1973; Kornegay et al., 1973; Easter and Baker, 1980). Feeding diets with dietary CP level from 12% to 16% results a higher weight gain and G:F ratio (Cromwell et al., 1978). Cromwell et al. (1993) and Chen et al. (1995) also observed that increased by ADG and G:F ratio in response to increasing CP content. Moreover, Cromwell et al. (1978) observed that dietary CP level from 16% to 20% had no effect on growth performance. Wagner et al. (1963) reported that increasing the CP level from 13% to 25% resulted in a significant quadratic effect on ADG.

In Kerr et al. (1995) experiment showed feeding low CP diets (15-12-11 %) should supplement with lysine, tryptophan and threonine, and high CP diet (19-16-14 %) had no need to use. Generally, when growing-finishing pigs fed low CP diets without amino acids supplementation showed lower ADG and G:F ratio and developed carcasses that contained a smaller longissimus muscle, greater average backfat depths, and a lower percentage of muscle when growing-finishing pigs fed low CP diets without amino acids supplementation compared with growing-finishing pigs fed the high-CP diets (Gilster and Wahlstrom, 1973; Kornegay et al., 1973; Easter and Baker, 1980). Thus, reducing 2-3% of CP in growing-finishing pig diets with amino acids supplemented had no negative effects on ADG and G:F ratio (Cromwell, 1996; Tuitoek et al., 1997). In addition, reducing more than 3% of CP in growing−finishing pig diet showed had not reduced on ADG and G:F ratio (Hahn et al., 1995; Kerr et al., 1995). However, Hansen and Lewis, (1993) and Gomez et al., (2002b) disagree with this results.

4.2.3 Gestating Pigs

Generally, sows BW and gain were increased when increased protein intake during gestation (Kim et al., 2009a; Otten et al., 2009; Yang et al., 2009; Rehfeldt et al., 2011; Zhang et al., 2011). Rehfeldt et al. (2011) reported that the BW gain of gestating gilts was increased when dietary CP level increased (from 6.5% to 12.1%). However, BF gain was decreased when increased dietary CP diet (from 13% to 16%) in gestating sows (Mahan, 1998). Based in these results, sows fed high level of protein during gestation showed increased sow BW but decreased BF gain. However, decreased BF gain by increased dietary CP level during gestation is unclear yet.

Many of the experiments reported that dietary CP level of gestating sow was affecting the reproductive performance (Mahan, 1998; Kusina et al, 1999b; Kim et al., 2009a; Yang et al., 2009; Zhang et al., 2011). Schoknecht et al. (1993) reported that birth litter weight was decreased when sows were provided limited protein intake. Qu et al. (2009) referred to the low protein intake during gestation may raise the mobilization of fetal body protein, and the sows with restricted protein intake affect the reduction of visceral organ mass at birth. Similarly, Pond et al. (1991) observed that limited protein intake during gestation affected the reduction of body and organ weight and protein mass in fetuses at mid−gestation and newborn offspring. Also, Schoknecht et al. (1994) reported that the protein restriction at early gestation period decreased placental growth, thereby decreasing both fetal growth and the possibility of compensatory growth. However, Mahan (1998) reported that litter birth weight and total piglet born were not affected by 13% or 16% of dietary CP level. Similar results were also observed by Rehfeldt et al (2011) that total piglet born was not influenced by dietary protein level in gestating gilts. Consequently, limited dietary protein level in gestation was effect on fetal growth but no effect on total piglet born.

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Chapter Ⅲ. Effects of Dietary Energy and Crude Protein Levels on Growth Performance, Blood Profiles, Nutrient Digestibility, and Economic Analysis in Weaning Pigs

Abstract: This experiment was conducted to investigate the effect of reducing dietary metabolizable energy (ME) and crude protein (CP) levels on growth performance, blood profiles, nutrient digestibility, and economic analysis in weaning pigs. A total of 240 crossbred pigs ([Yorkshire × Landrace] × Duroc) with an average body weight (BW) of 8.67±1.13 kg were used for 6 weeks feeding trial. Experimental pigs were allotted to a 2 × 3 factorial arrangement using a randomized complete block design. The first factor was two levels of dietary ME level (3,200 or 3,300 kcal of ME/kg) and the second factor was three dietary CP levels based on subdivision of early and late weaning phases (low CP level: 19.7%/16.9%; middle CP level: 21.7%/18.9%; or high CP level: 23.7%/20.9%). Over the entire experimental period, there was no significant difference in BW among groups, but average daily feed intake (ADFI) was increased ($P=0.02$) and gain to feed ratio (G:F ratio) was decreased by decreasing ME level in diet ($P<0.01$). Decreasing CP levels in the diet, average daily gain (ADG) was increased linearly ($P<0.05$) and G:F ratio was increased quadratically ($P<0.05$). In the early weaning period, blood urea nitrogen (BUN) concentration tended to increase when dietary ME decreased but it was decreased when CP level in the diet decreased ($P=0.09$ and $P<0.01$, respectively). Total protein concentration tended to increase when CP level was reduced ($P=0.08$). In the late weaning period, BUN concentration was decreased linearly as CP level decreased ($P<0.01$). Digestibility of crude protein and crude fat was decreased when ME was decreased by 100 kcal/kg ($P=0.05$ and $P=0.01$, respectively). Crude protein digestibility increased linearly as CP level decreased ($P=0.01$). In the late weaning period and during whole experimental period, feed cost per weight gain showed increased when ME decreased by 100 kcal/kg ($P<0.01$ and $P=0.02$, respectively), and increased linearly when CP level in the diet decreased ($P<0.01$ and $P<0.01$, respectively). Total feed cost per pig (get to 25 kg) was increased when dietary ME was high with low CP level ($P<0.05$). A weaning pig diet containing high ME level (3,300 kcal/kg) and low CP level (19.7%/16.9%) can improve growth performance and nutrient digestibility of pig and reduce the cost of production.

Key words: Energy; Crude Protein; Growth Performance; Blood Profiles; Economic Analysis; Weaning Pigs

Introduction

Nutritional concentration of feed is very important in the swine industry, as it affects both growth performance and profitability. Lower nutritional concentrations can decrease the growth rate of pigs, while higher concentrations can have a negative effect on the environment and increase production costs (Jongbloed and Lenis, 1992; Paik et al., 1996; Jeong et al., 2010). After weaning, piglets experience nutritional, physiological, environmental and social stresses (Pluske, 1995), which are linked to low feed intake, poor growth, and incidence of diarrhea (Gatnau, 1999). In general, a high feed intake could increase the health of weaning pigs and improve growth performance (Makkink, 1993; McCrachen et al., 1995).

Energy concentration in feed is an important factor of feed intake, as a high energy level can decrease feed intake, while a lower energy level can decrease the deposition of protein (Lewis and Southern, 2001). Deposition and intake of protein and amino acids is related to energy concentration (NRC, 1998). However, the optimal energy requirements of weaning pigs are difficult to determine accurately (Beaulieu et al., 2009), because different ADFI and weaning stress. Metabolizable energy (ME) requirements in editions of NRC differ, with an increased in ME from 1998 to 2012 (NRC, 1998; NRC, 2012). However, other studies were reported that ME levels in diets did not affect growth performance in weaning pigs (Ribeiro et al., 2016; Lee at al., 2017). In general, fat and oil are important energy sources in pig diets (Bajao and Lara, 2005), but weaning pigs do not utilize fat and oil very efficiently (Lewis and Southern, 2001).

In addition, recommended total N levels have decreased largely over the years in editions of NRC (NRC, 1998; NRC, 2012). However, other studies reported that the pigs fed low crude protein (CP) diet, showed better fecal score, improved enteric health and growth performance (Opapeju et al., 2009; Opapeju et al., 2015; Wu et al., 2015; Wen et al., 2018). Decreasing the protein level in feed can decrease the risk of post-weaning diarrhea, as undigested proteins can be utilized by pathogenic bacteria such as enterotoxigenic *Escherichia coli* (Wellock et al., 2008). Moreover, Jensen et al. (1997) reported that from birth to 56 days, the digestive enzymes of piglets have low activity for digestion of energy and protein. That means there is much more surplus protein and energy in diets for piglets than requirement. Other study reported that digestibility of CP at the terminal ileum was from 60% to 80% in weaning pigs (Högberg et al., 2004). Hence, optimizing energy and protein levels in the weaning pig diet is therefore important.

The current experiment was conducted to investigate the effect of reducing dietary ME and CP levels on growth performance, blood profiles, and nutrient digestibility in weaning pigs.

Materials and Methods

Experimental Animals and Management

A total of 240 crossbred pigs ([Yorkshire × Landrace] × Duroc) with an average body weight (BW) of 8.67±1.13 kg were used for a 6-week feeding trial. Pigs were reared at Seoul National University experimental farm. Weaning pigs were allotted to one of six treatments with five replications with 8 pigs per pan. Four male pigs and four female pigs were assigned to each pen of a weaning facility based on BW. Pigs were randomly allotted to their respective treatments by an EAAP (experimental animal allotment program; Kim and Lindemann, 2007). Pigs were reared in weaning (1.54 × 1.96 m) facilities for 6 weeks. Feed and water were provided ad libitum during the entie experimental period by a 4 hole stainless feeder and two nipples installed in each pen. Body weight and feed intake were recorded at 0, 3, and 6 weeks to calculate average daily gain (ADG), average daily feed intake (ADFI), and gain to feed ratio (G:F ratio). Experimental diets were formulated for two phases, namely early weaning phase (0-3 weeks) and late weaning phase (4-6 weeks).

Experimental Design and Diet

Experimental pigs were allotted to a 2 × 3 factorial arrangement using a randomized complete block design. The first factor was two levels of dietary ME (3,200 kcal of ME/kg or 3,300 kcal of ME/kg) and the second factor was three dietary CP levels based on subdivision of early and late weaning phases (low

CP level: 19.7%/16.9%; middle CP level: 21.7%/18.9%; or high CP level: 23.7%/20.9%). This corresponded to early weaning phase CP of 23.7%, 21.7%, and 19.7%; and late weaning phase of 20.9%, 18.9%, and 16.9%.

All nutrients in the experimental diets except ME and CP met or exceeded the NRC (1998) nutrient requirements. Formulae and chemical compositions of the experimental diet are in Tables 1 and 2.

Blood Analysis

Blood samples were taken from the jugular vein of six randomly selected pigs in each treatment when body weights were recorded to measure blood urea nitrogen (BUN), glucose, albumin, and total protein after three hours fasting. All blood samples were collected in serum tubes (SST™ Ⅱ Advance, BD Vacutainer®, Becton Dickinson, Plymouth, UK). Collected blood samples were centrifuged for 15 min at 3,000 rpm at 4 ℃ (5810R, Eppendorf, Hamburg, Germany). Serum was carefully transferred to 1.5 ml plastic tubes and stored at -20℃ until analysis. Total BUN (kinetic UV assay, Roche, Germany), albumin (Cobas 8000, Roche, Germany) and glucose (enzymatic kinetic assay, Roche, Germany) concentrations were analyzed using a blood analyzer. Total protein concentration was measured by a kinetic colorimetry assay using a blood analyzer (Modular Analytics, PE, Roche, Germany).

Digestibility Trial

A digestibility trial was conducted using a completely randomized design with three replicates. A total of 18 weaning barrows ([Yorkshire × Landrace] × Duroc) with an average BW of 13.94 ± 1.64 kg were individually allotted to an individual metabolic crate (0.4 × 0.8 × 0.9 m). A 5 day adaptation period was followed by 5 days of data collection.

The daily feed allowance required to provide 2.6 times the maintenance requirements for ME (106kcal of ME/kg of $BW^{0.75}$) was calculated (NRC, 1998; Kiarie et al., 2007). Experimental diets were provided during the late weaning phase at 07:00 and 19:00. At the first and last feeding, 1% ferric oxide and chromium oxide were added to the experimental diet. Water was provided ad libitum. Excreta and urine were collected daily and preserved at -20 ℃ until later analysis. When collection was finished, the excreta were dried in an air-forced drying oven at 60℃ for 96 h, and ground into 5mm particles in a Wiley mill for chemical analysis.

Economic Analysis

All of the experimental pigs were lived in the same environmental condition, economic efficiency was only thought about the feed cost. The feed cost (won) per body weight gain (kg) was calculated using total feed intake and feed price per kilogram.

The days to piglet weight get to 25kg was estimated from the body weight at the end of feeding trial at 6 weeks from beginning of experiment.

Statistical Analysis

All collected data were analyzed using least squares mean comparisons and evaluated using the general linear model (GLM) procedure implemented in the statistical software package SAS (SAS Institute Inc., Cary, NC, USA). Every pen was considered one unit in the feeding trial and economic analysis, and individual pigs were the experimental units in the digestibility trial and when assessing blood profiles. Orthogonal polynomial contrasts were used to detect linear and quadratic responses to CP levels when the significance of CP was evaluated. Differences were declared significant at $P<0.05$ or highly significant at $P<0.01$, while $P\geq0.05$ and $P<0.10$ was considered to indicate a trend in the data.

Results and Discussion

Growth Performance

The effect of dietary energy and CP levels on growth performance are presented in Table 3. In the early weaning period, ADG (linear, $P<0.01$) and ADFI (linear, $P<0.05$) increased when diet CP level decreased, and ADFI increased when dietary ME decreased ($P=0.04$). In the late weaning period, ADFI ($P=0.03$) increased and the G:F ratio ($P<0.01$) decreased when ME level was decreased by 100 kcal/kg. There were no significant differences in BW over the experimental period, but decreased ME levels were associated with an increase in ADFI ($P=0.02$) and a decrease in G:F ratio ($P<0.01$). A decrease in CP level resulted in a linear increase in ADG ($P<0.05$) and a quadratic increase in G:F ratio ($P<0.05$). Therefore, decreasing the ME level by 100 kcal/kg did not affect growth performance, and reducing the CP level by 4% improved ADG and the G:F ratio.

The effect of dietary energy density on weaning pig performance is a topic of debate among researchers. Decreasing dietary energy levels could decrease weight gain (Hastad et al., 2001a). However, some studies have reported that decreasing dietary energy concentration had no effect on growth (Tokach et al., 1995; Hastad et al., 2001b). Ribeiro et al. (2016) found that reducing dietary ME from 3,700 kcal/kg to 3,250 kcal/kg had no influence on growth performance. Beaulieu et al. (2006) reported that decreasing the digestible energy concentration from 3,650 kcal/kg to 3,350 kcal/kg in the weaning pig diet increased BW, ADG, and ADFI linearly, while the G:F ratio decreased linearly.

In this study, reducing the soybean meal (SBM) level to decrease CP level improved growth performance over the whole experiment period. A similar result for ADG and G:F ratio was reported by Li et al. (1991a, b). Le Bellego and Noblet (2002) described a reduction in N excretion and an increase in feed intake when CP level was reduced from 22.4% to 20.4%. In other studies, a lower CP level had no negative effects on growth performance (Nyachoti et al., 2006; Hermes et al., 2009). Hermes et al. (2009) reported that decreasing the CP level from 20% to 16% in the weaning pig (9−18 kg) diet had no effect on growth performance after weaning for 3 weeks. Nyachoti et al. (2006) reported ADG and ADFI were reduced when dietary CP level decreased (from 19% to 17%).

Blood Profiles

Blood profiles during the feeding trial are presented in Table 4. Blood urea nitrogen (BUN) concentration during the early weaning period, tended to increase when ME decreased and decrease when CP decreased ($P=0.09$, and $P<0.01$, respectively). Total protein concentration tended to increase when CP levels decreased in early weaning phase ($P=0.08$). In the late weaning period, BUN concentration decreased linearly as CP level decreased ($P<0.01$).

Blood urea nitrogen concentration is an indicator of protein utilization and affects amino acid balance and N−intake (Eggum, 1970; Whang and Easter, 2000). Increased energy intake in pig diet showed increase protein deposition (Fuller et al., 1977). This explains why in this study, BUN concentration increased when dietary ME level decreased. BUN concentration decreased when CP level decreased, because of optimal amino acid balance and less N-intake. Other studies reported consistent results with this study, BUN and plasma urea nitrogen concentration decreased when CP level in the weaning pig diet was reduced (Jeaurond et al., 2008; Heo et al., 2009).

Blood total protein level was increased when pig protein utilization increased (Matthews et al., 1998). In this study, total protein concentration tended to increase when CP levels decreased in early weaning phase. Also, ADG was increased when dietary CP level deceased. Results in this experiment indicate that a CP level of 19.7% in the early weaning pig diet is an optimal CP level.

Nutrient Digestibility

Differences in dietary energy and CP levels in the weaning pig diet resulted in significant difference in fat and protein digestibility (Table 5). Crude protein and crude fat (P=0.05, and P=0.01, respectively) digestibility were decreased when the ME was decreased by 100 kcal/kg. Crude protein digestibility increased in a linear manner when the CP level in the diet decreased (P=0.01).

This experiment decreased dietary ME concentration by reducing the soy oil content of the feed. Consequently, crude fat digestibility decreased by 3-4% when ME in the diet was reduced to 100 kcal/kg. Energy digestibility are affected by the type and proportion of ingredients as well as energy source in the diet (Beaulieu et al., 2006). Fat digestibility in this experiment was agreement with those of Tokach et al. (1995)

and Beaulieu et al. (2006).

Energy intake is known to influence protein deposition (Whittemore and Fawcett, 1976). Lawrence et al. (1994) and Beaulieu et al. (2006) reported that the amount of energy in the feed could change N-retention to increase protein digestibility. The results in this study are similar to those of van Lunen and Cole (1998) that decreasing energy density could reduce protein and lipid gain.

The main determinants of protein digestibility are the level and balance of essential amino acids (Jin et al., 2013). In this study, lysine%, methionine% and threonine% were the same for different CP treatments. In other words, although CP levels in the diet were reduced, but the limiting amino acids content was not. In this study, CP digestibility increased when dietary CP levels were decreased. Reducing the CP level without changing the level of essential amino acids can result in a better protein digestibility than a high CP level.

Economic Analysis

The effects of dietary ME and CP levels on feed cost per weight gain were presented in Table 6. There was no significant response to production cost per kg during early weaning period. However, In late weaning period and during whole experiment period, feed cost per weight gain showed increased by ME decreased ($P<0.01$, and $P=0.02$, respectively) and linear decreased by CP level ($P<0.05$, and $P<0.05$, respectively). Total feed cost per pig (get to 25 kg) was increased when dietary ME decreased ($P=0.02$), and CP level decreased linearly ($P<0.05$). Therefore, high ME and low CP diets showed the least cost of production.

Conclusion

Decreasing the energy content of the weaning pig diet by 100 kcal/kg (3,300 kcal/kg to 3,200 kcal/kg), had no effects on growth performance, but decreased fat and protein digestibility and cost of production. In addition, reducing CP level by 4% increased growth performance and the digestibility of protein, and decreased the BUN level and cost of production.

A weaning pig diet containing high ME level (3,300 kcal/kg) and low CP level (early weaning phase: 19.7% and late weaning phase: 16.9%) can improve pig growth performance and nutrient digestibility, and reduce the cost of production.

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Table 1. Formulae and chemical compositions of the diets of early weaning pigs (0−3 weeks).

Energy[1]	Low			High		
CP, %[2]	Low	Middle	High	Low	Middle	High
Ingredient, %						
Corn	24.80	20.17	15.61	22.74	18.02	13.29
Soybean meal	21.82	27.36	32.84	22.37	27.82	33.27
Barley	33.48	32.76	31.96	32.88	32.27	31.67
Whey powder	8.00	8.00	8.00	8.00	8.00	8.00
Lactose	4.00	4.00	4.00	4.00	4.00	4.00
Soypeptide	4.54	4.74	5.00	4.46	4.72	5.00
Soy−oil	0.00	0.00	0.00	2.18	2.18	2.18
Mono−dicalcium phosphate	1.25	1.14	1.05	1.27	1.17	1.07
Limestone	0.93	0.95	0.97	0.92	0.94	0.96
L−Lysine−HCl, 78%	0.39	0.20	0.01	0.39	0.20	0.00
DL−Methionine, 80%	0.07	0.04	0.01	0.07	0.04	0.01
L−Threonine, 99%	0.17	0.09	0.00	0.17	0.09	0.00
Vit. Mix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[4]	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30
ZnO	0.05	0.05	0.05	0.05	0.05	0.05
Total	100.00	100.00	100.00	100.00	100.00	100.00
Chemical composition (calculated value)						
Metabolizable energy (kcal/kg)	3,200.00	3,200.00	3,200.01	3,300.00	3,300.00	3,300.01
Crude protein (%)	19.70	21.70	23.70	19.70	21.70	23.70
Total lysine (%)	1.35	1.35	1.35	1.35	1.35	1.35
Total methionine (%)	0.35	0.35	0.35	0.35	0.35	0.35
Total threonine (%)	0.89	0.89	0.89	0.89	0.89	0.89
Calcium (%)	0.80	0.80	0.80	0.80	0.80	0.80
Total phosphorus (%)	0.65	0.65	0.65	0.65	0.65	0.65
Chemical composition (analyzed value)						
Crude protein (%)	20.46	21.76	23.85	19.39	21.24	22.77
Crude fat (%)	1.26	1.71	1.96	3.92	3.96	3.37
Crude ash (%)	6.41	6.31	6.17	6.23	6.48	6.77

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early weaning phase of 19.7% and late weaning phase of 16.9%; middle CP level: early weaning phase of 21.7%, and late weaning phase of 18.9%; high CP level: early weaning phase of 23.7%, and late weaning phase of 20.9%.
3) Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D3, 1,800 IU; vitamin E, 60 IU; vitamin K3, 2 mg; thiamine (vitamin B1), 2.00 mg; riboflavin (vitamin B2), 7.0 mg; pantothenic acid (vitamin B5), 25 mg; niacin (vitamin B3), 27 mg; pyridoxine (vitamin B6), 3 mg; d−biotin, 0.2 mg; folic acid, 1 mg; vitamin B12, 0.03 mg.
4) Provided per kg of diet. Minerals per kg of complete diet: Se, 0.3 mg; I, 1 mg; Mn, 51.6 mg; Cu, 105 mg; Fe, 150 mg; Zn, 72 mg; Co, 0.5 mg.

Table 2. Formulae and chemical compositions of the diets of late weaning pigs (4−6 weeks).

Energy[1]	Low			High		
CP, %[2]	Low	Middle	High	Low	Middle	High
Ingredient, %						
Corn	43.00	38.28	33.49	40.91	36.07	31.19
Soybean meal	21.09	25.48	29.86	21.66	25.94	30.22
Barley	25.65	25.50	25.44	25.04	25.10	25.17
Whey powder	3.00	3.00	3.00	3.00	3.00	3.00
Lactose	3.00	3.00	3.00	3.00	3.00	3.00
Soypeptide	0.81	1.81	2.81	0.75	1.80	2.83
Soy−oil	0.26	0.13	0.00	2.45	2.30	2.17
Mono−dicalcium phosphate	1.22	1.12	1.02	1.25	1.13	1.03
Limestone	0.82	0.84	0.85	0.81	0.83	0.85
L−Lysine−HCl, 78%	0.38	0.19	0.00	0.37	0.18	0.00
DL−Methionine, 80%	0.07	0.04	0.00	0.06	0.04	0.01
L−Threonine, 99%	0.17	0.08	0.00	0.17	0.08	0.00
Vit. Mix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[4]	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30
ZnO	0.03	0.03	0.03	0.03	0.03	0.03
Total	100.00	100.00	100.00	100.00	100.00	100.00
Chemical composition (calculated value)						
metabolizable energy (kcal/kg)	3,200.00	3,200.01	3,200.00	3,300.00	3,300.00	3,300.01
Crude protein (%)	16.90	18.90	20.90	16.90	18.90	20.90
Total lysine (%)	1.15	1.15	1.15	1.15	1.15	1.15
Total methionine (%)	0.31	0.31	0.31	0.30	0.31	0.31
Total threonine (%)	0.80	0.80	0.80	0.80	0.80	0.80
Calcium (%)	0.70	0.70	0.70	0.70	0.70	0.70
Total phosphorus (%)	0.60	0.60	0.60	0.60	0.60	0.60
Chemical composition (analyzed value)						
Crude protein (%)	18.64	19.65	22.63	18.26	18.61	20.47
Crude fat (%)	1.95	1.56	1.63	4.26	5.34	4.04
Crude ash (%)	4.91	5.23	5.67	5.01	5.86	5.84

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early weaning phase of 19.7% and late weaning phase of 16.9%; middle CP level: early weaning phase of 21.7%, and late weaning phase of 18.9%; high CP level: early weaning phase of 23.7%, and late weaning phase of 20.9%.
3) Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D3, 1,800 IU; vitamin E, 60 IU; vitamin K3, 2 mg; thiamine (vitamin B1), 2.00 mg; riboflavin (vitamin B2), 7.0 mg; pantothenic acid (vitamin B5), 25 mg; niacin (vitamin B3), 27 mg; pyridoxine (vitamin B6), 3 mg; d−biotin, 0.2 mg; folic acid, 1 mg; vitamin B12, 0.03 mg.
4) Provided per kg of diet. Minerals per kg of complete diet: Se, 0.3 mg; I, 1 mg; Mn, 51.6 mg; Cu, 105 mg; Fe, 150 mg; Zn, 72 mg; Co, 0.5 mg.

Table 3. Effect of dietary energy and crude protein levels on growth performance in weaning pigs.

Energy[1]	Low			High			SEM[3]	P−value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
Body weight, kg										
Initial	8.66	8.66	8.67	8.67	8.67	8.67	0.206	0.99	1.00	1.00
3 wk	13.59	12.23	12.88	13.33	12.23	12.34	0.280	0.65	0.22	0.93
6 wk	24.28	22.24	23.45	24.52	22.54	22.94	0.406	0.99	0.16	0.90
ADG, g										
0−3 wks[L]	234[a]	170[c]	201[b]	222[a]	170[c]	175[c]	7.6	0.33	<0.01	0.72
4−6 wks	509	477	505	536	491	505	7.8	0.41	0.17	0.84
0−6 wks[L]	372	323	352	377	330	340	6.5	0.99	0.01	0.76
ADFI, g										
0−3 wks[L]	433[a]	362[b]	388[b]	391[b]	335[c]	325[c]	10.6	0.04	0.01	0.84
4−6 wks	986	970	1,030	924	925	915	16.7	0.03	0.82	0.66
0−6 wks	709	666	704	658	630	620	11.9	0.02	0.44	0.67
G:F ratio										
0−3 wks	0.542	0.462	0.528	0.568	0.508	0.548	0.0148	0.31	0.15	0.93
4−6 wks	0.518[ab]	0.498[b]	0.490[b]	0.576[a]	0.532[ab]	0.554[a]	0.0084	<0.01	0.17	0.65
0−6 wks[Q]	0.524[b]	0.488[c]	0.502[bc]	0.575[a]	0.526[b]	0.549[ab]	0.0080	<0.01	0.04	0.91

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early weaning phase of 19.7% and late weaning phase of 16.9%; middle CP level: early weaning phase of 21.7%, and late weaning phase of 18.9%; high CP level: early weaning phase of 23.7%, and late weaning phase of 20.9%.
3)Standard error of the mean
abc Means with different superscripts in the same row differ significantly (P<0.05)
L Linear response (P<0.05) to dietary CP levels when a significant CP effect was detected.
Q Quadratic response (P<0.05) to dietary CP levels when a significant CP effect was detected.

Table 4. Effect of dietary energy and crude protein levels on blood profiles in weaning pigs.

Energy[1]	Low			High			SEM[3]	P−valve		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
Albumin, g/dL										
Initial			4.00				−	−	−	−
3 wk	3.04	3.18	3.00	3.02	3.10	3.02	0.054	0.82	0.63	0.94
6 wk	3.14[b]	3.00[b]	3.42[a]	3.04[b]	3.26[ab]	2.58[c]	0.096	0.12	0.94	0.01
BUN, mg/dL										
Initial			8.80				−	−	−	−
3 wk[L]	11.00[c]	13.78[b]	15.42[a]	6.64[d]	13.70[b]	13.58[b]	0.758	0.09	<.01	0.35
6 wk[L]	7.70[c]	10.66[b]	15.32[a]	5.92[d]	9.70[b]	13.50[ab]	0.744	0.13	<.01	0.92
Glucose, mg/dL										
Initial			120.20				−	−	−	−
3 wk	92.00	97.60	87.00	95.40	92.00	93.40	2.014	0.74	0.65	0.49
6 wk	99.20	94.40	100.80	97.20	104.40	94.60	1.700	0.86	0.92	0.16
Total protein, g/dL										
Initial			5.31				−	−	−	−
3 wk	5.18	5.16	4.90	5.08	5.18	4.62	0.076	0.21	0.08	0.60
6 wk	5.64	5.46	5.94	5.46	5.52	5.46	0.065	0.12	0.38	0.23

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early weaning phase of 19.7% and late weaning phase of 16.9%; middle CP level: early weaning phase of 21.7%, and late weaning phase of 18.9%; high CP level: early weaning phase of 23.7%, and late weaning phase of 20.9%.
3) Standard error of the mean
abcd Means with different superscripts in the same row differ significantly (P<0.05)
L Linear response (P<0.05) to dietary CP levels when a significant CP effect was detected.

Table 5. Effects of dietary energy and crude protein levels on nutrient digestibility in weaning pig.

Energy[1]	Low			High			SEM[3]	P-valve		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
Nutrient digestibility, %										
Dry matter	88.01	87.87	88.24	89.12	88.66	88.51	0.727	0.88	0.81	0.91
Crude protein[L]	87.81[ab]	85.07[b]	84.24[b]	89.41[a]	85.21[b]	85.11[b]	1.459	0.05	0.01	0.21
Crude ash	71.19	72.31	71.21	70.90	71.64	73.14	0.773	0.21	0.27	0.31
Crude fat	74.51[b]	73.41[b]	72.87[b]	78.74[a]	76.15[ab]	75.71[ab]	1.181	0.01	0.18	0.87

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early weaning phase of 19.7% and late weaning phase of 16.9%; middle CP level: early weaning phase of 21.7%, and late weaning phase of 18.9%; high CP level: early weaning phase of 23.7%, and late weaning phase of 20.9%.
3)Standard error of the mean
ab Means with different superscripts in the same row differ significantly (P<0.05)
L Linear response (P<0.05) to dietary CP levels when significance of CP effect was detected.

Table 6. Effect of dietary energy and crude protein levels on economic analysis in weaning pigs.

Energy[1]	Low			High			SEM[3]	P-value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
Feed cost per weight gain, won/kg										
0-3 wks	983[bc]	1,207[a]	1,012[b]	937[c]	1,066[b]	1,035[b]	34.8	0.43	0.12	0.62
4-6 wks[L]	826[b]	895[a]	925[a]	756[c]	846[b]	840[b]	14.7	<.01	<.01	0.82
0-6 wks[L]	866[bc]	963[a]	950[a]	807[c]	902[b]	887[bc]	14.9	0.02	<.01	0.99
Total feed cost per pig (get to 25kg), won/head[L]										
	14,140[bc]	15,412[a]	15,460[a]	13,185[c]	14,547[b]	14,140[bc]	246.7	0.02	0.04	0.90

[1)] Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
[2)] Low CP level: early weaning phase of 19.7% and late weaning phase of 16.9%; middle CP level: early weaning phase of 21.7%, and late weaning phase of 18.9%; high CP level: early weaning phase of 23.7%, and late weaning phase of 20.9%.
[3)]Standard error of the mean
[abc] Means with different superscripts in the same row differ significantly (P<0.05)
[L] Linear response (P<0.05) to dietary CP levels when a significant CP effect was detected.

Chapter Ⅳ. Effects of Dietary Energy and Crude Protein Levels on Growth Performance, Blood Profiles, Carcass Traits, and Economic Analysis in Growing-finishing Pigs

Abstract : This experiment was conducted to determine the effect of dietary energy and crude protein levels on growth performance, blood profiles, carcass traits, and economic analysis in growing-finishing pigs. A total of 180 crossbred pigs ([Yorkshire × Landrace] × Duroc) with an average body weight of 30.96±3.07 kg were used for a 12-week feeding trial. Experimental pigs were allotted to a 2 × 3 factorial arrangement using a randomized complete block design. The first factor was two levels of dietary metabolizable energy (ME) level (3,200 or 3,300 kcal/kg), and the second factor was three dietary crude protein (CP) levels based on subdivision of growing-finishing phases (low CP level: 16%/14.3%/14.3%/11.2; middle CP level: 17.0%/15.3%/15.3%12.2% or high CP level: 18.0%/16.3%/16.3%/13.2%). Average daily gain and G:F ratio were decreased linearly as dietary CP level decreased (linear, P=0.04 and P=0.03, respectively) in the early growing phase and G:F ratio was decreased linearly as dietary CP levels decreased (P=0.02) over the whole growing phase. Over the entire experimental phase, G:F ratio was decreased as dietary ME level decreased (P=0.01). There were no significant differences in glucose and total protein concentration in the blood when pigs were fed different dietary ME and CP levels during the growing period, but blood urea nitrogen (BUN) concentration increased when dietary ME decreased (P<0.01). There were no significant differences in glucose or BUN concentration in the blood when different dietary ME and CP were provided during the finishing period, but total protein concentration was decreased as dietary ME decreased (P=0.04). In this study, there were no significant differences in proximate analysis, physiochemical properties, muscle TBARS assay, pH changes or colors of longissimus muscles. However, saturated fatty acid (SFA) was increased (P<0.01) and polyunsaturated fatty acid (PUFA) was decreased (P=0.03) when ME decreased by 100 kcal/kg in growing-finishing pig diets. In addition, monounsaturated fatty acid (MUFA) tented to increase when CP level was decreased in growing-finishing pig diets (P=0.06). On economic analysis, there were no significant difference in total growing days from 30kg to 115kg and feed cost per weight gain of pig, but in total feed cost per pig and total feed cost per weight gain tended to increase when ME level in growing-finishing pig diet decreased (P=0.08 and P=0.07, respectively). A growing-finishing diet of high energy diet with the high level of CP can improve growth performance, pork quality, and reduce the cost of production.

Key words: Energy; Crude Protein; Growth Performance; Blood Profiles; Economic Analysis; Growing-finishing Pigs

Introduction

Supplying adequate nutrients has been noted as the most important factor in animal production in the swine industry. Several studies have reported that insufficient nutrients can limit the growth potential of animal, while excessive nutrients can increase economic profitability but cause environmental pollution (Jongbloed and Lenis, 1992; Paik et al., 1996; Jeong et al., 2010).

Insufficient nutrients or excessive nutrients may reduce growth production in swine (Buttery and Boorman, 1976; Noblet et al., 1987; Le Bellego et al., 2001; Kerr et al., 2003). Energy intake may effect the expression of high lean tissue growth potentials for much of growing-finishing period (Rao and McCracken, 1991; de Greef, 1992; Bikker, 1994). Moreover, pigs fed a low-energy diet, could decrease total energy intake and growth performance (Chadd and Cole, 1999; Smith et al., 1999; De la Llata et al., 2001). In addition, use of low-CP diets can reduce feed costs, N excretion, and plasma urea N in swine (Lopez et al., 1994; Kerr and Easter, 1995), while excessive intake of CP increased N excretion (Buttery and Boorman, 1976; Noblet et al., 1987; Le Bellego et al., 2001).

On the other hand, Nieto et al. (2012) reported that growth was based on the deposition of proteins and lipids in birth to finishing pigs. Whittemore (1993) showed that the pigs had the highest weight gain in growing period, and fat deposition was greater than protein deposition in the finishing period. The most important factor to maximize muscle development in growing pigs is to provide optimal protein and amino acid levels (Schinckel and de Lange, 1996). However, finishing feeds need to be formulated keeping fat deposition in mind, as this can affect carcass fatness and pork quality (Apple et al., 2004). Therefore, dietary energy and CP levels play a major role on growth performance in growing–finishing pig diets.

Ad libitum feeding is practiced in much of the world; thus, under commercial circumstances, dietary energy and CP concentration, is under producer control. So, this study was conducted to evaluate the effects of subdivision of the growing–finishing phases with different dietary energy and CP levels on growth performance, blood profiles, carcass traits and economic analysis.

Materials and Methods

Experimental Animals and Management

A total of 180 crossbred pigs ([Yorkshire × Landrace] × Duroc) with an average body weight (BW) of 30.96±3.07 kg were used for a 12-week feeding trial. Pigs were reared at the Seoul National University experimental farm. Three male pigs and three female pigs were assigned to each pen of a growing facility based on BW, and pigs in each pen were maintained until the end of experiment. Pigs were randomly allotted to their respective treatments by an experimental animal allotment program (Kim and Lindemann, 2007). Pigs were reared in growing-finishing (2.60 × 2.84 m) facilities for 12 weeks. Feed and water were provided ad libitum during the entire experimental period by a 6-hole stainless feeder and two nipples installed in each pen.

Experimental Design and Diet

Experimental pigs were allotted to a 2 × 3 factorial arrangement in randomized complete block design. The first factor was two levels of dietary metabolizable energy (ME) density (ME level: 3,200 kcal/kg or 3,300 kcal/kg), and the second factor was three dietary crude protein (CP) levels based on subdivision of growing-finishing phases (low CP level: 16%/14.3%/14.3%/11.2; middle CP level: 17.0%/15.3%/15.3%12.2% or high CP level: 18.0%/16.3%/16.3%/13.2%).

Experimental diets were formulated for four phases: the early growing phase (0-3 weeks), the late growing phase (4-6 weeks), the early finishing phase (7-9 weeks), and the late finishing phase (10−12 weeks). All nutrients in the experimental diets except ME and CP were met or exceeded the nutrient requirements of the NRC (1998). Formulae and chemical compositions of the experimental diets are provided in Tables 1, 2, 3, and 4.

Growth performance

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

Blood Profiles

Blood samples were taken from the jugular vein of six randomly selected pigs in each treatment to measure blood urea nitrogen (BUN), glucose, and total protein when BW was recorded in late growing and late finishing period. All blood samples were collected in serum tubes (SST^{TM} II Advance, BD Vacutainer®, Becton Dickinson, Plymouth, UK). Collected blood samples were centrifuged for 15 min at 3,000 rpm at 4℃ (5810R, Eppendorf, Hamburg, Germany). Serum was carefully transferred to 1.5 ml plastic tubes and stored at −20℃ until analysis. BUN (kinetic UV assay, Roche, Germany) and glucose (enzymatic kinetic assay, Roche, Germany) concentration were analyzed using a blood analyzer. Total protein concentration was measured by a kinetic colorimetry assay using a blood analyzer (Modular analytics, PE, Roche, Germany).

Carcass Traits

At the end of experiment, four pigs from each treatment group were selected and slaughtered for carcass analysis. Pork samples were collected nearby the 10th rib on the right side of the carcass. After chilling, 30 minutes after slaughter was regarded as the initial time. The pH was measured at 0, 3, 6, 12, and 24 hour and the color of the longissimus muscle was measured at the initial time and 24 hours later. The pH was measured using a pH meter (Model 720, Thermo Orion, Fullerton, CA, USA) and pork color was measured by CIE color L*, a*, and b* values using a CR300 (Minolta Camera Co., Osaka, Japan). Chemical analysis of pork samples was conducted using the AOAC method (AOAC, 1995).

Water holding capacity of pork was measured by the centrifuge method. Longissimus muscles were ground and sampled in a filter tube, the heated in water bath at 80 ℃ for 20 min and centrifuged for 10 min at 2,000 rpm at 10 ℃ (5810R, Eppendorf, Hamburg, Germany). To calculate cooking loss, longissimus muscles were packed in a polyethylene bag that was then heated in a water bath until the core temperature reached 72℃ and weighed before and after cooking. After heating, samples were cored (0.5 inch in diameter) parallel to the muscle fiber and the cores were used to measure shear force using a salter (Warner Barzler Shear, Norwood, MA, USA). Cooking loss, shear force and water holding capacity of pork were analyzed by the Animal Origin Food Science laboratory, Seoul National University.

Lipids in pork samples were extracted from duplicate 10 g samples with chloroform: methanol (2.1, v/v) (Folch et al., 1957) on a shaking incubator (25℃, 120 rpm) for 24 hours. Extracted lipids were filtered with filter paper (Whatman TM No.4, Buckinghamshire, UK). Twenty five milliliters of 0.88% NaCl was added to the filtered sample, which was then centrifuged at 2,090×g for 10 min (Continent 512R, Hanil Co., Ltd., Incheon, Korea). The supernatant was separated and pork lipids were concentrated using N_2 gas at 45℃. After concentrating the lipids, 0.1 g of lipids was transferred to a 15 mL tube with 1 mL of internal standard (1 mg of undecanoic acid in 1 mL of iso-octane) and 1.5 mL of 0.5 N methanolic NaOH. Samples were heated in a water bath at 85℃ for 10 min and cooled to room temperature. After cooling, 2 mL of 14% BF3-methanol was added and then the heating process was repeated one more time. Then, 2 mL of iso-octane and 1 mL saturated NaCl were added, and the sample was centrifuged at 2500 rpm for 3 min (Continent 512R, Hanil Co., Ltd., Incheon, Korea). Upper layer containing fatty acid methyl esters (FAMEs) was dehydrated with anhydrous sodium sulfate and transferred to a vial. The sample in the vial was analyzed using a gas chromatograph (HP 7890, Agilent Technologies, Santa Clara, CA, USA) with a split ratio of 50:1. A capillary column (DB-23, 60 m × 250 μm × 0.25 μm, Agilent, Santa Clara, CA, USA) was used. The injector and detector temperatures were maintained at 250C and 280C, respectively. Column oven temperature was varied as follows: 50℃ for 1 min, increased to 130℃ at 25℃/min, 170℃ at 8℃/min, then held at 215℃ after increasing to this temperature at 1.5℃/min. Nitrogen was used as a carrier gas at linear flow of 4 mL/min. Individual FAMEs were identified by comparison of relative retention times of peaks from samples, with those of external standards (37 FAME mix and CLA mix, Supelco, Bellefonte, PA, USA) calculated based on the Korean Food Standards Codex (MFDS, 2017).

Economic Analysis

All of the experimental pigs were lived in the same environmental condition, economical efficiency was only thought about the feed cost. The feed cost (won) per BW gain (kg) was calculated using total feed intake and feed price. The days to reach market weight (115kg) were estimated from the body weight at the end of feeding trial and ADG of 12 weeks.

Statistical Analysis

Data for the various groups were compared by least squares mean comparisons and evaluated using general linear models (GLMs) in SAS (SAS Institute Inc., Cary, NC, USA). Every pen was used as the one unit in feeding trial and economic analysis, and individual pigs were considered experimental units with regard to analysis of blood profiles and carcass analysis. Orthogonal polynomial contrasts were used to detect linear and quadratic responses to CP levels when the significance of the CP effect was evaluated. The treatment effect was considered to be significant if $P<0.05$, while $P\geq0.05$ and $P<0.10$ was considered to indicated a trend in the treatment effect.

Results and Discussion

Growth Performance

The effect of dietary energy and CP levels on growth performance are presented in Table 5. Average daily gain and G:F ratio decreased linearly as dietary CP level decreased (linear, P<0.05, and P<0.05, respectively) in the early growing phase, and G:F ratio decreased linearly as dietary CP levels decreased (P<0.05) over the entire growing phase. Dietary CP and amino acid levels affect protein deposition (Schinckel and de Lange, 1996; Jin et al., 1998). Several studies have demonstrated that ADG and G:F ratio decrease as CP level in the growing phase (Kerr et al., 2003). In this study, dietary energy density did not have any significant effect on growth performance during the growing period, which consistent with the study of Kil et al. (2013).

Dietary energy and protein levels did not differ significantly among groups in the finishing period. Similar to our findings, Kerr et al. (2003) reported that a 100 kcal decrease in NE/kg and 4% CP decreased in 88.3 kg−109.7 kg pigs did not significantly affect growth performance. Kil et al. (2013) reported that a 300 kcal/kg decreased in ME in the finishing pig diet had no effect on growth performance.

However, G:F ratio decreased when dietary ME level was decreased (P=0.01) during whole experimental period. Futhermore, BW and ADG showed significant differences over the course of the experiment (P<0.05), and high level ME and the high CP level resulted in the highest BW and ADG among the six treatments.

Blood Profiles

The effects of dietary energy and CP levels on blood profiles are presented in Table 6. There were no significant difference in glucose and total protein concentrations when pigs were fed different dietary ME and CP levels during the late growing period, but BUN concentration was increased with a decrease in dietary ME ($P<0.01$). In the late finishing period, total protein concentration decreased when pigs were fed lower dietary ME concentrations ($P=0.04$).

Ammonia is a by-product of the metabolism of protein and the liver produces urea as a waste product of protein digestion. Urea nitrogen is a waste product that is released by the liver and then filtered out of the blood by the kidneys (Bergner, 1977; Hahn et al., 1995). Therefore, BUN is used as a standard index for evaluating protein quality or excessive protein intake (Hatori et al., 1994; Cai et al., 1996; Coma et al., 1995). Blood urea nitrogen level is affected by N intake (Whang and Easter, 2000), and has a the negative correlations with ADG and G:F ratio (Hahn et al., 1995). In this study, BUN concentration decreased when pig feed high energy diet, it maybe cause pigs were fed high energy diet improved protein deposition and utilization.

Suboptimal protein intake can decrease the levels of blood total protein (Bergsjø et al., 1993). Matthews et al. (1998) observed that total protein concentration increased when protein utilization by pigs was improved. In this experiment total protein concentration decreased as ME level in the diet was decreased during the finishing period. This is consistent with the decrease in the G:F ratio with a decrease in dietary ME level.

Carcass Traits

The effect of dietary energy and CP levels on proximate analysis are presented in Table 7. In this study, there were no significant differences in moisture, CP, crude fat and crud ash in longissimus muscles among treatments. Other studies have reported similar results: Kil et al. (2011) showed there was no significant difference in CP and crude fat in pork when pigs were fed diets with different GE (4,380–3,870 kcal/kg). Stewart et al. (2013) showed that increased CP levels in growing–finishing pigs (growing diets: 17.83%–20.30%; finishing diets: 12.44%–15.21%) had no significant effects on moisture, CP, crude fat or crude ash in the resulting pork.

The effect of dietary energy and CP levels on cooking loss, shear force, and water holding capacity of the meat are presented in Table 7. Variations in diet had no detrimental effects on cooking loss, shear force, or water holding capacity. These results are consistent with those of Apple et al. (2004), who reported that cooking loss was not affected by different levels of ME (3,480–3,300 kcal/kg). Madeira et al. (2014) observed that decreasing CP level in the finishing diet (16%–13%) had no effect on cooking loss. Additionally, Widmer et al. (2008) observed that decreasing CP in the growing–finishing period by 2% had no effect on cooking loss. Meng et al. (2010) showed that decreasing energy (ME: 3,500–3,400 kcal/kg) and CP levels (growing period: 18%–17% and finishing period: 16%–15%) had no effects on water holding capacity or cooking loss. Widmer et al. (2008) reported that decreasing energy (growing period: 400 kcal/kg of ME and finishing period: 200 kcal/kg of ME) and CP levels (growing period: 21.3%–15.34%; early finishing period: 18.76%–15.34% and late finishing period: 13.64%–11.24%) had no effects on cooking loss and shear force.

Table 8 shows the effect of energy and CP levels on TBARS of muscle is an index of fat oxidation. Madsen et al. (1992) found that the process of fat oxidation could be accelerated in the logissimus by the intake of crude fat. In this study, decreasing in ME of 100 kcal/kg of ME and in CP of 2% had no significant effect on muscle TBARS assay. Other studies have also reported that a decrease in ME and CP levels had no effects on TBARS assay (Meng et al., 2010; Madeira et al., 2014).

Table 9 shows the effects of energy and CP level on fatty acid composition of longissimus muscles from growing-finishing pigs. Saturated fatty acids (SFA) was increased ($P<0.01$) and polyunsaturated fatty acid (PUFA) was decreased ($P=0.03$) as ME decreased by 100 kcal/kg in growing-finishing pig diets. In addition, monounsaturated fatty acids (MUFA) content was tented to increase when CP level was decreased in growing-finishing pig diets ($P=0.06$). European Food Safe Authority (EFSA) recommend that food to be considered healthy should have a low content of SFA (EFSA, 2010). Feed ingredients and nutrition composition can also affect fatty acid composition in pork (Teye et al., 2006; Wood et al., 2008). Davis et al. (2015) and Nemechek et al. (2015) reported that SFA content could be decreased and PUFA content could be increased by increasing tallow levels 5% or increasing ME by 150 kcal/kg in growing-finishing diets, because PUFA appear to be preferentially deposited over SFA in adipose tissue (Davis et al., 2015). Bessa et al. (2013) and Madeira et al. (2014) reported no significant differences in MUFA as CP levels were decreased by 3-4% in growing-finishing pig diets.

The change in pH after slaughter is a very important factor affecting the freshness, tenderness, color, texture, and storage of pork. In this study, there were no significant differences in pH at 0 and 24 hours after slaughter (Table 10). This result is in accordance with results of Apple et al. (2004), Widmer et al. (2008), Prandini et al. (2013), Madeira et al. (2014) who showed that the pH at 0 and 24 hours after slaughter were not affected by ME (3,480-3,300 kcal/kg and 3,700-3,300 kcal/kg) or CP levels (17.7%-14.5% and 16.%-13%).

Meat colors results are shown in Table 11. There were no significant differences in L*, a* or b* values as ME level was decreased by 100 kcal/kg or CP concentration was decreased by 2%. Apple et al. (2004) and Hinson et al. (2014) also observed that decreasing energy level in the diet did not affect meat colors (3,480-3,300 kcal/kg of ME and 3,500-3,200 kcal/kg of ME, respectively). In addition, Prandini et al. (2013) and Madeira et al. (2014) reported that decreasing CP level in diet did not affect meat color (17.7%-14.5% and 16%-13%, respectively).

Economic Analysis

The effect of dietary energy and CP levels on economic analysis was presented in Table 12. In this study, tthere were no significant difference in total growing days from 30kg to 115kg and feed cost per weight gain of pig, but in total feed cost per pig and total feed cost per weight gain tented to be increased when ME level in growing-finishing pig diet decreased (P=0.08 and P=0.07, respectively). High level of ME treatments was 39 won/head less cost than low level of ME.

Conclusion

High level ME in growing-finishing pig diets, increased the ADG and G:F ratio in whole experiment period, and increased blood total protein levels in the finishing period. Furthermore, increased ME level in diet, could decrease BUN concentration during the growing period, SAF concentration in the longissimus muscles, and reduce cost of production over the entire experimental period.

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

In summary, a growing-finishing diet of high level ME and high level CP can improve growth performance, pork quality and reduce the cost of production.

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Table 1. Formulae and chemical compositions of the diet of early growing pigs (0-3 weeks).

Energy[1]	Low			High		
CP, %[2]	Low	Middle	High	Low	Middle	High
Ingredient, %						
Corn	66.26	63.57	60.86	63.54	60.84	58.10
Soybean meal	22.04	24.80	27.58	22.48	25.25	28.01
Wheat bran	4.02	4.01	3.99	3.98	3.96	3.99
Palm kernel meal	3.04	3.05	3.04	3.04	3.03	3.07
Tallow	1.05	1.11	1.18	3.37	3.44	3.50
Mono-dicalcium phosphate	2.56	2.52	2.50	2.55	2.55	2.50
Limestone	0.29	0.30	0.31	0.31	0.30	0.30
L-Lysine-HCl, 78%	0.21	0.12	0.03	0.20	0.11	0.02
DL-Methionine, 99%	0.03	0.02	0.01	0.03	0.02	0.01
Vit. Mix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[4]	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00
Chemical composition[5]						
metabolizable energy (kcal/kg)	3,200.01	3,200.00	3,200.00	3,300.01	3,300.02	3,300.01
Crude protein	16.00	17.00	18.00	16.00	17.00	18.00
Total lysine	0.95	0.95	0.95	0.95	0.95	0.95
Total methionine	0.27	0.27	0.27	0.27	0.27	0.27
Calcium	0.66	0.66	0.66	0.66	0.66	0.66
Total phosphorus	0.56	0.56	0.56	0.56	0.56	0.56

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early growing phase of 16.0%; middle CP level: early growing phase of 17.0%; high CP level: early growing phase of 18.0%.
3) Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,800 IU; vitamin E, 60 IU; vitamin K_3, 2 mg; thiamine (vitamin B_1), 2.00 mg; riboflavin (vitamin B_2), 7.0 mg; pantothenic acid (vitamin B_5), 25 mg; niacin (vitamin B_3), 27 mg; pyridoxine (vitamin B_6), 3 mg; d-biotin, 0.2 mg; folic acid, 1 mg; vitamin B_{12}, 0.03 mg.
4) Provided per kg of diet. Minerals per kg of complete diet: Se, 0.3 mg; I, 1 mg; Mn, 51.6 mg; Cu, 105 mg; Fe, 150 mg; Zn, 72 mg; Co, 0.5 mg.
5) Calculated value.

Table 2. Formulae and chemical compositions of the diets of late growing pigs (4-6 weeks).

Energy[1]	Low			High		
CP, %[2]	Low	Middle	High	Low	Middle	High
Ingredient, %						
Corn	71.62	68.86	66.09	68.92	66.11	63.37
Soybean meal	17.24	20.00	22.74	17.63	20.42	23.17
Wheat bran	4.03	3.99	3.97	3.98	4.00	4.00
Palm kernel meal	2.89	2.99	3.11	2.95	3.01	3.06
Tallow	0.69	0.76	0.83	3.00	3.08	3.15
Mono-dicalcium phosphate	2.39	2.35	2.30	2.38	2.35	2.32
Limestone	0.22	0.23	0.24	0.22	0.22	0.22
L-Lysine-HCl, 78%	0.37	0.28	0.19	0.37	0.27	0.18
DL-Methionine, 99%	0.05	0.04	0.03	0.05	0.04	0.03
Vit. Mix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[4]	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00
Chemical composition[5]						
metabolizable energy (kcal/kg)	3,200.01	3,200.01	3,200.00	3,300.01	3,300.02	3,300.01
Crude protein (%)	14.30	15.30	16.30	14.30	15.30	16.30
Total lysine (%)	0.95	0.95	0.95	0.95	0.95	0.95
Total methionine (%)	0.27	0.27	0.27	0.27	0.27	0.27
Calcium (%)	0.59	0.59	0.59	0.59	0.59	0.59
Total phosphorus (%)	0.52	0.52	0.52	0.52	0.52	0.52

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: late growing phase of 14.3%; middle CP level: late growing phase of 15.3%; high CP level: late growing phase of 15.3%.
3) Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,800 IU; vitamin E, 60 IU; vitamin K_3, 2 mg; thiamine (vitamin B_1), 2.00 mg; riboflavin (vitamin B_2), 7.0 mg; pantothenic acid (vitamin B_5), 25 mg; niacin (vitamin B_3), 27 mg; pyridoxine (vitamin B_6), 3 mg; d-biotin, 0.2 mg; folic acid, 1 mg; vitamin B_{12}, 0.03 mg.
4) Provided per kg of diet. Minerals per kg of complete diet: Se, 0.3 mg; I, 1 mg; Mn, 51.6 mg; Cu, 105 mg; Fe, 150 mg; Zn, 72 mg; Co, 0.5 mg.
5) Calculated value.

Table 3. Formulae and chemical compositions of the diets of early finishing pigs (7−9 weeks).

Energy[1]	Low			High		
CP, %[2]	Low	Middle	High	Low	Middle	High
Ingredient, %						
Corn	71.85	69.27	66.55	69.60	66.59	63.53
Soybean meal	17.53	20.30	23.10	18.02	20.74	23.50
Wheat bran	4.22	3.97	3.99	3.90	3.95	3.99
Palm kernel meal	2.86	3.05	3.03	2.73	3.01	3.29
Tallow	0.53	0.55	0.62	2.75	2.86	2.99
Mono−dicalcium phosphate	2.10	2.05	2.05	2.10	2.05	2.05
Limestone	0.18	0.18	0.15	0.18	0.18	0.15
L−Lysine−HCl, 78%	0.20	0.11	0.01	0.19	0.10	0.00
DL−Methionine, 99%	0.03	0.02	0.00	0.03	0.02	0.00
Vit. Mix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[4]	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00
Chemical composition[5]						
metabolizable energy (kcal/kg)	3,200.01	3,200.01	3,200.02	3,300.00	3,300.02	3,300.00
Crude protein (%)	14.30	15.30	16.30	14.30	15.30	16.30
Total lysine (%)	0.82	0.82	0.82	0.82	0.82	0.82
Total methionine (%)	0.25	0.25	0.25	0.25	0.25	0.25
Calcium (%)	0.52	0.52	0.52	0.52	0.52	0.52
Total phosphorus (%)	0.47	0.47	0.47	0.47	0.47	0.47

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early finishing phase of 14.3%; middle CP level: early finishing phase of 15.3%; high CP level: early finishing phase of 16.3%.
3) Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,800 IU; vitamin E, 60 IU; vitamin K_3, 2 mg; thiamine (vitamin B_1), 2.00 mg; riboflavin (vitamin B_2), 7.0 mg; pantothenic acid (vitamin B_5), 25 mg; niacin (vitamin B_3), 27 mg; pyridoxine (vitamin B_6), 3 mg; d−biotin, 0.2 mg; folic acid, 1 mg; vitamin B_{12}, 0.03 mg.
4) Provided per kg of diet. Minerals per kg of complete diet: Se, 0.3 mg; I, 1 mg; Mn, 51.6 mg; Cu, 105 mg; Fe, 150 mg; Zn, 72 mg; Co, 0.5 mg.
5) Calculated value.

Table 4. Formulae and chemical compositions of the diets of late finishing pigs (10−12 weeks).

Energy[1]	Low			High		
CP, %[2]	Low	Middle	High	Low	Middle	High
Ingredient, %						
Corn	80.44	77.74	75.13	78.12	75.06	72.13
Soybean meal	9.56	12.33	15.10	10.03	12.77	15.50
Wheat bran	4.02	4.00	3.97	4.04	3.99	3.92
Palm kernel meal	3.03	3.02	3.02	2.63	2.97	3.30
Tallow	0.18	0.24	0.28	2.42	2.56	2.65
Mono−dicalcium phosphate	1.90	1.90	1.85	1.90	1.90	1.85
Limestone	0.16	0.15	0.14	0.15	0.15	0.15
L−Lysine−HCl, 78%	0.19	0.10	0.01	0.18	0.09	0.00
DL−Methionine, 99%	0.02	0.01	0.00	0.03	0.01	0.00
Vit. Mix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[4]	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Total	100.00	100.00	100.00	100.00	100.00	100.00
Chemical composition[5]						
metabolizable energy (kcal/kg)	3,200.00	3,200.01	3,200.00	3,300.01	3,300.00	3,300.01
Crude protein (%)	11.20	12.20	13.20	11.20	12.20	13.20
Total lysine (%)	0.60	0.60	0.60	0.60	0.60	0.60
Total methionine (%)	0.21	0.21	0.21	0.21	0.21	0.21
Calcium (%)	0.46	0.46	0.46	0.46	0.46	0.46
Total phosphorus (%)	0.43	0.43	0.43	0.43	0.43	0.43

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: late finishing phase of 11.2%; middle CP level: late finishing phase of 12.2%; high CP level: late finishing phase of 13.2%.
3) Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 8,000 IU; vitamin D_3, 1,800 IU; vitamin E, 60 IU; vitamin K_3, 2 mg; thiamine (vitamin B_1), 2.00 mg; riboflavin (vitamin B_2), 7.0 mg; pantothenic acid (vitamin B_5), 25 mg; niacin (vitamin B_3), 27 mg; pyridoxine (vitamin B_6), 3 mg; d−biotin, 0.2 mg; folic acid, 1 mg; vitamin B_{12}, 0.03 mg.
4) Provided per kg of diet. Minerals per kg of complete diet: Se, 0.3 mg; I, 1 mg; Mn, 51.6 mg; Cu, 105 mg; Fe, 150 mg; Zn, 72 mg; Co, 0.5 mg.
5) Calculated value.

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

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

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early growing phase of 16.0%, late growing phase of 14.3%, early finishing phase of 14.3%, late finishing phase of 11.2%; middle CP level: early growing phase of 17.0%, late growing phase of 15.3%, early finishing phase of 15.3%, late finishing phase of 12.2%; high CP level: early growing phase of 18.0%, late growing phase of 15.3%, early finishing phase of 16.3%. late finishing phase of 13.2%.
3)Standard error of the mean
L Linear response ($P<0.05$) to dietary CP levels when a significant CP effect was detected.
abc means with different superscripts in the same row differ significantly ($P<0.05$)

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

Energy[1]	Low			High			SEM[3]	P-value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
Blood urea nitrogen (BUN), mg/dL										
6 wk	11.05	11.68	12.93	10.30	9.22	9.42	0.403	<.01	0.71	0.31
12 wk[L]	10.72	11.28	13.78	9.68	13.48	12.35	0.525	0.93	0.07	0.28
Glucose, mg/dL										
6 wk	87.33	82.00	83.33	85.17	83.17	90.67	1.192	0.37	0.27	0.26
12 wk	81.50	83.67	85.17	88.17	83.17	82.67	0.986	0.54	0.84	0.16
Total protein, g/dL										
6 wk	6.53	6.73	6.75	6.37	6.73	6.92	0.074	1.00	0.10	0.65
12 wk	6.73	6.55	6.70	6.85	6.92	7.00	0.060	0.04	0.73	0.68

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early growing phase of 16.0%, late growing phase of 14.3%, early finishing phase of 14.3%, late finishing phase of 11.2%; middle CP level: early growing phase of 17.0%, late growing phase of 15.3%, early finishing phase of 15.3%, late finishing phase of 12.2%; high CP level: early growing phase of 18.0%, late growing phase of 15.3%, early finishing phase of 16.3%. late finishing phase of 13.2%.
3) Standard error of the mean
L Linear response (P<0.05) to dietary CP levels when a significant CP effect was detected.

Table 7. Effect of dietary energy and crude protein levels on proximate analysis and physiochemical properties (water holding capacity, shear force, and cooking loss) of longissimus muscles from growing-finishing pigs.

Energy[1]	Low			High			SEM[3]	P-value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
Proximate analysis, %										
Moisture	74.21	73.81	74.73	73.18	74.07	72.97	0.247	0.10	0.91	0.25
Crude ash	1.15	1.29	1.19	1.21	0.95	1.07	0.720	0.16	0.99	0.15
Crude protein	22.84	23.36	23.37	23.50	23.35	23.10	0.231	0.82	0.96	0.74
Crude fat	2.12	2.03	2.40	1.74	1.63	2.46	0.352	0.20	0.82	0.13
Physiochemical property										
WHC, %[4]	68.94	67.48	68.89	71.69	70.57	69.23	0.592	0.10	0.61	0.59
Shear force, kg/0.5 inch	7.45	7.23	7.59	7.34	6.94	7.64	0.261	0.84	0.75	0.97
Cooking loss, %	31.36	31.07	31.85	30.22	30.83	31.23	0.293	0.30	0.59	0.83

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early growing phase of 16.0%, late growing phase of 14.3%, early finishing phase of 14.3%, late finishing phase of 11.2%; middle CP level: early growing phase of 17.0%, late growing phase of 15.3%, early finishing phase of 15.3%, late finishing phase of 12.2%; high CP level: early growing phase of 18.0%, late growing phase of 15.3%, early finishing phase of 16.3%. late finishing phase of 13.2%.
3)Standard error of the mean
4)Water holding capacity

Table 8. Effect of dietary energy and crude protein levels on TBARS assay in the longissimus muscles of growing-finishing pigs.

Energy[1]	Low			High			SEM[3]	P-value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
TBARS, mgMA/kg										
Day 0	0.23	0.22	0.23	0.22	0.23	0.24	0.004	0.70	0.56	0.69
Day 5	0.21	0.22	0.24	0.21	0.22	0.21	0.004	0.21	0.44	0.53
Day 7	0.57	0.56	0.57	0.55	0.55	0.56	0.007	0.50	0.97	0.93

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early growing phase of 16.0%, late growing phase of 14.3%, early finishing phase of 14.3%, late finishing phase of 11.2%; middle CP level: early growing phase of 17.0%, late growing phase of 15.3%, early finishing phase of 15.3%, late finishing phase of 12.2%; high CP level: early growing phase of 18.0%, late growing phase of 15.3%, early finishing phase of 16.3%. late finishing phase of 13.2%.
3)Standard error of the mean

Table 9. Effect of dietary energy and crude protein levels on fatty acid composition of longissimus muscles from growing-finishing pigs.

Energy[1]	Low			High			SEM[3]	P-value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
Fatty acid composition, %										
SFA[4]	39.67	40.69	39.08	37.39	37.24	37.75	0.427	<.01	0.82	0.53
MUFA[5]	42.23	39.14	41.37	41.77	40.46	40.86	0.366	0.86	0.06	0.47
PUFA[6]	18.10	20.17	19.56	20.84	22.30	21.40	0.512	0.03	0.35	0.93

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early growing phase of 16.0%, late growing phase of 14.3%, early finishing phase of 14.3%, late finishing phase of 11.2%; middle CP level: early growing phase of 17.0%, late growing phase of 15.3%, early finishing phase of 15.3%, late finishing phase of 12.2%; high CP level: early growing phase of 18.0%, late growing phase of 15.3%, early finishing phase of 16.3%. late finishing phase of 13.2%.
3)Standard error of the mean
4)SFA: Saturated fatty acids.
5)MUFA: Monounsaturated fatty acids.
6)PUFA: Polyunsaturated fatty acids.

Table 10. Effect of dietary energy and crude protein levels on the pH of longissimus muscles from growing−finishing pigs.

Energy[1]	Low			High			SEM[3]	P−value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
pH										
0 hours	6.11	6.05	6.05	5.84	6.07	6.14	0.040	0.21	0.45	0.16
3 hours	5.68	5.75	5.64	5.51	5.66	5.70	0.030	0.22	0.31	0.27
6 hours	5.58	5.64	5.58	5.51	5.54	5.56	0.016	0.08	0.49	0.59
12 hours	5.62	5.62	5.62	5.62	5.58	5.62	0.019	0.72	0.87	0.90
24 hours	5.60	5.64	5.60	5.66	5.59	5.63	0.016	0.74	0.93	0.42

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early growing phase of 16.0%, late growing phase of 14.3%, early finishing phase of 14.3%, late finishing phase of 11.2%; middle CP level: early growing phase of 17.0%, late growing phase of 15.3%, early finishing phase of 15.3%, late finishing phase of 12.2%; high CP level: early growing phase of 18.0%, late growing phase of 15.3%, early finishing phase of 16.3%. late finishing phase of 13.2%.
3)Standard error of the mean

Table 11. Effect of dietary energy and crude protein levels on color of longissimus muscles in growing-finishing pigs.

Energy[1]	Low			High			SEM[3]	P-value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
CIE value, L*										
0 hour	38.88	38.93	39.34	39.61	39.21	40.72	0.356	0.30	0.55	0.84
3 hour	39.97	40.19	39.53	40.11	38.43	39.69	0.392	0.86	0.95	0.38
6 hour	40.07	40.38	40.73	42.14	40.86	41.07	0.515	0.40	0.94	0.78
12 hour	43.02	41.76	43.97	44.34	43.39	43.38	0.434	0.40	0.53	0.57
24 hour	45.11	45.82	44.89	44.54	45.53	46.08	0.367	0.89	0.66	0.63
CIE value, a*										
0 hour	1.73	1.22	1.83	1.87	1.93	1.54	0.101	0.35	0.66	0.15
3 hour	2.48	1.89	1.87	2.40	2.18	2.41	0.120	0.31	0.39	0.58
6 hour	2.86	2.18	2.06	2.70	2.43	2.78	0.123	0.28	0.26	0.35
12 hour	3.42	2.56	3.14	3.21	3.01	3.23	0.105	0.60	0.11	0.43
24 hour	4.26	3.73	4.11	4.13	4.37	4.20	0.132	0.49	0.92	0.53
CIE value, b*										
0 hour	3.90	3.66	4.30	4.02	4.17	4.12	0.083	0.36	0.29	0.24
3 hour	4.54	4.55	4.36	4.54	4.29	4.72	0.095	0.89	0.86	0.47
6 hour	4.93	4.57	4.64	5.10	4.70	5.22	0.127	0.28	0.48	0.74
12 hour	5.76	5.15	5.60	5.93	5.48	5.65	0.103	0.38	0.14	0.86
24 hour	6.59	6.12	6.34	6.37	6.70	6.71	0.121	0.42	0.98	0.51

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).

2) Low CP level: early growing phase of 16.0%, late growing phase of 14.3%, early finishing phase of 14.3%, late finishing phase of 11.2%; middle CP level: early growing phase of 17.0%, late growing phase of 15.3%, early finishing phase of 15.3%, late finishing phase of 12.2%; high CP level: early growing phase of 18.0%, late growing phase of 15.3%, early finishing phase of 16.3%. late finishing phase of 13.2%.

3)Standard error of the mean

Table 12. Effect of dietary energy and crude protein levels on economic analysis in growing-finishing pigs.

Energy[1]	Low			High			SEM[3]	P-value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
Total day from 30kg to 115kg, day										
	97	96	101	99	93	92	1.6	0.34	0.69	0.42
Total feed cost per pig, won/head										
0-3 wks	10,085	9,794	10,690	9,792	10,799	10,540	296.5	0.77	0.68	0.66
4-6 wks	16,861	15,916	16,034	15,262	13,939	17,184	606.2	0.53	0.55	0.55
7-9 wks	20,244	18,834	18,516	18,199	19,789	20,062	409.4	0.86	1.00	0.20
10-12 wks	22,942	22,407	22,488	20,558	23,922	23,387	463.9	0.99	0.42	0.20
12wk-115kg	13,786	11,697	16,555	13,257	10,112	7,364	1,516.8	0.24	0.79	0.48
Total cost (get to 115 kg)	83,919	78,648	84,283	77,068	78,562	78,537	1,170.4	0.08	0.60	0.45
Feed cost per weight gain, won/kg										
0-3 wks	1,016	1,024	906	1,050	916	862	29.1	0.50	0.12	0.61
4-6 wks	796	757	810	796	687	745	32.5	0.52	0.67	0.90
7-9 wks	1,036	924	1,063	960	956	1,020	26.7	0.60	0.34	0.72
10-12 wks	1,137	1,065	1,157	1,019	1,124	1,108	24.1	0.47	0.66	0.35
Total (get to 115 kg)	999	936	1,003	917	935	935	13.9	0.07	0.58	0.44

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: early growing phase of 16.0%, late growing phase of 14.3%, early finishing phase of 14.3%, late finishing phase of 11.2%; middle CP level: early growing phase of 17.0%, late growing phase of 15.3%, early finishing phase of 15.3%, late finishing phase of 12.2%; high CP level: early growing phase of 18.0%, late growing phase of 15.3%, early finishing phase of 16.3%. late finishing phase of 13.2%.
3) Standard error of the mean

Chapter Ⅴ. Effect of Dietary Energy and Crude Protein Levels on Reproductive Performance, Litter Performance, Milk Quality, and Blood Profiles in Gestating Sows

Abstract : This experiment was conducted to evaluate the effect of dietary energy and crude protein levels on reproductive performance, litter performance, milk quality and blood profiles in gestating sows. A total of 59 multiparous sows (Yorkshire × Landrace) with similar body weight (BW), backfat thickness (BF) and parity were assigned to one of six treatments with 9 or 10 sows per treatment using a 2 × 3 factorial arrangement and completely randomized design. The first factor was two levels of dietary energy (3,200 or 3,300 kcal/kg) and the second factor was three dietary crude protein (CP) levels based from 35 day in gestating phases (low CP level: 10.5%; middle CP level: 12% or high CP level: 13.5%). There were no significant differences in BW, BW change in sows from gestation 35 day to 21 day of lactation, ADFI during lactation, and weaning to estrus interval (WEI). Backfat thickness change in lactating sows decreased linearly as CP level increased (P=0.03). Increased energy level in the gestating sow diet tended to increase the total number of piglet born (P=0.07), but piglet weight decreased (P=0.02). Litter weight gain was not affected by dietary energy and CP level in the diet of gestating sows. There was no significant differences in milk quality on day 21 of lactation according to dietary energy level (ME: 3,200−3,300 kcal/kg) or CP level (10.5%−13.5%), but casein (P=0.03), protein (P=0.04), total solids (P=0.03) and solids−not−fat (P=0.03) concentration increased linearly and lactose (P=0.06) level tends to decreased linearly in colostrum when decreasing CP level in gestating sow diets. There were no significant differences in blood glucose concentration in gestating sows when sows were fed different levels of energy during gestation, but blood glucose increased at 21 day of lactation when energy increased by 100 kcal/kg (P=0.04). Blood urea nitrogen concentration increased linearly when dietary CP levels increased at 110 day in gestation , 24−hours postpartum, and 21 days of lactation (linear, $P<0.05$, $P<0.05$, and $P<0.05$, respectively), and it also increased when dietary energy increased at 110 days of gestation and 24−hours postpartum ($P<0.01$, and $P<0.01$, respectively). A gestating sow diet containing high ME level and low CP level can improve reproductive performance, litter performance and colostrum quality.

Key words: Energy; Crude Protein; Reproductive Performance; Litter Performance; Blood Profiles; Gestating Sows

Introduction

Various management practices coupled with research on physiology, nutrition, genetics, animal behavior, and the environment and housing have improved reproductive efficiency in sows over the past 40 years (Kraeling and Webel, 2015). In the swine industry, an accepted measure of reproductive performance is piglets per sow per year (PSY). Total piglets born and PSY have increased every year for more than 6 years in Europe (BPEX, 2015). In South Korea, PSY increased by 1.5 piglets from 2011 to 2013 (Choe et al., 2015), but still trails behind Europe (BPEX, 2015). Boyd et al. (2000) reported that the increase in number of litters and milk production in recent years was due to provision of more nutrients during the normal reproductive cycle. In addition, gestating sows should be fed a diet that ensures sufficient maternal protein and fat deposition to optimize fetal growth (Ji et al., 2005). Therefore, the nutritional requirements of gestating sows should be met to satisfy both body maintenance and fetal growth (NRC, 1998).

Many studies had shown that adequate energy intake during the gestation period has favorable effects on fetal growth and mammary development (Trottier and Johnston, 2001; Cerisuelo et al., 2009). However, excessive energy intake in gestation can reduce feed intake during lactation (Revell et al., 1998), and have a negative effect on milk production (Messias de Bragança et al., 1998).

Protein deposition affects the reproductive performance of sows (Kim et al., 2009). Pettigrew and Yang (1997) reported that high protein storage in sows influenced milk production and reproductive performance. High dietary protein intake in gestating sow was shown to improve litter weight and piglet weight (Jang et al., 2014), but had no detectable effect on mammary gland development (Kusina et al., 1995a). Low protein intake in gestating sows had found a negative effect on lactation performance (Head and Williams, 1991) or performance at next parity (Svajgr et al., 1972). Other studies showed that low dietary protein intake during gestation did not affect litter size or litter birth weight, but had detrimental influence on litter weight gain even though lactating sows were fed an adequate amount of protein (Baker et al., 1970; Kusina et al., 1999b).

Some studies have been conducted on the energy or crude protein requirements for gestating gilts, but few studies have focused on multiparous sows.

Consequently, this experiment was conducted to evaluate the effects of dietary energy and crude protein levels on reproductive performance, litter performance, milk quality, and blood profiles in multiparous gestating sows.

Materials and Methods

Experimental Animals and Housing Environment

A total of 59 multiparous sows (Yorkshire × Landrace; 35 day of gestation) with body weights (BW) around 241.67 ± 8.86 kg were used in this study. Each sow was kept in an individual gestation stall (2.4 × 0.64 m) with a feeder and a nipple drinker. Sows (parity: 3–6) were fed 2.4 kg/day. On 110 day of gestation, sows were transferred into environmentally controlled farrowing rooms and placed in individual farrowing crates (2.5 × 1.8 m). Each farrowing crate was equipped with a feeder and a nipple waterer.

Experimental Design, Treatment and Animal Management

Experimental sows (Yorkshire × Landrace) with similar BW, backfat thickness (BF), and parity were assigned to one of six treatments with 9 or 10 sows per treatment using a 2 × 3 factorial arrangement and completely randomized design. The first factor was two levels of dietary metabolizable energy (ME) density (ME level: 3,200 kcal/kg or 3,300 kcal/kg), and second factor was three dietary crude protein (CP) levels based on subdivision of gestating phases (low CP level: 10.5%; middle CP level: 12% or high CP level: 13.5%). Sows in the lactating period were fed the same lactation diet. Formulae and chemical compositions of the experimental gestation and lactation diets are presented in Tables 1 and 2.

After farrowing, sow lactation diet was restricted to 1 kg on the first day and gradually increased by 1 kg per day for the first 5 days, with no limitation for the remaining lactation period. 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 (formale piglets) were practiced to all piglets. All piglets were fed breast milk only and creep feed were not provided until weaning.

Measurements and Analysis

During gestation and lactation period, BW (CAS Co. Ltd., Yangju-si, Gyeonggi-do, Korea) and BF at P2 position (Lean Meter®, Renco Corp., Minneapolis, USA) of sows were measured at 35 day and 110 days of gestation, at 24 hours post-farrowing, and at 21 day of lactation. The number of piglets born alive, still born, mummified fetuses, total born, and body weight of piglet were measured at 24 hours post-parturition and 21 day of lactation. Individual piglet weight and litter size of lactating sows were recorded postpartum and at day 21 of lactation. Weaning-to-estrus interval (WEI) of weaned sows was recorded after weaning, as this is an important maker of reproductive performance. Voluntary feed intake of sows was measured during lactation.

Gestating and lactating sows were bled via the anterior vena cava. Samples were collected on days 35 and 110 of gestation, and 24 hours post-farrowing. Blood samples were collected in disposable culture tubes, and centrifuged at 3,000 rpm for 15 min; the plasma was harvested from all blood samples and stored at -20℃ until analysis. After injection of 0.3 mL of oxytocin

(Komi oxytocin inj. Komipharm International Co., Ltd., Siheung-Si, Gyeonggi-Do, Korea), colostrum and milk samples were collected in falcon tubes (Milkoscan FT 120., FOSS, Hillerod, Demark) and stored at -20℃ until analysis. Concentrations of glucose and blood urea nitrogen (BUN) were analyzed at a later stage. BUN (kinetic UV assay, Roche, Germany) and glucose (enzymatic kinetic assay, Roche, Germany) concentration were analyzed using a blood analyzer.

Colostrum and milk samples were taken from functional mammary glands of each sow at 24 hours post-farrowing and at day 21 of lactation, respectively. After collection, samples were stored in a freezer (-20℃) until further analysis. Proximate analysis of colostrum and milk was conducted using the Milkoscan FT120 system (FOSS, Hillerod, Denmark).

Statistical Analysis

All collected data were analyzed using least squares mean comparisons and evaluated using general linear models (GLM) in the statistical software package SAS (SAS Institute Inc., Cary, NC, USA). Individual sow was considered the experimental units when comparing reproductive performance, blood profiles, and milk composition among groups. Litters were used as the experimental units when assessing piglet growth. Orthogonal polynomial contrasts were used to detect linear and quadratic responses to CP levels when a significant CP effect was detected. Differences were considered significant at $P<0.05$ or highly significant at $P<0.01$, while $P\geq0.05$ and $P<0.10$ was considered to indicate a tendency in the data.

Results and Discussion

Sows Performance

Effects of dietary energy and CP levels on performance of gestating–lactating sows are shown in Tables 3. There were no significant differences in BW, BW change, BF, average daily feed intake (ADFI), or WEI of sows among groups. However, BF change in the lactating period decreased linearly as gestation dietary CP level increased (P=0.03).

Long et al. (2010) reported that BW gain and BW change increased when gestating gilts was fed with increased dietary ME intake (ME: 6,330–6,930 kcal/day). Many studies have showed similar results with previous study (Dourmad, 1991; Kusina, 1999b; Averette et al, 2002). In this study, there were no significant differences in BW and BW change when dietary ME increased 100 kcal/kg. This discrepancy with previous studies may be due to the small difference between the two energy levels or because we used multiparous sows compared with previous studies that used young sow. The growth of sows during their third parity has been shown to be slower than that of first and second parity sows (Mahan, 1998). The current study showed that dietary CP levels ranging from 10.5% to 13.5% had no effect on the BW of sows, consistent with previous studies. Jang et al. (2014) observed that there was no significant difference in BW when sows were fed diets with different CP levels (11.4%–17.1%). Mahan (1998) also reported no differences in BW or BW change when CP levels were varied from 13% to 16% in the first to fifth parities.

Backfat thickness and BF change did not change when the ME in the diet of gestating sows was increased from 3,200 to 3,300 kcal/kg. Another study showed that BF changed from 17 mm to 21 mm as increasing dietary ME intake per day from 6,330 kcal to 6,930 kcal in gestating gilts (Long et al., 2010). Backfat thickness change in lactating sows decreased as gestation dietary CP level increased (P=0.03). Mahan (1998) and Jang et al. (2014) reported similar result, BF change in lactation decreased numerically when dietary CP level in gestating sows was increased.

Average daily feed intake in lactating sows and WEI were not significantly affected by dietary energy and CP levels. In general, low feed intake has a negative effect on body condition and WEI (King and Williams, 1984; Baidoo et al., 1992) and can decrease ovulation rate in the next parity (Foxcroft et al., 1995). Long et al. (2010) reported that increasing ME intake by 600 kcal/day during gestation could reduce ADFI in lactation. A similar result was reported by Revell et al. (1998). Previous studies have reported that dietary CP levels during gestation have no effects on ADFI and WEI (Mahan, 1998; Jang et al., 2014).

Reproductive Performance and Litter Performance

The effects of dietary energy and CP levels on total piglets born per litter, litter weight, litter weight gain, average BW of piglets, and average BW gain of piglets are shown in Table 4. The total number of piglet born tended to increased (P=0.07) and piglet weight decreased (P=0.02) when dietary energy level in the gestating sow diet was increased. Previous study demonstrated that litter size was maximized when daily energy intake was 6,000 kcal ME per day (Frobish et al., 1973). However, Long et al. (2010) showed that gilts received 6,730kcal ME per day had more number of piglets born. In addition, multiparous sows require more energy than first parity sows (NRC, 2012). The NRC increased the recommended dietary energy requirements for gestating sows from 1998 to 2012 (NRC, 1998; NRC, 2012). In this study, gestating sows (parity: 3−6) with a daily intake of 7,920 kcal ME/day (3,300 kcal/kg) tended to have more total born piglets than those with a daily intake of 7,680 kcal ME/day (3,200 kcal/kg).

Litter weight gain was not affected by dietary energy or CP level. However, a diet containing 12% dietary CP during gestating was associated with greater piglet weight at 21 days (P=0.06) as well as piglet weight gain (P=0.04) because the number of weaning pigs was lower than in other treatments. Sows fed a 10.5% CP diet resulted in the better colostrum quality. Therefore, number of piglet deaths upon weaning was lower in sows that received a diet with 10.5% CP (P=0.03), and high ME with low CP treatment showed the most number of weaning pigs (P<0.05) among treatments. This is consistent with the results of Mahan (1998) who reported that the number of piglets deaths increased as dietary CP level was increased by 3% in gestating sows. Previous studies have reported that low dietary protein intake in gestating sows did not affect litter size or litter birth weight, but had a detrimental influence on litter weight gain even though lactating sows were fed an adequate protein level (Baker et al., 1970; Kusina et al., 1999b). Results in this study are not consistent with those of previous studies, this may be because low CP level (10.5%) is sufficient for gestating sows.

Milk Composition

The effects of dietary energy and CP levels on the chemical composition of colostrum and milk in sows are shown in Table 5. There was no significant differences in milk quality on day 21 of lactation according to dietary gestation energy level (ME: 3,200−3,300 kcal/kg) or CP level (10.5%−13.5%), but casein (P=0.03), protein (P=0.04), total solids (P=0.03) and solid s−not−fat (P=0.03) concentration increased linearly and lactose (P=0.06) level tended to decrease linearly in colostrum when decreasing CP level in gestating sow diets. The high protein content in colostrum is due to presence of immunoglobulins (Klobasa et al., 1987). Immunoglobulins content was increased when protein content increased in colostrum (Devillers et al., 2007). The sow prioritizes protein content in colostrum and milk if the protein content in the feed is scarce, by metabolizing body reserves, which indicates that protein is extremely important to the piglets (King et al., 1996). The newborn piglet depends on colostrum to ingest immunoglobulins because of the structure of the pig placenta does not allow immunoglobulins to pass over from the sow to the fetus (Rooke and Bland, 2002). The ingestion is needed in order to be able to obtain passive immunity. A piglet that does not ingest colostrum will consequently not only be more sensitive to infections, but also to starvation and hypothermia.

The findings of this study demonstrate that decreasing CP level in gestating sow diet increased casein, protein, total solids and solids-not-fat linearly of colostrum. Therefore, low CP level in gestating sow diet found better colostrum quality. However, other researchers did not find any effect on colostrum composition when gilts were feed different levels of CP in gestation diets (Elliott et al.. 1971; Mahan, 1998; Jang et al., 2014). The sows reduced feed intake at the first day postpartum. It means that nutrients accumulated in the sow body are used to produce colostrum. So, the ability for catabolism of the nutrients in the body is important in farrowing sows. In this study, BF change in lactating sows decreased as gestation dietary CP level increased (P=0.03), and ADFI of lactating sows was not significant (P=0.48). It may agree that low CP intake (10.5%) in gestating sows was found higher catabolism of the body reserves to make higher quality of colostrum than high CP intake (13.5%). However, further study is needed to clearly demonstrate a possible correlation among protein level in gestating sows diet, catabolism of the body reserves and colostrum composition.

Blood Profiles of Sows

The effects of dietary energy and CP levels on blood glucose and BUN concentration during the gestation-lactation period are shown in Table 6. There was no significant difference in blood glucose concentration in gestating when sows were fed different levels of ME during gestation, but blood glucose concentration increased at 21 day of lactation when ME levels increased by 100 kcal/kg (P=0.04). In this study, the treatment with 3,300 kcal/kg of dietary ME showed lower ADFI than 3,200 kcal/kg of

ME, and it had an agreement with Cozler et al. (1998) who reported blood glucose concentration had a negative effect on ADFI.

Blood urea nitrogen is one of the indicator of protein utilization. A low BUN level is associated with improved protein synthesis and reduced amino acid oxidation, which can lead to reduced availability of ammonia (Wu and Morris, 1998). Fuller et al. (1977) reported that CP synthesis was improved by carbohydrate intake. In addition, increasing total N intake could increase BUN concentration (Whang and Easter, 2000). In this study, BUN concentration increased linearly with dietary CP level at 110 day of gestation, 24 hours postpartum and 21 day of lactation ($P<0.05$, $P<0.05$, and $P<0.05$, respectively), and also increased with an increase in dietary energy at day 110 of gestation and 24 hours postpartum ($P<0.01$, and $P<0.01$, respectively). Results of the study by Jang et al. (2014) are consistent with the current results, they reported that plasma urea nitrogen concentration increased when dietary CP level in gestating sows was increased.

Conclusion

Total number of born and blood glucose concentration at day 21 of lactation increased with an increase in daily dietary ME of 100 kcal/kg (3,200 kcal/kg to 3,300 kcal/kg) in gestating sows. Backfat thickness change and colostrum quality decreased and piglet death during lactation and BUN level increased as dietary CP level (10.5%−13.5%).

A gestating sow diet containing high ME with low CP level can improve reproductive performance, litter performance, and colostrum quality.

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Table 1. Formulae and chemical compositions of diets in the gestation phase.

Energy[1]	Low			High		
CP, %[2]	Low	Middle	High	Low	Middle	High
Ingredient, %						
Corn	78.81	74.79	70.72	76.12	72.20	68.13
Soybean meal	7.02	11.59	16.14	7.43	11.99	16.54
Wheat bran	8.02	8.01	8.04	8.08	7.99	8.02
Soy-oil	1.62	1.66	1.71	3.83	3.85	3.90
Mono-dicalcium phosphate	1.38	1.31	1.24	1.40	1.33	1.26
Limestone	1.55	1.55	1.55	1.54	1.54	1.54
L-lysine, 78%	0.31	0.15	0.00	0.30	0.15	0.00
DL-methionine, 99%	0.04	0.02	0.00	0.05	0.03	0.01
L-threonine, 99%	0.15	0.08	0.00	0.15	0.08	0.00
Tryptophan, 10%	0.50	0.24	0.00	0.50	0.24	0.00
Vit. Mix[3]	0.10	0.10	0.10	0.10	0.10	0.10
Min. Mix[4]	0.10	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30	0.30
Choline-Cl	0.10	0.10	0.10	0.10	0.10	0.10
Total	100.00	100.00	100.00	100.00	100.00	100.00
Chemical composition[5]						
Metabolizable energy (kcal/kg)	3,200.08	3,200.09	3,200.08	3,300.06	3,300.10	3,300.09
Crude protein (%)	10.50	12.00	13.50	10.50	12.00	13.50
Total lysine (%)	0.67	0.67	0.67	0.67	0.67	0.67
Total methionine (%)	0.24	0.24	0.24	0.24	0.24	0.24
Total threonine (%)	0.54	0.54	0.54	0.54	0.54	0.54
Total tryptophan (%)	0.14	0.14	0.14	0.14	0.14	0.14
Calcium (%)	0.88	0.88	0.88	0.88	0.88	0.88
Total phosphorus (%)	0.60	0.60	0.60	0.60	0.60	0.60

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: 10.5%; middle CP level: 12.0%; high CP level: 13.5%.
3) Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 12,000 IU; vitamin D_3, 2,000 IU; vitamin E, 100 IU; vitamin K_3, 4.5 mg; thiamine (vitamin B_1), 2.00 mg; riboflavin (vitamin B_2), 7.0 mg; pantothenic acid (vitamin B_5), 30 mg; niacin (vitamin B_3), 45 mg; pyridoxine (vitamin B_6), 4.50 mg; d-biotin, 0.5 mg; folic acid, 3.5 mg; vitamin B_{12}, 0.03 mg.
4) Provided per kg of diet. MineralS per kg of complete diet: Se, 0.15 mg; I, 0.3 mg; Mn, 37 mg; Cu, 11 mg; Fe, 150 mg; Zn, 85 mg; Co, 2 mg.
5) Calculated value.

Table 2. Formulae and chemical compositions of diets in the lactation phase.

Item	%
Ingredient, %	
Corn	65.35
Soybean meal	27.23
Wheat bran	2.01
Soy−oil	2.42
Mono−dicalcium phosphate	1.26
Limestone	1.13
Vit. Mix[1]	0.10
Min. Mix[2]	0.10
Salt	0.30
Choline−Cl	0.10
Total	100.00
Chemical composition[3]	
Metabolizable energy (kcal/kg)	3300.06
Crude protein (%)	17.20
Total lysine (%)	0.94
Total methionine (%)	0.28
Total threonine (%)	0.70
Total tryptophan (%)	0.19
Calcium (%)	0.75
Total phosphorus (%)	0.60

1) Provided per kg of diet. Vitamins per kg of complete diets: vitamin A, 10,000 IU; vitamin D_3, 1,900 IU; vitamin E, 80 IU; vitamin K_3, 3.25 mg; thiamine (vitamin B_1), 2.00 mg; riboflavin (vitamin B_2), 7.0 mg; pantothenic acid (vitamin B_5), 27.5 mg; niacin (vitamin B_3), 36 mg; pyridoxine (vitamin B_6), 3.75 mg; d−biotin, 0.35 mg; folic acid, 2.25 mg; vitamin B_{12}, 0.03 mg.

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

3) Calculated value.

Table 3. Effects of dietary energy and crude protein levels on body weight, backfat thickness, weaning to estrus interval, and daily feed intake of gestating-lactating sows.

Energy[1]	Low			High			SEM[3]	P-value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
No. of sows	10	10	10	10	9	10				
Body weight, kg										
Day 35	244.0	239.1	239.7	239.9	239.3	243.0	2.56	0.98	0.91	0.85
Day 110	259.0	254.0	252.3	252.7	254.0	259.2	2.40	0.96	0.93	0.56
Change (d 35-110)	15.0	14.9	12.6	12.9	14.7	16.2	1.67	0.97	0.91	0.99
24 hrs. postpartum	239.6	233.4	226.2	230.3	234.4	243.1	2.57	0.57	0.97	0.12
Day 21 of lactation	238.7	241.2	231.8	230.7	235.0	243.8	2.89	0.93	0.88	0.32
Changes (d 0-21)	0.9	7.8	5.6	0.4	0.6	0.7	1.36	0.21	0.35	0.42
Backfat thickness, mm										
Day 35	20.2	20.2	20.2	21.6	21.8	20.2	0.76	0.51	0.90	0.90
Day 110	20.7	21.4	21.3	23.8	22.8	22.3	0.83	0.30	0.98	0.85
Gain (d 35-110)	0.5	1.2	1.1	2.2	1.0	2.1	0.71	0.41	0.95	0.75
24 hrs. postpartum	20.2	18.9	18.7	23.9	22.2	20.4	0.84	0.10	0.47	0.87
Day 21 of lactation	16.7	18.6	19.6	21.6	21.9	19.1	0.81	0.13	0.84	0.39
Changes (d 0-21)[L]	-3.4	-0.3	0.9	-2.3	-0.3	-1.3	0.46	0.73	0.03	0.31
Lactation feed intake, kg/d	6.58	7.20	6.93	6.49	6.40	6.93	0.139	0.37	0.48	0.48
WEI[4], d	4.61	4.61	4.94	4.72	4.93	5.00	0.087	0.37	0.35	0.82

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: 10.5%; middle CP level: 12.0%; high CP level: 13.5%.
3) Standard error of the mean
4) Weaning to estrus interval
L Linear response (P<0.05) to dietary CP levels when a significant CP effect was detected.

Table 4. Effects of dietary energy and crude protein levels in the diets of gestating sows on reproductive and litter performance.

Energy[1]	Low			High			SEM[3]	P−value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
No. of sows	10	10	10	10	9	10				
Litter size, no. of piglets										
Total born	12.90	10.40	12.90	13.80	13.44	13.50	0.426	0.07	0.30	0.44
Born alive	12.90	10.40	12.30	13.30	13.22	12.40	0.395	0.17	0.39	0.31
After cross−fostering	11.40	11.80	11.80	11.50	11.56	11.88	0.093	0.81	0.31	0.75
No. of deaths upon weaning	0.20	0.60	0.50	0	1.00	0.88	0.508	0.48	0.03	0.48
Weaning pigs (d 21)	11.20[b]	11.20[b]	11.30[ab]	11.50[a]	10.56[c]	11.00[bc]	0.127	0.43	0.34	0.31
Litter weight, kg										
At birth	18.58	16.44	19.55	19.34	18.64	18.31	0.477	0.55	0.35	0.35
After cross−fostering	17.41	19.06	18.96	17.18	16.66	17.96	0.289	0.04	0.23	0.28
Day 21 of lactation	66.38	72.95	69.55	69.32	66.96	64.89	1.286	0.33	0.65	0.32
Weight gain (d 0−21, kg)	48.97	53.89	50.59	52.14	50.30	46.94	1.200	0.58	0.53	0.43
Piglet weight, kg										
At birth	1.47	1.62	1.54	1.41	1.39	1.41	0.028	0.02	0.75	0.31
After cross−fostering	1.53	1.61	1.61	1.50	1.44	1.52	0.022	0.03	0.63	0.43
Day 21 of lactation	5.94	6.51	6.14	6.02	6.33	5.86	0.084	0.41	0.06	0.63
Weight gain (d 0−21, kg)[Q]	4.41	4.90	4.53	4.53	4.89	4.34	0.080	0.81	0.04	0.71

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: 10.5%; middle CP level: 12.0%; high CP level: 13.5%.
3)Standard error of the mean
abc Means with different superscripts in the same row differ significantly (P<0.05)
Q Quadratic response (P<0.05) to dietary CP levels when a significant CP effect was detected.

Table 5. Effects of dietary energy and crude protein levels in the diets of gestating sows on chemical compositions of the colostrum and milk of sows.

Energy[1]	Low			High			SEM[3]	P−value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
24 hours postpartum, %										
Casein[L]	9.83	7.37	5.46	8.35	8.06	5.67	0.550	0.85	0.03	0.66
Fat	6.63	6.71	5.38	6.73	3.45	4.99	0.497	0.24	0.34	0.33
Protein[L]	13.31	9.83	7.30	11.28	10.85	7.47	0.767	0.85	0.04	0.67
Lactose[L]	3.42	4.08	4.28	3.65	3.95	4.54	0.146	0.68	0.06	0.82
Total solids[L]	27.16	23.36	19.14	24.77	21.10	18.98	1.042	0.41	0.03	0.87
Solids−not−fat[L]	16.94	13.91	11.75	14.98	14.96	12.05	0.641	0.86	0.03	0.56
Day 21 of lactation, %										
Casein	4.29	4.68	4.58	4.10	4.62	4.54	0.086	0.58	0.11	0.93
Fat	5.95	7.08	6.79	5.67	6.51	6.66	0.245	0.53	0.23	0.93
Protein	4.86	5.19	5.21	4.54	5.24	5.00	0.122	0.53	0.24	0.83
Lactose	6.04	6.37	6.11	6.50	6.12	6.38	0.067	0.22	0.98	0.10
Total solids	18.61	20.19	19.76	18.34	19.42	19.46	0.321	0.50	0.24	0.94
Solids−not−fat	11.02	11.44	11.37	10.87	11.42	11.34	0.085	0.69	0.11	0.94

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: 10.5%; middle CP level: 12.0%; high CP level: 13.5%.
3) Standard error of the mean
L Linear response ($P<0.05$) to dietary CP levels when a significant CP effect was detected.

Table 6. Effects of dietary energy and crude protein levels in gestating sow diet on blood profiles of sows.

Energy[1]	Low			High			SEM[3]	P-value		
CP, %[2]	Low	Middle	High	Low	Middle	High		ME	CP	M×C
Glucose, mg/dL										
Day 35			72.56				–	–	–	–
Day 110	79.02	80.73	79.02	74.31	79.78	82.69	0.985	0.82	0.28	0.25
24 hours postpartum	110.02	99.82	105.69	92.67	106.67	100.84	2.277	0.33	0.95	0.13
Day 21 of lactation	81.02	72.30	77.01	81.30	81.71	80.78	1.137	0.04	0.27	0.22
BUN, mg/dL										
Day 35			10.32				–	–	–	–
Day 110[L]	6.89	7.56	9.81	9.11	9.22	9.43	0.305	<.01	0.01	0.05
24 hours postpartum[L]	6.45	6.32	11.21	8.11	10.10	10.31	0.494	<.01	<.01	<.01
Day 21 of lactation[L]	16.61	20.91	21.32	20.67	19.78	19.45	0.444	0.24	0.02	<.01

1) Low energy level: ME (3,200 kcal/kg); High energy level: ME (3,300 kcal/kg).
2) Low CP level: 10.5%; middle CP level: 12.0%; high CP level: 13.5%.
3)Standard error of the mean
L Linear response ($P<0.05$) to dietary CP levels when a significant CP effect was detected.

Chapter Ⅵ. Overall Conclusion

This study was carried out to investigate the dietary energy and crude protein levels in swine diet. Therefore, three experiments were conducted: 1) the effect of dietary energy and crude protein levels on growth performance, blood profiles, nutrient digestibility and economical analysis in weaning pigs; 2) the effect of dietary energy and crude protein levels on growth performance, blood profiles, pork quality and economical analysis in growing-finishing pigs; and 3) the effect of dietary energy and crude protein levels on reproductive performance, litter performance, milk quality and blood profiles in gestating sows.

In experiment 1, A weaning pig diet containing high ME level (3,300 kcal/kg) and low CP level (early weaning phase: 19.7% and late weaning phase: 16.9%) can improve pig growth performance and nutrient digestibility, and reduce the cost of production.

In experiment 2, a growing-finishing diet of high level ME and high level CP can improve growth performance, pork quality and reduce the cost of production.

In experiment 3, A gestating sow diet containing high ME with low CP level can improve reproductive performance, litter performance, and colostrum quality.

Consequently, there results implied that high ME and low CP level in weaning pig diet, high ME and high CP level in growing-finishing diet and high ME and low CP level in gestating sow diet, could improve swine performance and reduce the cost of production.

Chapter Ⅶ. Summary in Korean

지난 15년동안 생리적, 영양적, 유전적, 행동학적, 환경적, 돈사의 발전을 통해 번식장의 번식 효율, PSY와 MSY가 유의적으로 증가한 것으로 알려져 있다. 양돈 산업의 생산효율이 개선됨에 따라, NRC (NRC, 1998; NRC, 2012)에서 돼지의 에너지, 아미노산 수준과 단백질 농도 영양소 요구량은 변화되어 왔다. 결론적으로, 더 높은 양돈 생산 효율을 충족시키고, 적절한 단백질과 에너지 요구량을 공급하기 위해 3가지 실험이 수행되었다. 1) 이유자돈 사료 내 에너지와 단백질 수준이 성장성적, 혈액성상, 영양소 소화율과 경제성에 미치는 영향 2) 육성비육돈 사료 내 에너지와 단백질 수준이 성장성적, 혈액성상, 도체 특성과 경제성에 미치는 영향 3) 임신돈 사료 내 에너지와 단백질 수준이 번식성적, 포유자돈의 성적, 돈유 품질, 혈액성상에 미치는 영향.

Experiment Ⅰ. Effect of Dietary Energy and Crude Protein Levels on Growth Performance, Blood Profiles, Nutrient Digestibility and Economic Analysis in Weaning Pigs

본 실험은 이유자돈 사료 내 에너지와 단백질수준이 자돈의 성장성적, 혈액성상, 영양소 소화율과 경제성을 검증하기 위해 수행되었다. 총 240두 이유자돈 평균 체중 8.67 ± 1.13kg인 삼원 교잡종([Landrace × Yorkshire]) × Duroc)을 공시하였으며, 서울대학교 부속 실험 목장에서 6주 동안 사양실험을 수행하였다. 처리구는 총 6처리, 5반복으로 돈방 당 8두씩 성별과 체중에 따라 난괴법 (RCBD; Randomized Completely Block Design)으로 배치하였다. 에너지의 수준과 단백질 수준에 따라 2 × 3 factorial design으로 설계되었으며, Factor 1은 저에너지 (3,200 kcal of ME/kg)와 고에너지 (3,300 kcal of ME/kg)로 구성된 에너지 수준이고, Factor 2는 사료 내 낮은 단백질 수준

(19.7%/16.9%), 중간 단백질 수준(21.7%/18.9%) 와 높은 단백질 수준(23.7%/20.9%)으로 설정하였다. 총 시험기간에서 전체 처리구 간 체중에서는 유의적 차이를 나타내지 않았다. 하지만 사료 내 에너지 수준이 100 kcal/kg 증가함에 따라 ADFI는 감소하고 (P=0.02), G:F ratio는 증가했다 (P<0.01). 또한 사료 내 단백질 수준이 감소함에 따라 ADG와 G:F ratio는 유의적으로 증가했다 (P=0.01, P=0.04, respectively). 이유자돈 전기에서, 사료 내 에너지 수준의 증가와 단백질 수준의 감소에 따라 혈액 내 BUN 농도는 감소하였다 (P=0.09, P<0.01, respectively). 또한 사료 내 단백질 수준이 감소에 따라 혈액 내 total protein은 유의적으로 감소하는 경향을 보였다 (P=0.08). 이유자돈 후기에서, 사료 내 단백질 수준이 감소함에 따라 혈액 내 BUN 농도는 감소하였다 (P<0.01). 영양소 소화율에서는 사료 내 ME가 100 kcal/kg 증가함에 따라 조단백질과 조지방의 소화율은 증가하였다 (P=0.05, P=0.01, respectively). 또한 사료 내 단백질 수준이 감소함에 따라 조단백질의 소화율은 증가하였다 (P=0.01). 이유자돈 후기와 전체 실험기간에서는 자돈 1kg 증체당 소요되는 비용은 사료 내 ME가 증가함에 따라 감소하였고 (P<0.01, P=0.02, respectively), 사료 내 단백질 수준이 감소함에 따라 감소하였다 (P<0.01, P<0.01, respectively). 또한 사료 내 에너지수준이 감소할수록, 사료 내 단백질 수준이 증가할수록 자돈 한 마리당 25kg까지 성장하는데 필요한 사료비가 증가하였다 (P=0.02, P<0.05, respectively). 결론적으로 사료 내 높은 수준의 에너지와 낮은 수준의 단백질은 이유자돈의 성장과 소화율을 증가시켰고, 생산비를 감소시키는 결과를 나타냈다.

Experiment Ⅱ. Effect of Dietary Energy and Crude Protein Levels on Growth Performance, Blood Profiles, Pork Quality and Economic Analysis in Growing-finishing Pigs

본 연구는 육성비육돈 사료 내 에너지와 단백질 수준이 육성비육돈의 성장성적, 혈액성분, 돈육 품질과 경제성에 미치는 영향을 검증하기 위해서 수행되었다. 평균 체중 30.96 ± 3.07 kg의 3원 교잡종 ([Yorkshire × Landrace]) × Duroc) 180두를 공시하였으며, 사양시험은 총 6처리 5반복, 반복 당 6마리씩 성별과 체중에 따라 난괴법 (RCBD; Randomized Complete Block Design)으로 배치하였다. 실험기간은 육성전기 (1-3주), 육성후기 (4-6주), 비육전기 (7-9주) 와 비육후기(10-12주)로 분류하였고, 에너지 수준과 단백질 수준에 따라 2 × 3 factorial design으로 설계되었으며, Factor 1은 저에너지수준 (3,200 kcal of ME/kg)와 고에너지수준 (3,300 kcal of ME/kg)로 구성된 에너지 수준이고, Factor 2는 사료 내 낮은 단백질 수준 (16%/14.3%/14.3%/11.2), 중간 단백질 수준 (17.0%/15.3%/15.3%12.2%)과 높은 단백질 수준 (18.0%/16.3%/16.3%/13.2%)으로 설정하였다. 실험 결과, 육성전기에서 ADG와 G:F ratio는 사료 내 단백질수준이 감소함에 따라 감소하였으며 (P=0.04; P=0.03, respectively), 육성기에서 G:F ratio는 사료 내 단백질수준이 감소함에 따라 감소하였다 (P=0.02). 또한 전체 실험기간에서 G:F ratio는 사료 내 ME가 3,300kcal/kg-3,200kcal/kg까지 감소함에 따라 감소하였다 (P=0.01). 양돈 사료 내 ME의 100 kcal 감소가 전체 실험기간 혈액 성분에서 육성기의 혈중 BUN 농도를 증가 시키고 (P<0.01), 비육기에서 혈액 내 total protein을 감소시켰다 (P=0.04). 돈육 품질에서는 일반성분 분석, 이화학적 특성, 지방 산패도 분석, pH와 육색에 영향을 주지 않았으며, 사료 내 ME의 100kcal/kg 감소가 포화지방산농도를 증가시키고, 고도 불포화지방산 농도를 감소시켰다 (P<0.01; P=0.03, respectively). 또한, 사료 내 단백질 수준의 감소가 단일 불포화지방산 농도를 유의적으로 증가시키는 경향을 나타내었다 (P=0.06). 경제성 분석에서는 사료 내 100 kcal/kg의 에너지 감소가 육성비육돈 1마리당 출하 비용과 육성비육돈 1kg 증체당 소요되는 비용에서 유의적으

로 증가하는 경향이 나타났다 (P=0.08; P=0.07, respectively). 결론적으로 양돈 사료 내 고 에너지와 높은 단백질 수준은 육성비육돈 성장성적을 개선시키고, 돈육 품질을 개선하고, 생산비를 감소시키는 결과를 나타냈다.

Experiment Ⅲ. Effect of Dietary Energy and Crude Protein Levels on Reproductive Performance, Litter Performance, Milk Quality and Blood Profiles in Gestating Sows

본 연구는 임신돈 사료 내 에너지 수준과 단백질 수준이 모돈의 번식성적, 포유자돈의 성적, 돈유 품질과 혈액성상에 미치는 영향을 검증하기 위해 수행되었다. 2원 교잡종 (Yorkshire×Landrace) F1 모돈 (평균산차 : 4산; 실험 모돈 산차: 3-6산) 59두를 선발하여 6처리, 처리 당 9/10 두씩 완전임의 배치법 (CRD; Completely randomized design)으로 배치하였다. 실험은 사료 내 에너지 수준과 단백질 수준에 따라 2 × 3 factorial design으로 설계되었으며, Factor 1은 저에너지 (3,200 kcal of ME/kg) 와 고에너지 (3,300 kcal of ME/kg)로 구성된 에너지 수준이고, Factor 2는 사료 내 단백질 수준: 낮은 단백질 수준 (11.5%), 중간 단백질 수준 (12%) 와 높은 단백질 수준 (13.5%)으로 설정하였다. 실험 결과,임신돈 사료 내 에너지와 단백질 수준이 증가함에 따라 모돈 체중, 체중변화량, 포유기 사료섭취량과 재귀발정일에서는 유의적인 차이를 나타내지 않았다. 임신돈 사료 내 단백질 수준이 증가함에 따라 포유기 모돈의 등지방 변화량이 유의적으로 감소하였다 (P = 0.03). 임신돈 사료 내 에너지 100 kcal/kg 증가가 복당 생시체중에 유의적인 영향을 미치지 않았으며, 복당 총 산자수가 증가하는 유의적인 경향을 나타내었기 때문에 (P = 0.07), 자돈 생시체중이 유의적으로 감소하는 것으로 나타났다 (P = 0.02). 전체 포유기간에서는 임신기 사료 내 에너지와 단백질 수준이 증가함에 따라 복당 포유자돈의 체중 증가량에는

영향을 미치지 않았다. 또한 임신기 사료 내 에너지와 단백질 수준이 상유 품질에서 유의적인 차이를 나타내지 않았다. 초유 품질에서는 임신돈 사료 내 단백질 수준이 증가함에 따라 초유 품질이 감소하였다 (Casein: P = 0.03; Protein: P = 0.04; Lactose: P = 0.06; Total solid: P = 0.03; Solid not fat: P = 0.03). 모돈의 포유 21일령에서 임신돈 사료 내 에너지 수준이 증가함에 따라 모돈 혈액 내 glucose가 유의적으로 증가 하는 것으로 나타났다 (P = 0.04). 임신 110일령, 분만직후와 포유 21일령에서는 모돈의 혈액 내 BUN 농도가 임신돈 사료 내 단백질 수준이 증가함에 따라 유의적으로 linear하게 증가하였다 (linear, P<0.05, P<0.05, and P<0.05, respectively). 또한 임신 110일령과 포유 21일령에서는 모돈의 혈액 내 BUN 농도가 임신돈 사료 내 에너지 농도가 증가함에 따라 유의적으로 증가하였다(P<0.01, and P<0.01, respectively). 따라서, 임신돈 사료 내 높은 에너지 수준 과 낮은 단백질 수준이 번식성적 및 초유품질을 개선시키고, 포유자돈의 폐사를 감소시키고, 농가의 생산성을 개선시키는 결과를 나타냈다.