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Different Energy and Protein Levels in Diet on Growth Performance, Blood Profiles, Pork Quality and Feed Cost in Growing-finishing Pig

사료 내 에너지, 단백질 수준이 육성-비육돈의 성장성적, 혈액성상, 도체특성 및 경제성에 미치는 영향

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Summary

This study was conducted to evaluate the optimal energy and protein level in feed of growing-finishing pigs for growth, blood profiles, pork quality and feed cost. This experiment was done by a factorial design and factor 1 was two level of energy (3,150 or 3,300 kcal of ME/kg), and factor 2 was also two level of dietary protein in feed (90% of NRC CP requirements in 2012 or NRC CP requirements in 2012). Growth performance of growing-finishing pigs was improved when pigs were fed high dietary energy and high protein treatment diet (HH) both in late growing phase and the late finishing phase, respectively (P=0.03; P=0.05). Average daily gain (ADG) was increased when higher protein diets (LH and HH) were provided to growing-finishing pigs (P=0.03) and dietary protein was much more potent nutrient than dietary energy for growth of pigs during the whole experimental period. Average daily feed intake (ADFI) was also increased when pigs were fed higher protein diet particularly during growing phase (P=0.01) and this trend was maintained during finishing phase (P=0.03). Gain to feed ratio (G:F), however, was mainly affected by dietary energy (P=0.06) rather than dietary protein level (P=0.67). Blood urea nitrogen (BUN), total protein, creatinine and blood glucose were lowered when low energy and low protein diet (LL) was provided (P=0.01), resulted in an interaction (P=0.01). Although pH of pork was lowered when pigs were fed low protein treatment diet (P=0.03), but other measurements of pork quality, such as color, chemical analysis and TBARS, were not affected by dietary levels of energy and protein. Feed cost per weight gain was lowered when pigs were fed high energy and low protein treatment diet however, feed cost per pig was increased when dietary protein level was increased (P=0.01). Although total feed cost to 110kg of body weight was the lowest in low energy and low protein treatment (LL), days to market weight from 27.22 to 110kg was the shortest in high energy and high protein treatment (HH) among dietary treatments. Even

though feed cost could be saved in LL treatment, days to market weight was delayed about 19 d compared to HH treatment subsequently LL treatment would not be efficient feed formulation for growing-finishing pigs. Consequently, this experiment demonstrated that high protein diet resulted in improved growth performance in growing pigs but high energy (3,300 kcal of ME/kg) and low protein (90% of NRC(2012)) diet would be desirable feed formulation based upon feed cost, days to market weight and pork quality.

Key words: Dietary energy and protein, Growing-finishing pig, Growth performance, Blood profiles, Pork quality, Feed cost

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List of Abbreviation

AA	Amino acid
AAFCO	Association of American Feed Control Officials
ADFI	Average daily feed intake
ADG	Average daily gain
AOAC	Association of official analytical chemists
ARG	Arginine
BF	Backfat
BUN	Blood urea nitrogen
BW	Body weight
CP	Crude protein
DE	Digestible energy
EE	Ether extract
FCR	Feed conversion ratio
FFA	Free fatty acid
G:F	Gain to feed
IMF	Intramuscular fat
KFSS	Korean feeding standard for swine
LYS	Lysine
ME	Metabolizable energy
MET	Methionine
MUFA	Mono unsaturated fatty acid

NRC	National research council
PUFA	Polyunsaturated fatty acid
RCBD	Randomized complete block design
SAS	Statistical analysis system
SBM	Soybean meal
SD	Standard deviation
SFA	Saturated fatty acid
TBARS	2-thiobarbituric acid reactive substances
THR	Threonine
TRP	Tryptophane
USFA	Unsaturated fatty acid
WHC	Water holding capacity

I. Introduction

Recently, global grain price tends to increase with various reasons. Extreme climate change, decrease of cultivation acreage and increase of meat consumption are also having a significant impact on global grain prices subsequently prices of feed ingredients will be increased continually in the future. In South Korea, it is known that feed cost comprised approximately 60 percent of the total cost of pig production and about 60 to 70 percent of ingredients in swine feed is consisted of corn and soybean. Over the last two decades, pig industry in Korea has been developed greatly and pork price has been maintained about 2~3 times higher than that of USA and EU. Therefore, swine producers in Korea are concerned about fast growing of pigs regardless of cost of feed or pork quality and are less interested in saving of production cost and improving productivity of farm. Moreover, many feed companies have been selling high-nutritive feed at high prices, and swine producers do not aware of the serious situation by feeding over-nutritive feed to pigs. Swine feed contained excessive nutrients not only increased Growing-finishing period is an important time to maximize the growth of pigs, in addition, pigs are generally consuming much more feed compared to other phase of pigs subsequently feed cost during this period is being comprised approximately 70% of total cost of feed of pigs. To save feed cost, swine producers need to avoid wasting of feed and formulate efficient feed which contains adequate nutrients for normal growth of pigs.

When swine feed is formulated efficiently, nutrients in feed will be well utilized in growing-finishing pigs subsequently growth rate of pigs has improved and days to market weight can be reduced. Not only price of swine feed, but also pollutants in environment will be great concerned when feed contained excessive nutrients. Among of nutrients, crude protein and energy contents in swine feed determine the price of feed, resulting in affecting net profit of swine farm. Consequently, this study was conducted to evaluate the optimal levels of energy and protein in swine diet on growth performance, blood profiles, carcass characteristics and feed cost in growing-finishing pigs.

II. Literature Review

1. Introduction

1.1 Genetic Improvement and Nutrient Requirement for Pigs

Genetic improvement of pigs, supported by constant breeding programs and genetic discoveries, has steadily been enhanced since its start in the early 20th century (especially in Northern Europe). In its initial phase, the focus was mainly on lean mass and feed efficiency of pigs. Studies have seen gradual advances in genotype or phenotype, so that enhancement of breed characteristics (such as type, color, and back fat thickness) was achieved, and daily gain and feed efficiency were constantly improved.

Since the beginning of animal domestication, humans have been aiming to breed animals best satisfying our interests. In its start, our goals concerned general features like size and color, and the matter of docility. Dickerson (1952, 1974) studies concerning crossbreeding of plants and poultry garnered attention from pig farms. The phenotypic trends of Dutch Landrace pigs and Dutch Yorkshire pigs from 1930 through 1990 is shown in Table 1. Merks (2000) reports 50-plus percent increase in daily gain, outstanding enhancement in feed efficiency, and approximately 50% of decrease in backfat thickness. Figure 1 shows main genetic trends through the century (including daily gain, backfat thickness, and litter size).

Table 1. Phenotypic trends in central test results in the Netherlands from 1930 until 1990

Race	Daily gain (g/d)	Feed efficiency (kg/kg)	Backfat thickness (mm)
Dutch landrace			
1930	500	3.5	45
1947	650	3.4	33
1972	788	2.6	26
1990	840	2.8	24
Great Yorkshire			
1930	550	3.4	48
1947	680	3.2	35
1972	815	2.5	27
1990	840	2.7	22

Sources:Merks,2000

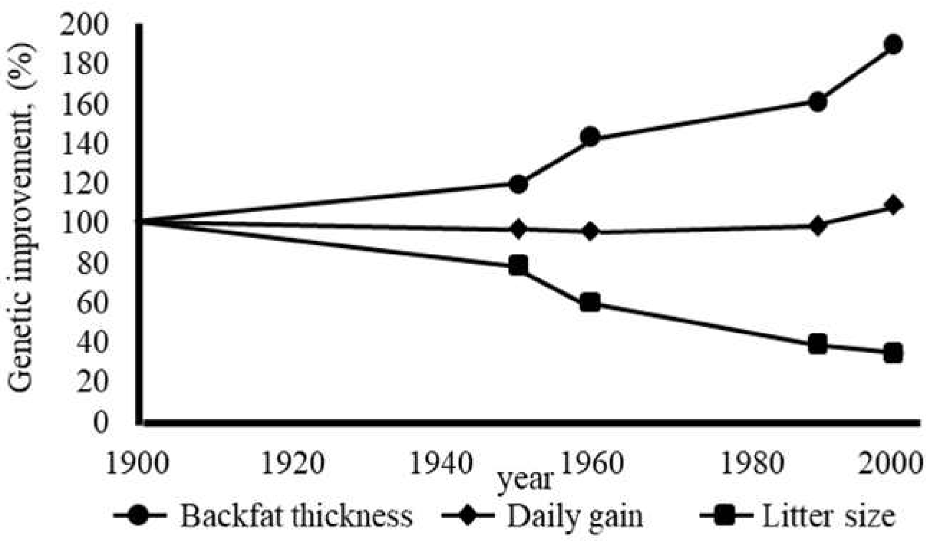

Figure 1. Schematic description of one century of genetic progress in pigs (Merks, 2000)

Advancement in the field of genetics (such as that of molecular genetics) continued into the last decade of 20th century, allowing improvement of sire and dam lines for swine reproduction systems.

Enhancement in growth performance and feed efficiency keeps proceeding, according to Knap (2009) and Torres et al. (2005). Intramuscular fat (IMF) content shows decrease in Brewer et al. (2001), as an outcome of breeding for leaner genotype.

The purpose of breeding programs was centered on daily gain, feed efficiency and litter size, and has evolved to also include characteristics like meat quality and vitality of piglets (Knol, 1998). There are also some studies involving gene-environment interaction (Andersen et al., 1998; Merks and Hanenberg, 1998) and inbreeding (Meuwissen, 1998).

Some scientists concentrated on the nutrient requirements of pigs. Ideal lysine/digestible energy (DE) ratio in growing pigs can be seen in Table 2, according to their genotype. Van Lunen and Cole (1996) observed that through genetic improvement, protein deposition and lysine requirements have increased. Naturally, it would be safe to assume that there will be steady increase of the nutrient requirements in pigs.

Table 2. Optimum lysine/digestible energy ratios in growing pigs by different genotype

Genotype	PD (g/day)	Weight (kg)	Lysine/DE ratio		
			Castrate	Gilt	Boar
Unimproved	100	<25	0.78	0.80	0.83
		25-55	0.73	0.75	0.78
Average	125	<25	0.85	0.85	0.88
		25-55	0.78	0.80	0.83
High	150	<25	0.88	0.90	0.93
		25-55	0.83	0.85	0.88
Hybrid	175	<25	1.20	1.20	1.20
		25-55	1.10	1.10	1.10

Sources: Van Lunen and Cole 1996

1.1.1 Nutrient requirement

Dietary energy is used in maintenance, accretion of protein and lipid, and heat loss of production (Van Milgen and Noblet, 2003). From pigs' birth to the point where they reach market weight, daily energy intake keeps increasing. The energy is firstly spent on maintenance, then on protein and lipid accretion (Lizardo et al., 2002). Spare energy will be accumulated as fat. The amount of energy for maintenance takes up about a third of their total energy intake, and the rest is spent on protein and lipid accretion (Black and Lange, 1995; NRC, 1998).

The interaction between energy intake and protein deposition decides the accretion of protein and lipid (through dietary energy) above the animal's maintenance needs. Bikker et al. (1995) states that the genotype and energy intake has influence on the effect of a dietary energy intake on body composition. Davies (1983) states that compared to pigs with low feeding level, pigs with high feeding level accumulated more fat and less muscle. Kanis (1988) and Bikker et al. (1995) suggested that increase in energy intake dropped the efficiency of lean tissue gain. Older pigs, according to Bikker et al. (1996) were shown to preserve more lipid per unit of extra energy than protein. Rao and McCracken (1991) reported an even increase of protein deposition up to 230 g/d, affected by the nitrogen balance of approximately 38 MJ of DE/d. Ellis et al. (1983) and Jorgensen et al. (1985) demonstrated that lowering the energy intake also increases the lean portion and decreases the fat portion in a pig's body. Raising the energy intake has been found to boost the ratio of lipid and protein deposition (LD : PD) (Campbell et al., 1983; De Greef et al., 1994; Bikker et al., 1995). Campbell and Taverner (1988) agreed to these influences of energy intake on body composition. Bikker et al. (1995) claimed that higher energy intake in growing female pigs lessened the protein deposition of lean tissue. De Greef et al. (1994), illustrated the increase of LD : PD as pigs' body weight increased, claimed that LD : PD increased in boars weighing 25 ~ 105 kg, regardless of high or low feeding level.

1.1.2 Nutrient Requirement of Pigs

In pig farming industry, two important factors for maximum result are growth rate and feed cost. Swine production aims to get more products from various feeds that provide proper nutrients. There are several nutrients crucial for synthesis of muscle, adipose tissue, bone, hair, skin and other body parts. They include energy, protein, amino acid, minerals, vitamins, water, etc. Nutrients also play great part in body maintenance, growth, reproduction and lactation.

Meanwhile, Wilson and Bayer (2000) claimed that feed ultimately affects 60% of the cost for producing market-weight pigs. Overfeeding nutrients is reported to have negative influence on the environment (Swine Nutrition 2nd Edition, 2001). Underfeeding is reported to affect pigs' 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). As these claims imply, nutrient concentration influences swine performance, and thus connected to cost of production. Accordingly, we need studies appraising changes in requirements of nutrients and resulting swine performance. The studies would enable us to enhance swine productivity and save feed cost.

1.2. Nutrient Requirement for Growing-Finishing Pigs

As nutrients intake is vital for growth, breeding and production of livestock animals, there has been continuous study on animal nutrition, in order to provide enough nutrients for animals without either excess or deficiency. As of pigs, there are enough information acquired through numbers of experiments (concerning pig's weight gain, feed efficiency, protein accretion rate, etc.). However, some differences exist depending on changing body weight and circumstances of animals. As a result, the standard of nutrient requirement for pigs was set by institutions worldwide (e.g. NRC of the USA (1998), ARC of the UK (1981), SCA of Australia (1987) and JRC of Japan (1993)). Rural Development Administration of South Korea also joined in by publishing the Korean Feeding Standard for Swine (2007).

Feed intake of growing-finishing swine depends on energy content in feed. Feed of high energy content leads to decrease in feed intake, increase in weight gain, and decrease in lean percentage following increased lipid accumulation. Daily energy requirement is obtained through the sum of the requirements for maintenance, protein and fat deposition, and thermo-regulation. Pigs of growing-finishing period need energy to grow and maintain bodily functions. Maintenance energy is fundamental in supporting life and body temperature and is gauged from heat production in fasting period. NRC (1998) suggests 110 $W^{0.75}$ kcal of DE daily or 106 $W^{0.75}$ kcal of metabolizable energy (ME) daily for pigs of all weights.

Because stage of growth, dietary energy and other nutrients influence fat and protein deposition, energy requirements for growth may vary. They are needed in synthesis of bone, tissue, organ, muscle and fat by protein and lipid deposition. Verstegen et al. (1987) stated that 10.6 Mcal of ME is needed for synthesis of a gram worth of protein, 12.5 Mcal of ME for synthesis of equal amount of fat. According to Wenk et al. (1980), protein took up 23% in a kilogram of muscle tissue; fat took up 80~95% in a kilogram of fat tissue. This shows that muscle synthesis requires more energy than fat deposition.

Table 3 shows standardized energy requirements for growing-finishing pigs set up by different institutions worldwide. NRC suggested 3,265 kcal/kg of ME (1998) as energy requirement of growing-finishing pigs (3,300 kcal/kg in its 2012 report). KFFS suggested 3,265 kcal/kg of ME (2007) as well (2012 report details the amount as follows: 3,350 kcal on 25 ~ 45 kg pigs, 3,300 kcal on 45 ~ 120 kg pigs). SCA (1987) and JRC (1993) shares similar information regarding pigs of growing-finishing phase. ARC (1981) shows lower energy requirement according to their own data of genotype, growth rate, lipid deposition and environmental factors.

Table 3. 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
EstimatedME[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	
EstimatedME[1)], kcal/kg	2,983		2,983	
SCA, 1987	20 - 50		50 - 90	
DE. kcal/kg	3,346		3,346	
EstimatedME[1)], kcal/kg	3,212		3,212	
JRC, 1993	30 - 70		70 - 110	
DE. kcal/kg	3,300		3,300	
EstimatedME[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)

Protein level in pigs in general represents 15~18% of their body mass, and 45~60% of it is shared to dissectible muscle or lean meat. Others spread to pigs' visceral organs, hair, bone, skin, blood and other tissues. Dietary protein replaces proteins lost in protein turnover, and is disposed as cells, amino acids, other nitrogenous compounds and unabsorbed enzyme secretions from the intestine ("metabolic fecal losses" or "endogenous fecal losses"), or urea from the kidney ("urinary losses"). In addition, amino acids found in protein are needed for the synthesis of non-protein compounds (hormones, neurotransmitters, immunoglobulins and other bioactive peptides). As seen in Table 4, which shows protein requirement for growing-finishing pigs, they require less protein as they mature. Quite a few researchers proposed that adequate amino acids balance is more effective for pigs' growth than protein level.

Table 4. Protein requirements for growing-finishing pigs

Item	Body weight (kg)			
NRC, 1998	20 - 50	50 - 80		80 - 120
Protein, %	18.0	15.5		13.2
NRC, 2012	25 - 50	50 - 75	75 - 100	100 - 135
Protein[1)],%	15.8	13.8	12.2	10.5
KFSS, 2007	25 - 50	50 - 80		80 - 120
Protein, %	18.0	16.0		13.0
KFSS, 2012	25 - 45	45 - 65	65 - 85	85 - 120
Protein, %	-	-	-	-
ARC, 1981	15 - 50		50 - 90	
Protein, %	15.6		11.2	
SCA, 1987	20 - 50		50 -90	
Protein, %	15.6		11.5	
JRC, 1993	30 - 70		70 - 110	
Protein, %	15.0		13.0	

[1)]Calculated from total nitrogen X 6.25

Main ingredients for swine feed like corn, barley and wheat can cover 30~60% of total amino acid requirements. Soybean meal is also an ample provision of pigs' requirements of protein and amino acid. The following 9 amino acids are indispensable amino acids that should be obtained through pigs' diet: lysine, methionine, threonine, tryptophan, histidine, isoleucine, leucine, phenylalanine and valine. Cysteine and tyrosine can only be synthesized from essential amino acids (from methionine and tyrosine, respectively), and these can be viewed as semi-essential. Lysine generally is considered the first-limiting amino acid in cereal-grain-based pig diets. Dietary amino acids requirement for swine is closely associated with protein accretion, energy intake and dietary energy density in their growing-finishing phase (NRC, 1998). The whole-body protein accretion rate differs according to genetic strain, gender, health and stock density, or to combination of these or other factors. However, the amount of lysine needed for growing-finishing pigs decreases linearly (Figure 2).

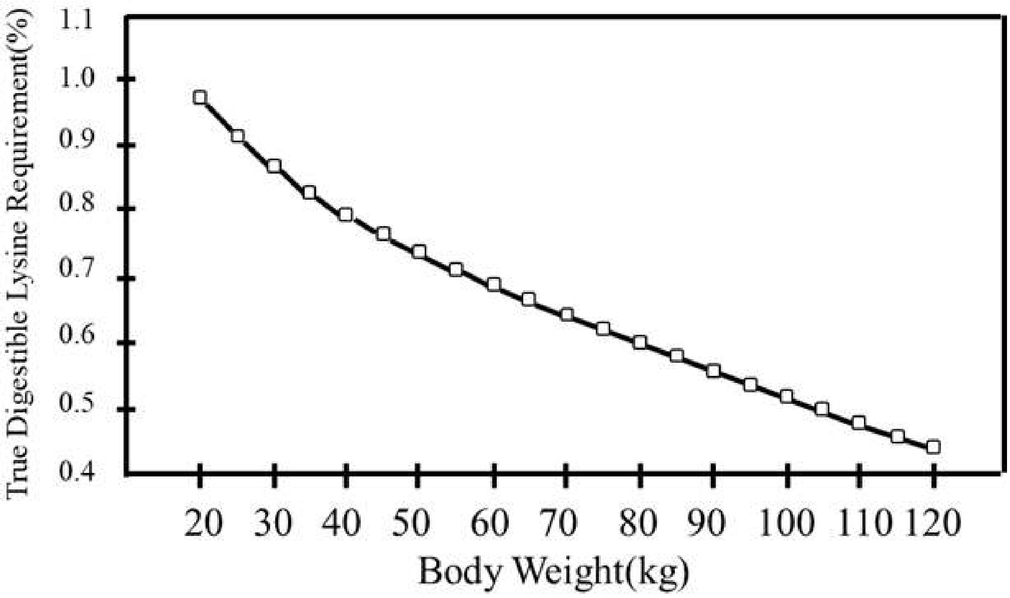

Figure 2. Lysine requirements (%, true ileal digestible basis) of pigs with a mean lean growth rate (NRC, 1998)

Institutes differ as to the requirement of lysine for growing-finishing pigs (Table 5). They all show linear decline of lysine requirement through pigs' growth. Nonetheless, these feeding standards show distinction, taking into account genetic strain, gender, health, growth rate, etc.

Table 5. Lysine requirements for growing-finishing pigs

Item	Body weight (kg)			
NRC, 1998	20 - 50	50 - 80		80 - 120
Lysine[1)], %	0.95	0.75		0.60
NRC, 2012	25 - 50	50 - 75	75 - 100	100 - 135
Lysine[1)], %	1.12	0.97	0.84	0.71
KFSS, 2007	25 - 50	50 - 80		80 - 120
Lysine[1)], %	0.98	0.82		0.64
KFSS, 2012	25 - 45	45 - 65	65 - 85	85 - 120
Lysine[1)], %	1.22	1.01	0.91	0.76
ARC, 1981	15 - 50		50 - 90	
Lysine[1)], %	1.10		0.78	
SCA, 1987	20 - 50		50 -90	
Lysine[1)], %	0.83		0.60	
JRC, 1993	30 - 70		70 - 110	
Lysine[1)], %	0.75		0.56	

[1)]Lysine requirement for total basis(%)

Dietary protein is vital source for the synthesis of body tissue, organ, hair, bone, skin, blood and other tissues. Moreover, some amino acids in protein are necessary for the synthesis of non-protein compounds; hormones, neurotransmitters, immunoglobulins to name a few, and other bioactive peptides.

Nutrient requirements decrease as pigs grow, and one way to provide appropriate nutrients for growing-finishing pigs is phase feeding. Phase feeding prevents the waste of nutrition, saves the cost for feedstuff, as well as curtails the emission of nitrogen.

Table 6 shows crude protein (CP) requirements for growing-finishing pigs set by the NRC. It shows that NRC (2012) has divided the phases of growing-finishing pigs into four, whereas in NRC (1998) the phases had been divided into three. CP requirements according to pigs' weight has lessened in NRC (2012) than in NRC (1998). This, along with many other reports, suggests that providing precise balance of amino acids is more effective for pigs' growth than protein level is.

Table 6. Crude protein requirements for growing-finishing pigs in NRC 1998 and 2012

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

[1)]Calculated from total nitrogen X 6.25

1.3 Protein Deposition

1.3.1 Protein and Amino Acids

Proteins are primary nutrients for biological processes. They are macromolecules that make possible, virtually all molecular transformations and biochemical reactions.

Amino acids can combine into various chemical substances apart from proteins, including peptides, hormones, neurotransmitters, purine and pyrimidine nucleotides, creatine, carnitine, porphyrins, polyamines, and nitric oxide in an animal body (Wu and Morris, 1998). All natural proteins consist of 20 α-amino acids. These have a carbon that includes a primary amino group and a carboxyl group. Amino acids vary according to different structures of side chains contained in them. Since animal cells cannot utilize inorganic N (like urea or ammonia) to form amino acids when carbon skeletons are unavailable, essential amino acids must be included in the animal diets. Chung and Baker (1991) observed that piglets are fattened when provided a diet with crystalline amino acids as the only source of nitrogen. Easter and Baker (1976) observed that gilts go through normal pregnancy during the last 84-day phase of gestation when fed the same diet. Amino acids not only act as precursors of protein, but also of nitrogenous substances (such as nitric oxide, polyamines, creatine, dopamine, and catecholamines) that are crucial for whole-body homeostasis (Wu and Meiniger, 2002; Odenlund et al., 2009; Suryawan et al., 2009).

1.3.2 Protein Deposition

PDmax refers to the upper limit of protein deposition achieved or achievable by a pig. To get maximum results in growth rate and body weight gain (especially lean tissue growth), pigs' genotype and their PDmax were considered on the preferential basis. Energy usage for maintenance is followed by energy usage for protein accretion, which is followed by PDmax curve. PDmax curve is set up by numerous studies (Carr et al., 1977; Moughan and Verstegen, 1988; Thompson et al., 1996; De Greef et al., 1994; Van Lunen and Cole, 1998; Weatherup et al., 1998).

In Figure 3 is displayed the interrelationship between energy intake and body protein deposition. When body weight reaches certain amount, protein deposition slowly increases while energy intake approaches PDmax point (This is on the assumption that there are no factors hindering the protein deposition.) (Campbell and Taverner, 1988; Bikker et al., 1995, 1996; Quiniou et al., 1995, 1996). More energy intake from this point on results only in more lipid deposition. This will lead to fatter carcass and poorer feed efficiency. Pig farming is most efficient when energy intake is at PDmax level.

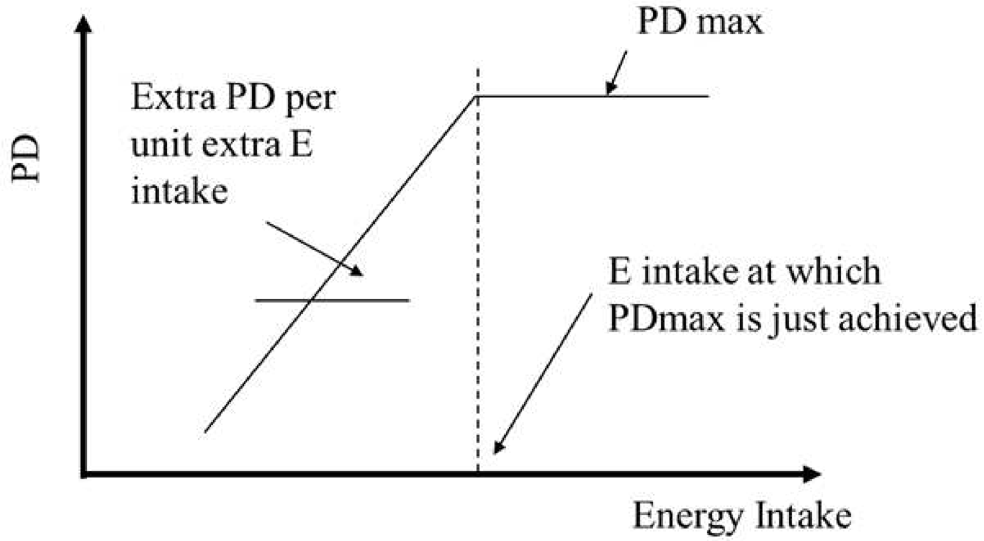

Figure 3. Relationship between energy intake and body protein deposition(PD) in growing pigs (Swine nutrition, 2nd edition)

PDmax point in growing-finishing pig is between 90~160 g/day (Carr et al., 1977; Moughan and Verstegen, 1988; Thompson et al., 1996). Recently, boars occasionally show PDmax of above 200 g/day (De Greef et al., 1994; Van Lunen and Cole, 1998; Weatherup et al., 1998). This shows that PDmax can be enhanced to a great extent, which is linked to great possibilities of lean growth through genetic selection. PDmax curve can be maintained or increased as energy intake in a 40 ~ 90 kg weighing pig, depending on pig’s genotype (Campbell and Taverner, 1988; De Greef et al., 1994; Quiniou et al., 1995; Bikker et al., 1996).

PDmax is highest in boars, then in gilts, and is lowest in castrates. When fully grown, there is approximately 5% difference in PDmax between gilts and castrates (Moughan and Verstegen, 1988; Stranks et al., 1988; Thompson et al., 1996), approximately 20 ~ 30% difference between boars and castrates (Moughan and Verstegen, 1988; Van Lunen and Cole, 1998).

1.4 Lipid Deposition

Protein deposition and lipid deposition occur simultaneously, but extra dietary energy is utilized first in protein deposition and then on lipid deposition.

Whittemore (1993) defined 'target fat' as the minimum amount of fat when animals would feel physiologically comfortable, so that available nutrients can be properly shared, and metabolism for reaching potential rate of lean tissue growth can be maximized. When remaining energy level for lipid deposition is lower than certain target fat level, achievement of protein deposition rates will be altered to achievement of target fat levels. This condition would set the physiological priority to restore fat levels to target fat level. Whittemore et al. (1988) explains the minimum amount of lipid (connected to the amount of protein deposition a growing pig can achieve) through the target fat level. This is because protein gains will be held back until target fat level is reached. Before lean-tissue growth rate reaches the full extent, the ratio of fat to lean will indicate the percentage of fat in the gain, which is the target level (Figure 4, Whittemore, 1993).

Kyriazakis and Emmans (1992) explained that the rate of lipid deposition is determined by the protein deposition rate that an animal may

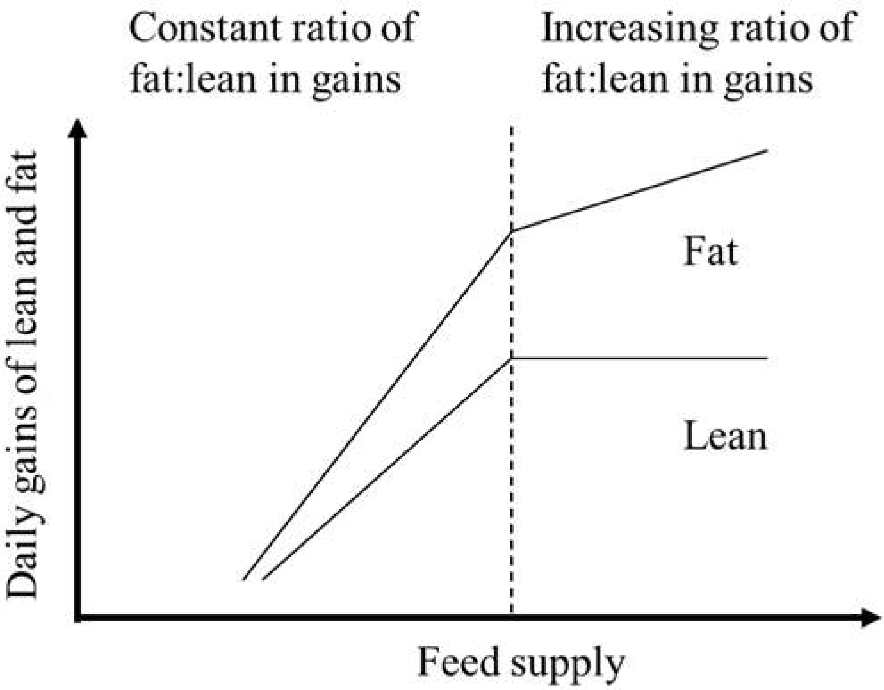

Figure 4. The ratio of lean to fat in gain (Whittemore, 1993)

achieve in its attempt to reach the normal level in a non-limiting environment. If the animal lacks in both protein and lipid level, each will aid the other in their balance. Increasing feed intake in the state of protein deficiency improves lipid retention rates (Kyriazakis and Emmans, 1992; Ferguson and Gous, 1997; Ferguson et al., 2000).

Whittemore (1998) explains, when animals become or are made overweight (through high quality diet, for example), they use remaining body fat to maintain their normal protein level, or they accumulate less lipid to restore by the lipid : protein ratio. Ferguson and Theeruth (2002) states that empty bodies of the pigs that are provided high-protein diet showed notably lower response from the lipid : protein ratio compared to those provided with low-protein diet, also agreed with Kyriazakis and Emmans (1991) and Ferguson and Gous (1997) reports. Pigs given feed of deficient protein are reported to acquire lipid rapidly compared to those given feed with appropriate amount of protein, and try meeting their potential protein growth rate (Kyriazakis et al., 1991; Ferguson and Gous, 1997).

2. Dietary Energy of Growing-Finishing pig

2.1 Effect of Dietary Energy Levels in Growing-Finishing Pigs

Dietary energy level is an important factor for having variety in feed intake. Controlling feed intake is dependent on energy density. Pettigrew and Moser (1991) explained that growing-finishing pigs generally showed less average daily feed intake (ADFI), more average daily gain (ADG) and gain to feed ratio (G : F) when provided with high dietary energy level. Few studies suggested that increasing energy in growing-finishing pigs' diet — although it did not have noteworthy effect on body weight and ADG — enhanced G : F (Baird et al., 1958; Clawson et al., 1962; Wagner et al., 1963). Chadd and Cole (1999), Smith et al. (1999) and De la Llata et al. (2001) however, represented that energy level too low for pigs lessened the energy intake and growth performance. Energy level too high on the other hand (according to Stahly et al. (1981), Southern et al. (1989), Williams et al. (1994) and Dunshea et al. (1998)), decreased ADG, ADFI and G : F. Cromwell et al. (1978) and Matthews et al. (2003) claimed different results altogether, stating different levels of energy on growing-finishing pigs do not affect growth rate and ADFI.

Stahly (1984) pointed to fat as a crucial component in growing-finishing pigs' diet, having high energy level. According to Young et al. (2003), adding 2.5% and 5% fat in the feed for growing-finishing pigs resulted in similar ADG and G : F. Haydon et al. (1989) claimed likewise, that 5% fat added for growing pigs did not produce any effect on their growth performance. However, adding 4.5% or 10% fat produced higher G : F and lower ADFI (Southern et al., 1989; Azain et al., 1991; Williams et al., 1994; Matthews et al., 2003). Some experiments achieved enhanced ADG and G : F in summer season by adding 5% fat in growing-finishing pigs' diet (Stahly and Cromwell, 1979; Stahly et al., 1981). De la Llata et al. (2001) reported enhanced ADG and G : F, reduced ADFI by adding 0%-6% of fat with 3.31~3.61 Mcal.

2.2 Dietary Energy Level and Fat Deposition

Pigs nowadays are leaner and require less feed intake. This means that growth rate can be enhanced by increasing energy intake, and pigs are less likely to become fatter (Young et al., 2003). Additionally, humans have achieved the desirable level of energy density in growing-finishing pigs' diet. Many countries have found diets using the available energy sources with least cost to satisfy the energy levels of pigs. Quite a few studies report that increasing energy density by including fat in growing-finishing pigs' diets generally enhances ADG and feed efficiency, while cutting down the ADFI. Pigs up to 59 kg go through an energy-dependent phase in growing phase (De la Llata et al., 2001). Bikker et al. (1996) noticed an energy-dependent phase in gilts from 45 ~ 85 kg and reasoned that protein deposition increased with more energy intake. Pigs from 93 ~ 120 kg were not in an energy-dependent phase, and therefore energy density of diet did not boost ADG. Smith et al. (1999) similarly observed added dietary fat had no effect on ADG from pigs weighing 73 ~ 104 kg. Put together, it can be said that dietary energy density is a crucial factor in protein or fat deposition. If pigs get more dietary energy than needed in growing phase, they will use leftover energy in lipid deposition or other body functions. If they get less than required, however, they will spend the energy not only in protein deposition but also in fat deposition. In finishing phase, dietary energy will be used in maintenance and protein deposition, and the excess will usually be spent in lipid deposition.

There are many studies demonstrating the relationship between dietary protein level and fat deposition in animals. Several reports that decrease in dietary protein level causes increase in fat deposition (Cromwell et al., 1978; Karlsson et al., 1993; Chiba et al., 2002). Teye et al. (2006) states that researchers have been applying CP diets containing unbalanced amino acids with net energy in order to bolster pigs' fat deposition (especially IMF). There are still some claims, however, of inclination for higher fat deposition with low-protein diets, even if the pigs are supplied balanced amino acids (Figueroa et al., 2002; Gomez et al., 2002b). Wood et al. (2013) study states that feeding low-protein diet, especially those with unbalanced amino acids content, boosted the IMF accumulation. This study, however, does not display much difference between low-protein diet group and control group in subcutaneous or intermuscular fat deposition.

Several studies explain the reason behind fat deposition when low-protein diets are provided. The gap between lipogenesis and lipolysis rates decides fat deposition. The reactions are controlled by metabolic enzymes and functional genes in the growth, and the following development process of muscle tissue (Wang et al., 2012). Jurie et al. (2007) suggested that fatty acid transport in muscle tissue also regulates IMF deposition.

Chen et al. (2008) discovered a beneficial link between IMF deposition and expression level of SREBP-1 messenger RNA (mRNA) in muscle tissue of pigs. Some other studies also discovered a connection between stearoyl-CoA desaturase (SCD) protein expression and the amount of total fatty acids in muscle of pigs that are provided a low-protein diet (Doran, 2006). Wang et al. study (2012) claimed that low-CP diet increases the mRNA and protein expression of SREBP-1c, ACC, FAS and SCD. mRNA and protein expression level of lipolytic genes including HSL and CPT-1 were seen to decrease in the low-protein diet group. Furthermore, a positive connection between an elevated IMF content in pigs that are fed low-protein diet and activation of PPAR-ɣ and H-FABP mRNA expression is also suggested (Guo et al., 2011). According to Zhao et al. (2010), pigs fed low-protein diet showed increase in subcutaneous fat deposition. This result was induced primarily by up-regulation of lipogenic genes for pigs weighing 60 ~ 100 kg, down-regulation of lipolytic genes for pigs weighing 60 kg, and up-regulation of lipolytic genes for those weighing 100 kg.

Dietary protein level affects muscular fatty acid composition. Wang et al. (2012) claimed that pigs with low-protein diet showed higher concentration of C18:2, C18:3 and poly-unsaturated fatty acid (PUFA) than pigs with high-protein diet. The difference of fatty acid composition between low-protein/high-protein diet may come from the variance of SCD. According to Cohen and Jeffrey (2004), SCD is accountable for the generation of mono-unsaturated fatty acids, which catalyzes its substrates palmitic (16:0) and stearic acid (18:0) to produce palmitoleic (16:1) and oleic acid (18:1). Wang et al. (2012) demonstrated that pigs fed low-protein diet showed higher mRNA and protein expressions of SCD than those of high-protein diet. Additionally, Wood et al. (2013) pointed out that oleic acid is the central outcome from de novo fat synthesis in pigs and deduced that its concentration is heightened as the pig gets fatter.

Meanwhile, there are studies displaying considerably lower PUFA and higher IMF content in pigs with low-protein diet (Teye et al., 2006; Alonso et al., 2010). Lambe et al. (2013) claimed that the CT scans of growing pigs showed no meaningful differences in total fat deposition.

2.3 Effect of Dietary Energy Level on Growth Performance

High dietary energy diet for growing-finishing pigs generally enhances ADG, G : F and carcass fatness, and diminishes ADFI (Pettigrew and Moser, 1991).

Young et al. (2003) demonstrates that through quadratic effect of added fat, adding 2.5% fat in the diet caused 2% enhancement in ADG; adding 5% fat resulted in 2.1% increase in ADG. Feed efficiency also was almost coinciding among 2.5% and 5% added fat levels. Following these results, adding 5% or 10% fat in growing-finishing pig's diet increased G : F and decreased ADFI (Southern et al., 1989; Azain et al., 1991; Williams et al., 1994). Furthermore, growing-finishing pigs bred in high temperature conditions showed enhanced ADG and G : F when fed diet of high energy level with 5% added fat, without difference in carcass leanness (Stahly and Cromwell, 1979; Stahly et al., 1981). Increasing fat percentage with 3.31 ~ 3.61 mcal (De La Llata et al., 2001) or energy density (Smith et al., 1999) also proved effective in boosting ADG and G : F while decreasing ADFI.

Feeding increasing choice white grease have been observed to garner similar effects in growing-finishing pigs (Stahly and Cromwell, 1979; Stahly et al., 1981). Campbell and Taverner (1986) and Southern et al. (1989) also reported enhancement of ADG in pigs provided with added fat.

Few researches report important advancement in feed efficiency by adding energy, albeit seeing no noteworthy effect on growth rate (Baird et al., 1958; Clawson et al., 1962; Wagner et al., 1963).

Smith et al. (1999) introduces an experiment of adding 0%, 1.5%, 3%, 4.5% and 6% CWG in the diet of growing-finishing pigs (energy density ranging 3.31 ~ 3.56 mcal/kg of ME in growing diets, 3.32 ~ 3.56 mcal/kg of ME in finishing diets). As energy density increased, ADG and ADFI were lessened, and feed efficiency saw improvement during the course of experimental phase (44.5 ~ 104.3 kg). Tribble et al. (1979), Stahly et al. (1981) and Southern et al. (1989) coincided with the outcome.

Apple et al. (2004) conducted an experiment centered on energy density in finishing phase (3.30 mcal/kg and 3.48 mcal/kg). During the final week of finishing phase, pigs fed 3.48 mcal/kg showed higher ADG then those fed 3.30 mcal/kg, although no such important variation was seen in other phases. Le Dividich et al. (1987) and Matthews et al. (2003) describes no noteworthy result on ADG despite having increased the energy density of late-finishing diets. Williams et al. (1994) and Dunshea et al. (1998) failed to find any interactions between energy density and growth rate in pigs. Again, Seerley et al. (1978), Campbell and Taverner (1986) and Southern et al. (1989) reported to have seen the effect of increased dietary energy on feed efficiency.

Contrary to previous reports, there are claims of no relationship between dietary energy level and growth performance of growing-finishing pigs. Cromwell et al. (1978) and Matthews et al. (2003) stated no influence of higher dietary energy level on growth performance and feed intake, respectively. Matthews et al. (2003) elaborated that high-ME diet (added 200 kcal by 4.5% fat to control diet) did not affect ADG in pigs' early growing phase (although ADFI was increased and G : F was decreased). The ME level in diet did not have noteworthy influence on the growth performance during other phases (late-grower, early-finisher, late-finisher and overall phases). Haydon et al. (1989) also concurred with aforementioned reports that 5% added fat did not affect growth performance.

2.4 Effect of Dietary Energy Level on Carcass Characteristics

Energy level is closely related to carcass fat level in pigs that are provided ad libitum access to feed.

Stein and Easter (1996) experimented with finishing pigs (weighing 55 ~ 112 kg), feeding them diet with 2,700 ~ 3,500 kcal/kg of ME. When dietary energy increased from 3,300 kcal/kg to 3,500 kcal/kg of ME, feed intake lessened. At lower energy density in diet, no change was observed in feed intake. Dietary energy below 3,300 kcal/kg of ME increased carcass lean content. It can be concluded from this experiment that low dietary energy density helps increasing the carcass lean content. Factors pointed out to increase carcass fatness in growing-finishing pigs include added fat (Pettigrew and Moser, 1991), dietary ME (Seerley et al., 1978; Coffey et al., 1982; Myer et al., 1992) and energy intake (Nossamen et al., 1991; Ellis et al., 1996; Wood et al., 1996). Cromwell et al. (1978) and Ellis et al. (1996) observed increased LM area following increased dietary energy intake. Myer et al. (1992) and Matthews et al. (2003) reported few instances when energy density didn’t affect LM area. Other studies claimed that marbling and IMF content was increased by higher dietary energy density (Cromwell et al., 1978; Le Dividich et al., 1987) or energy intake (Ellis et al., 1996; Wood et al., 1996; Lebret et al., 2001). Drew et al. (1971) experimented with the diet of 10% added fat and discovered that IMF content was higher in longissimus (22.4% vs 14.6%) and gluteus medius (14.7% vs 11.1%). According to Wagner et al. (1963), when IMF was augmented in high-energy diet, no difference could be observed in nitrogen content of the meat. It induced thicker carcass backfat, lower lean cut yield, and notably higher dressing yield. Additionally, increase in energy level produced higher dressing yield ― matching the claims of Bowland and Berg (1959) ― and decrease in energy level produced lower lean cut yield ― also proposed by Mulholland et al. (1960). Sewell and Cartoon (1959) study, on the other hand, claimed no relationship between energy level in diets and total yield of lean cuts.

Cromwell et al. (1978) states that dietary fat has no influence on carcass characteristics except for lower yield of lean cuts. Similarly, Matthews et al. (2003) explained that no difference in carcass traits were made by ME level in diet. According to them, carcass temperature (45 min.) and CIE L value showed some increase in pigs given high-ME diets, but shear force was decreased. According to Apple et al. (2004), energy density in finishing pigs’ diets did not affect hot carcass weights and dressing percent. In fact, dietary energy density (3.30 or 3.48 Mcal) did not affect any quality traits (e.g., muscle pH, drip loss, meat color, marbling, firmness, moisture, protein, lipid, ash, cooking loss and shear force). Other researches also concur that dietary energy level is insignificant regarding ultimate LM pH, drip loss percentage (Matthew et al., 2003), meat color and firmness (Coffey et al., 1982; Matthews et al., 2003), marbling scores and intramuscular lipid content (Seerley et al., 1978; Coffey et al., 1982; Myer et al., 1992), and cooking loss (Matthews et al., 2003; Lebret et al. 2001).

Backfat thickness is strongly related to carcass fatness in regard to pork quality and can be an indirect indication of pork quality. Cromwell et al. (1978) claimed that pigs produced more carcass backfat when provided with diet that was higher in energy level. This outcome many other researchers agree to, such as Heitman (1956), Kennington et al. (1958) and Boenker et al. (1960). Smith et al. (1999) measured 10th rib fat depth or longissimus muscle area with real-time ultrasound before slaughter and saw no effect of energy density. After slaughter, however, backfat thickness showed a variance according to different dietary energy density. These discrepancies between the real-time ultrasound and commercial plant fat depths might be coming from the skinning procedure during the slaughter process. Apple et al. (2004), comparing with pigs fed low-energy diets (3.30 mcal/kg), stated that pigs' fat thickness – measured with ultrasound – was greater on d14 and 28 in pigs fed high-energy diets (3.48 mcal/kg). However, dietary energy level did not affect scanned LM area or live weight.

There have been many studies claiming low-protein diet elevates the IMF deposition (Teye et al., 2006; Alonso et al., 2010; Wood et al., 2013). According to Fernandez et al. (1999), increase of IMF content in muscle may be of good influence on meat quality (such as tenderness, flavor, juiciness, and the nutritional value of meat). Various studies agree with this relationship between the meat quality and IMF content in meat that was fed a low-protein diet (Cisneros, Ellis, Baker, Easter and McKeith, 1996; Teye et al., 2006). Font-i-Furnols et al. (1987) went on to report that pork with high IMF content won favor from consumers. Dikeman (1987) stated that IMF activates saliva secretion and improves the juiciness by coating the inside of the mouth. Accordingly, pig farms strived to gain pork with enough IMF content that, not only guarantees taste but also assuages health-related issues concerning high-fat pork (Fortin et al., 2005). (According to Zhang et al. (2007), high consumption of saturated fatty acids heightens the plasma cholesterol level, which may bring cardiovascular disease.)

As of meat color, increase of Hunter L* value in pork fed low-protein diet contributes to visual aspects, giving it more lightness (Suárez-Belloch et al., 2016; Teye et al., 2006). Also, Hunter b* value has been reported to have connection with marbling (Suárez-Belloch et al., 2016). Goerl et al. (1995) observed that low-protein diet increases the Hunter b* value of pork.

Glycolytic potential refers to the potential amount of all muscular substrates that will be utilized in generating lactate after butchery (Monin and Sellier, 1985). It is another crucial factor, considering the effect muscle glycogen content at slaughter has on the rate and the extent of post-mortem pH drop (Henckel et al., 2000). According to Huff-Lonergan and Lonergan (2005), glycogen contained in muscle produces lactic acid during glycolysis, resulting in lower pH level. Ruusunen et al. (2007) observed higher glycolytic potential in pigs fed low-protein diet than in pigs fed high-protein diet. Katsumata et al. (2003) study shares similar point, claiming higher glycogen content in the low-lysine group than the high-lysine group.

3. Dietary Protein and AA in Growing-Finishing Pig

3.1 Protein and amino acid requirements for swine diets

3.1.1 Transition of Protein and Amino Acid Requirements in NRC

Table 7 is the change of protein and amino acid requirements set by NRC. Growth phase is more detailed in 2012 model than in 1998 model. This elaboration can aid in pig farmers' saving the feed cost and decreasing excess nutrient composition of the feed. 2012 model displays higher ME as well, from 3,265 kcal to 3,300 kcal. Moreover, it shows lower CP requirement and higher amino acids requirement compared to its previous report; this comes from preventing lack of limiting amino acids (or imbalance of them). Any deficiency of essential amino acids caused by low-CP diet is suggested that they be filled out by crystalline amino acids.

Table 7. Nutrient requirements of growing-finishing pig (NRC)

NRC, 1998	BW, kg	5-10	10-20	20-50	50-80		80-120
	ME, kcal	3,265	3,265	3,265	3,265		3,265
	CP, %	23.7	20.9	18	15.5		13.2
	Lys, %	1.35	1.15	0.95	0.75		0.6
	Met, %	0.35	0.3	0.25	0.2		0.16
NRC, 2012	BW, kg	7-11	11-25	25-50	50-75	75-100	100-135
	ME, kcal	3,400	3,350	3,300	3,300	3,300	3,300
	CP, %[1)]	20.6	18.9	15.7	13.8	12.1	10.4
	Lys, %	1.53	1.4	1.12	0.97	0.84	0.71
	Met, %	0.44	0.4	0.32	0.28	0.25	0.21

[1)]Calculated from total nitrogen X 6.25

3.1.2 Transition of Ideal Amino Acid Profile

Lack of limiting amino acids may hinder protein synthesis in the body. However, they are essential amino acids that can easily be insufficient in the feed. Mainly, the first limiting amino acid is lysine.

Mitchell (1964) report was first of many researches that specified the 'ideal amino acids profiles.' It indicates amino acids profiles that are adequate for animals' performance, so that all amino acids are equally limiting. ARC (1981), based on the pig carcass, displayed the ideal amino acid ratio of essential amino acids. Wu (2010) however, claimed that their report centers only on the essential amino acid composition of the animal body. Similarly, Wu (2014) claimed that ARC's ideal protein concept fails to consider the relative contribution of maintenance to the total amino acid pigs need. It goes on to assert that ARC did not include arginine, glycine and all synthesizable amino acids.

Wang and Fuller (1989) provided another ideal amino acid profile. They took account of the requirements for both maintenance and tissue protein accretion. Their study featured high content of glutamate in the diet, a reinforcement for non-specific nitrogen source. Non-specific nitrogen source was thought to make up for lack of non-essential amino acids.

Baker made an attempt to assess the amino acid requirements of pigs between 1990 and 2000. Chung and Baker (1992) produced the ideal amino acid profile that includes arginine, glycine, histidine and proline. Their report does not take into account other synthesizable amino acids. They don't elaborate on the reason for using arginine, glycine, histidine and proline proportions to lysine. Whether glutamate is an effective precursor or not, and the influence of high glutamate content on metabolism is also not explained thoroughly. NRC and Baker (2000) does not include proline or glycine in ideal amino acids profiles.

Meanwhile, NRC (2012) increased the requirement of amino acid for pigs, while keeping the ratio among amino acids unchanging. This made the need of limiting amino acids increased. Plus, lower CP level brought about new limiting amino acids such as valine.

3.1.3 Effects of Dietary CP Levels in Growing-finishing Pigs

Growing-finishing pigs, when fed enough CP level in diet, showed higher ADG, G : F and carcass leanness (Gilster and Wahlstrom, 1973; Kornegay et al., 1973; Easter and Baker, 1980). According to Cromwell et al. (1978), diets with dietary CP level from 12 ~ 16% caused greater weight gain and G : F. Cromwell et al. (1993) and Chen et al. (1995) saw similar response in ADG and G : F when fed higher CP content diet. Cromwell et al. (1978) also noticed no influence on growth performance when dietary CP level ranges from 16 ~ 20%. Wagner et al. (1963) observed that boosting the CP level from 13% to 25% caused enhancement in ADG.

Kerr et al. (1995) study states that when fed low-CP diets (15-12-11%), pigs should be supplemented with lysine, tryptophan and threonine. Pigs with high-CP diets (19-16-14%) showed no such need. Growing-finishing pigs mostly showed low ADG and G : F when fed low-CP diets without amino acids supplementation. Also, compared to those fed high-CP diets, their carcasses displayed smaller longissimus muscle, thicker average backfat, and lower percentage of muscle overall (Gilster and Wahlstrom, 1973; Kornegay et al., 1973; Easter and Baker, 1980). Cromwell et al. (1996) and Tuitoek et al. (1997) claimed that decreased CP level (2-3%) with amino acids supplementation did not have negative influences on ADG and G : F of growing-finishing pigs. Plus, CP level lower than 3% did not decrease ADG and G : F in growing-finishing pigs (Hahn et al., 1995; Kerr et al., 1995). Hansen and Lewis (1993) and Gomez et al. (2002b) show different results.

3.2 Dietary Protein and AA Metabolism

3.2.1 Lysine Metabolism

Numerous studies established for decades that dietary supply of protein, or its components, amino acids are crucial to the pigs' growth and development of muscles. About 20 natural amino acids exist that are utilized in protein biosynthesis (called standard proteinogenic amino acids). Not all amino acids are essential dietary components, since through de novo synthesis pigs can acquire approximately 10 of them. 'Essential amino acids' refer to those that pigs cannot acquire on their own (or at least not enough for their metabolic needs) and need to be provided from outside sources (Fuller et al., 1987). Lysine is the first and main limiting one among these essential amino acids, it being the most lacking amino acids in almost every swine diets based on cereal grains (Lewis, 2001; NRC, 2012). This reason puts lysine in a predominant position in nutritional management of the pigs (Figure 5).

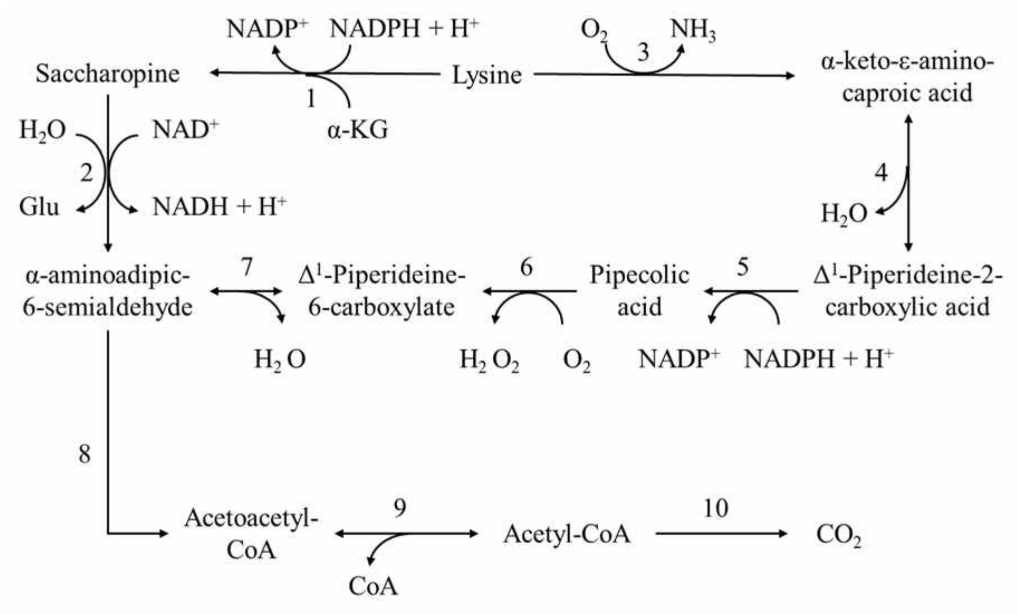

Figure 5. Lysine catabolism in monogastric animals. (Chung, 2018)

Papes et al. (1999) and Gatrell et al. (2013) stated that the main pathway of lysine catabolism is the saccharopine pathway in liver. By the catalysis of lysine-ketoglutarate reductase, lysine is initially combined with α-ketoglutarate to produce saccharopine. Then, saccharopine is transformed to α-aminoadipic-6-semialdehyde and glutamate by saccharopine reductase. Saccharopine reductase (also called saccharopine dehydrogenase), like lysine-ketoglutarate reductase, is a part of a polypeptide, bifunctional aminoadipate δ-semialdehyde synthase (Gatrell et al., 2013). Through several more phases, the α-aminoadipate-6-semialdehyde will then be transformed to acetyl-coenzyme A (Wu, 2013). This pathway is a rare reaction, because ε-amino group is carried to α-ketoglutarate and then to the general nitrogen pool. Oxidizing acetyl-coenzyme A generates CO2 and energy through the citric acid cycle.

1) Physiological Functions of Lysine

Lysine, apart from metabolic functions, plays a part in physiological functions of monogastric animals as well. Lysine influences metabolism of nutrients, hormone production, and immunity of animals (Wu, 2010a; Wu, 2013). Peptide-bound lysine is also where post-translational modification and epigenetic regulation of gene expression happens. In order to utilize lysine properly for animals, scientists and farmers need to be well-acquainted with these functions that lysine can provide.

2) Lysine Mechanism and Perspectives

Wittmann and Becker (2007) mentions that late 1980s saw an introduction of commercial feed-grade crystalline lysine in animal feed industry. Animal nutritionists should take into deep consideration the replenishment of dietary lysine, since the lack of lysine impedes animals' health maintenance and growth performance. (Oversupply of lysine, on the other hand, is harmless.)

Dietary supplementation of crystalline lysine is proved to aid in muscle protein accretion and whole-body growth of pigs. Researchers found out that lysine supplementation helps in nitrogen retention and protein accretion, as well as the growth performance of the animals (Sharda et al., 1976; Fuller et al., 1987; Salter et al., 1990; Shelton et al., 2011). Additionally, Salter et al. (1990) attributed the increase of muscle protein accretion to the increase in the rate of protein synthesis, as opposed to the decrease in the rate of protein degradation.

The metabolic/molecular mechanisms in which dietary lysine controls muscle mass accumulation in pigs was not clarified (Wu, 2010b; Rezaei et al., 2013). Then, Liao et al. (2015) discovered the metabolic and physiological roles of lysine, concerning swine muscle growth and development. Relevant studies have been scarce concerning pigs, and so much of the knowledge amassed up to now have been dependent on studies of other monogastric animals, including humans.

3.2.2 Methionine Metabolism

There are metabolic relationships between methionine and cysteine that are now academically accepted (Figure 6). Methionine, by adenosine triphosphate, can be turned into S-adenosyl methionine. This methionine-derivative gives its methyl group to various acceptors (Finkelstein, 1990). S-adenosyl-L-homocysteine is formed, and then is hydrolyzed to homocysteine and adenosine. Homocysteine holds a pivotal place, since it can be recycled into methionine, or be condensed with serine, forming cystathionine and then cysteine. The fact that the conversion of homocysteine into cysteine is irreversible is noteworthy (Bauchart-Thevret et al., 2009). Overall, these metabolic pathways show that methionine can be transformed into cysteine, but not so vice versa. De-/re-methylation process between methionine and homocysteine in the activated methyl cycle needs B-vitamin coenzymes (Finkelstein, 1998).

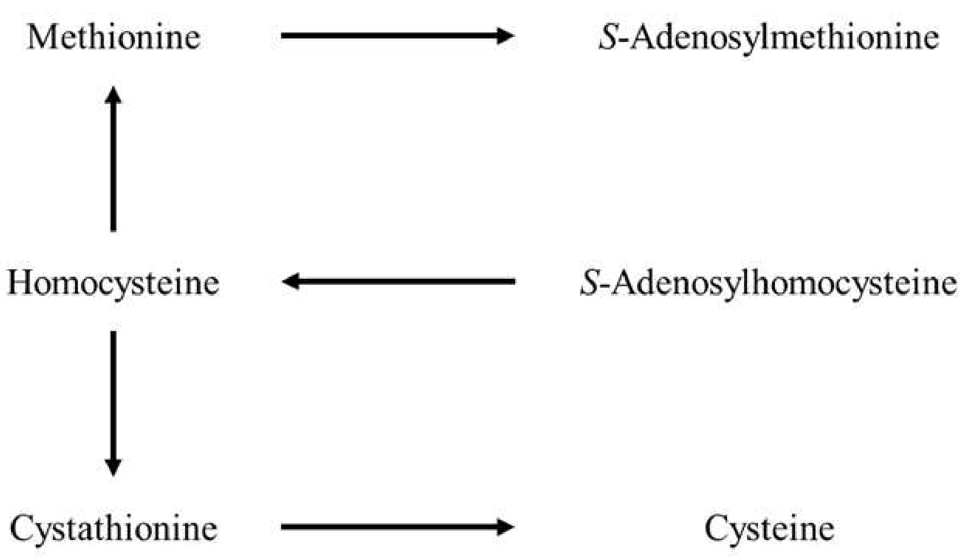

Figure 6. Metabolic pathways of sulfur amino acids. (Chung, 2018)

3.2.3 Tryptophan Metabolism

Another essential amino acid is tryptophan. It is a crucial component for its biological roles, main one being its connection to metabolic pathways involved in tryptophan catabolism. Tryptophan is a precursor for the synthesis of serotonin, a neurotransmitter related to mood, stress response, sleep and appetite regulation. From the perspective of quantity, the rate of tryptophan usage in creating serotonins is very low. This is because the tryptophan transport and availability in the brain might be limiting for the synthesis of brain serotonin. Diets with low tryptophan lower feed intake. The mechanism concerning this effect of low tryptophan diets is generally linked with the relationship between tryptophan and serotonin. Adding the fact that tryptophan is one of the essential amino acids that can only be gained from outer source, it can be suggested that deficiency of tryptophan limits protein synthesis, accretion and growth rate.

3.2.4 Threonine Metabolism

Portal-drained viscera is known to oxidize some essential amino acids (Van Goudoever et al., 2000; Riedijk et al., 2007). However, it cannot be said that the essential amino acids will doubtlessly be catabolized inside the intestinal tissues. Threonine catabolism through L-threonine 3-dehydrogenase pathway is a small factor within the visceral tissues, not influenced by intestines (Le Floc'h and Sève, 2005; Schaart et al., 2005). Schaart et al. (2005) states that splanchnic oxidation (measured by 13CO2 production from 13C-labeled threonine) takes up 2% of intestinal utilization of threonine, 13% of whole-body threonine oxidation.

These results imply that protein synthesis controls the dietary threonine utilization by the intestinal mucosa of pigs (Le Floc'h and Sève, 2005; Schaart et al., 2005), probably by being included into mucins. According to Montagne et al. (2004), mucins are polymeric glycoproteins featuring heavily in mucus layer that coats the epithelium of the gastrointestinal tract, or all epithelia of mammals. Most mucins are secreted, and some of them are membrane-bound. Secreted mucins are important in the inborn immune defense of mucosa. Lots of threonine can be found in the core protein of the major intestinal mucins. Faure et al. (2002) study involving rats reports that the fractional synthesis rate of mucin glycoproteins stayed comparatively same following the length of intestine (range 112 ~ 138%/d). However, it was considerably higher compared to the total mucosal protein synthesis rate, notably in the ileum (77%/d) and colon (44%/d).

Around 11% of endogenous protein in ileal digesta of pigs consists of mucins, 30% of them being threonine (Lien et al., 1997). When amino acids from proteins that are secreted internally reach the large intestine, they are lost by the animal. Similarly, secretion of mucins, erosion of the mucus, and recovery of mucins following endogenous ileal losses are susceptible to many factors, be it dietary or anti-nutritional (Montagne et al., 2004). The need for threonine seems to receive huge influence from secretion, recycling, or loss of intestinal mucins, triggering the energy needs of the organism. In 12-hour feeding phase and 12-hour fasting period, intestinal recycling of amino acids from secretory proteins are crucial regulatory mechanism for systemic availability of dietary amino acids (Van der Schoor et al., 2002). Noteworthy threonine recycling from mucosal protein in the portal circulation, however, was absent. This indicates either that these proteins can cope with digestion or that recycled threonine are re-absorbed directly into mucosal protein.

3.3 Dietary Protein Level and Protein Deposition

Synthesis of body tissue, organ, etc. essentially needs dietary protein as its source. Protein intake, however, is not a primary factor to pigs' growth. Their growth depends on energy intake and usage of that energy. The energy took in by the pigs is used in maintenance, body protein deposition and fat deposition. Most of them will constantly be spent on maintenance. The remainder then goes to body protein deposition, and then finally, the surplus will be utilized in body fat deposition.

Body protein deposition, a significant factor in utilization of energy in pigs, is regulated by PDmax. PDmax level is generally consistent in pigs weighing up to approximately 80 ~ 90 kg (Moughan and Verstegan, 1988;

Quiniou et al., 1995). Mathematical models like Gompertz function can illustrate the decrease in PDmax level following pigs' growth; pigs provided high-protein diet can utilize appropriate amount of protein that meets PDmax requirement. The remainder will either be secreted or utilized in other bodily functions and energy production. Therefore, protein intake higher than PDmax requirement is crucial to maximum growth of pigs.

3.4. Effect of Dietary Protein Level on Carcass Characteristics

Many studies claimed that adequate amount of dietary protein for pigs contribute to enhancement of carcass characteristics.

Cromwell et al. (1978) states that increase in protein level caused increase in longissimus area and lean cut yield. Backfat did not seem to be influenced by protein level, but pigs provided low-protein diet showed highest IMF content in longissimus, and vice versa. Difference in shear values of loin was insignificant, only to the point where pigs fed low-protein diets produced marginally lower numbers than those with high-protein diets. Flavor and overall satisfaction scores also showed minimal contrast (Pigs fed low-protein diets showed slightly higher scores). Roasts prepared from pigs with low-protein diets performed greater in tenderness and juiciness, owing to the higher IMF content. Along with Wagner et al. (1963), Wyllie et al. (1969) and Drews et al. (1971), the study also states that dietary protein level has considerable effect on the IMF content of longissimus.

Wagner et al. (1963) states that increase in protein level causes carcass backfat, dressing percentage and IMF content to decrease, and the percent yield of lean cuts to increase. However, tissue nitrogen content showed no sign of noteworthy change by increasing protein level. Figueroa et al. (2002) observed that decreasing dietary protein level from 16% to 12% increased backfat and decreased longissimus muscle area.

Apple et al. (2004) (along with Cromwell et al. (1978), Goerl et al. (1995) and Kerr et al. (1995)) states that increasing dietary CP decreased LM marbling and IMF. The study concurs with Goodband et al. (1990) and Goerl et al. (1995) that it has no influence on proportion of ash in the longissimus muscle. Increasing CP level caused increase in LM are and lean yield.

Kerr et al. (1995) states that decrease in dietary CP increases the firmness and marbling of the longissimus muscle. Decrease in dietary CP also brought about the decrease of longissimus muscle area and overall percentage of muscle in pigs. Pigs that were provided low-CP diet (reduced CP level by 4% compared to control group) showed increase in average backfat thickness, 10th rib fat thickness, leaf fat weight and total fat in the longissimus muscle. Increase of carcass fat and decrease of longissimus muscle occurred concurrently when pigs were fed low-CP diet. Also, compared to pigs with high-CP diet, pigs with low-CP diet (with supplementation in amino acids) showed tendency for higher fatness. (This result is also claimed by Stahly et al. (1981), Fuller et al. (1984, 1986), Noblet et al. (1987), Schoenherr (1992) and Tuitoek et al. (1993)). There are two possible reason for this increase in carcass fatness; (1) Carcass quality is responsive to nitrogen content in the diet rather than amino acid from CP. (2) Low-CP level diets may possess higher net energy value. This allows the leftover energy that are related with low-CP/amino acids supplemented diets to be accumulated as fat.

Hansen and Lewis (1993), having experimented with growing-finishing pigs, states that the 10th backfat thickness showed curvilinear reaction to dietary protein level, proposing the possibility that subcutaneous fat would increase at dietary protein level over 23%. Increase in dietary protein also resulted in curvilinear reaction from longissimus muscle area and carcass lean percentage. Dietary protein level of 11% to about 19% caused longissimus muscle to increase almost linearly in pigs. However, longissimus muscle decreased when dietary protein level was boosted up to 23%. When protein level went over 19%, it ended up abating possible advances in carcass lean percentage. In conclusion, both lack and excess of dietary protein proved to be of adverse circumstance for carcass quality of growing-finishing pigs.

4. Dietary Energy and Protein Intake

4.1 Dietary Energy Level and Voluntary Feed Intake

One of the many theories concerning regulating factors of voluntary feed intake of pig points to dietary energy intake. According to this theory, pigs take energy according to their near or past energy needs. This will affect their meal size and time between meals. Gastric distension and emptying also have been pointed out to be a regulating factor of pigs' feed intake (Martin et al., 1989).

Both ARC (1981) and NRC (1998) points to DE content in diet and live body weight as main factors of voluntary feed intake in pigs. However, differences of up to 20 ~ 30% in voluntary feed intake are discovered according to different pig genotypes (Forbes et al., 1989; Schinckel, 1994) and gender (Schinckel, 1994).

Figure 7 shows the possible link between energy density of diet, levels of feed and energy intake according to Cole et al. (1971). There was a theoretical range of dietary energy levels that researchers thought the pigs can adapt their feed intake for maintaining constant energy intake. The physiological control of feed intake, however, is likely to be associated, not with maintenance of energy intake but with other mechanisms. These mechanisms include full gut capacity with diets of low nutrient density and a lack of gut capacity with diets of high nutrient density (Cole et al., 1971).

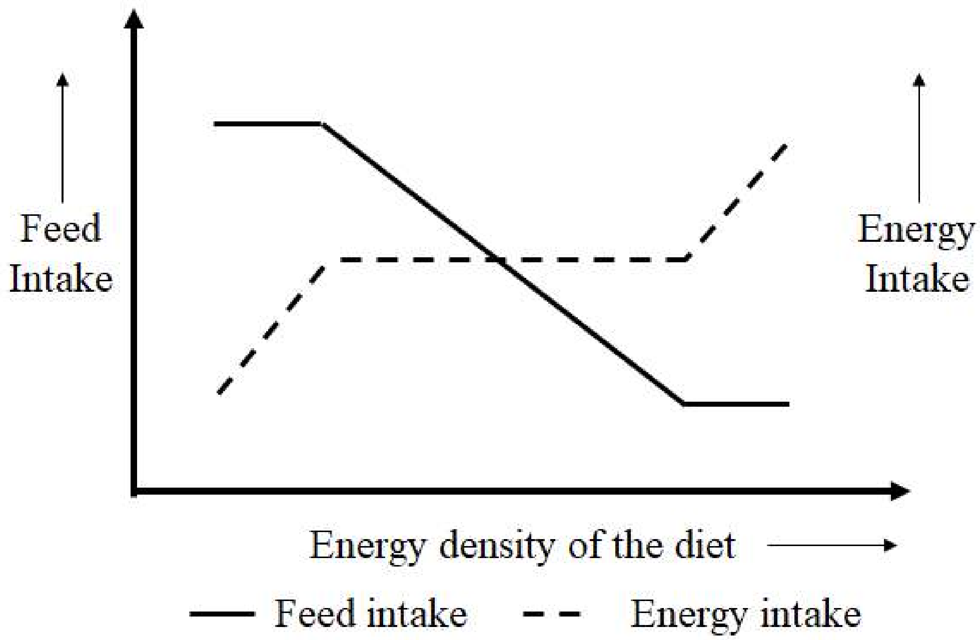

Figure 7. Schematic representation of the relationship between feed and energy intakes and the energy density of the diet. (Cole et al., 1971).

There are numerous factors of functional importance that can influence these relationships to decide the feed intake of pigs provided a specific diet. They include the size, genotype, sex, previous nutrition of the animal, dietary concentration of protein and other nutrients, and the sources of energy in the diet (especially concerning the type of fat or fiber). According to Giles et al. (1998), pigs weighing below 20 kg were not capable of increasing feed intake, in order to adapt to decreasing dietary energy density (roughly under 16 MJ/kg of DE concentration). Pigs weighing between 20 ~ 50 kg were able to increase feed intake with DE concentration of 14 MJ/kg, those weighing above 70 kg with 10 MJ/kg.

4.2 Dietary Protein Level and Protein Intake

The level of other essential nutrients in the diet can have effect on the voluntary feed intake of pigs, especially in the perspective of deficiencies or imbalances. Several studies point out that lacking protein or essential amino acids in diets can decrease the feed intake of growing-finishing pigs (Rogerson and Campbell, 1982; Hahn et al., 1995). Imbalance of adequate amino acids shares similar effect (Henry et al., 1992; Henry, 1995; Hahn and Baker, 1995). Friesen et al. (1994) contrarily claimed an increase in feed intake by dietary protein deficiency.

Protein level in diet and the amount of voluntary feed intake decides the content of protein intake. Studies below show nutrient factors (energy and protein) that are crucial to protein intake.

According to Kyriazakis and Emmans (1992), only the rate of protein supply at low levels of protein intake determines the rate of protein deposition. Energy supply at high levels of protein intake determines the protein deposition. Poultry performance have been reported to be affected by the ratio of protein to energy in the diet (Baldini and Rosenberg, 1955; Leong et al., 1955; Matterson et al., 1955; Scott and Staheli, 1955; Lockhart, 1955; Combs and Romoser, 1955). The effects of protein and energy content in pigs' feed on performance and carcass characteristics are also claimed by numerous researches (Bowland and Berg, 1959; Noland and Scott, 1960; Pond et al., 1960; Constain and Morgan, 1961).

Devilat et al. (1970) and Davey (1978) experimented with choice feeding method, in which pigs are given choice between two isoenergetic diets with different protein level and can choose according to their needs. This plan is built upon a hypothesis that pigs can control their feed intake to match their nutrient requirements. It has been suggested by Kyriazakis (1989) and Kyriazakis et al. (1990) that individually housed pigs can distinguish their diets between different protein levels, and they likely will choose feed intake adequate for their needs. Bradford and Gous (1991) study also imply similar remark, stating that choice feeding appears to be more beneficial to commercial swine farm than phase feeding is. Braude (1967) contradicts and claimed that pigs are often incapable of selecting certain diet that matches their requirements, and so that choice feeding method is not much better than single feeding. Gourley et al. (1993), Owen et al. (1994) and Nam and Aherne (1995) joins this refutation, concurring with pigs' inability to make a choice among isoenergetic diets with different protein level.

4.3 Dietary Energy Level and Protein Intake

A high-energy diet tends to contain high concentration of other nutrients, and vice versa. It is unpractical, however, to lessen the concentration of various nutrients even in lower energy diets.

The process of forming ingested amino acids into body protein requires energy. About 30 ~ 50% of energy is utilized in the anabolism of lean tissue for growing pigs. Meanwhile, dietary amino acids can also be utilized as a source of energy. It will maintain a lot of body functions and support the synthesis of body lipid after the nutrients are degraded into carbon and hydrogen. The synthesis of protein from pigs' feed shows 30 ~ 60% efficiency. Accordingly, there is a significance in the energy yield from the deamination of amino acids that are not accumulated in pigs' body or milk. Deaminated amino acids not linked with protein can also be effective precursors for other bodily activities (e.g. the formation of fatty tissues). However, main functions of proteins through feed are supply of amino acid elements in swine protein deposition (in growth or milk) and maintenance of tissues.

Henry (1988) claims that provision of amino acids matching the energy density of diet is crucial to maintaining the ratio of amino acid and energy steadily. Some studies like Carr et al. (1977) and Whittemore and Fawcett (1976) suggested that the ratio of available lysine/MJ of DE did not display linearly during the whole of pigs' life span. However, others like Chiba et al. (1991) implied linear response from linkage between energy intake and the rate of protein deposition (for growing pigs weighing up to 50 kg).

Pigs’ altering amino acid/energy needs, and their extent of feed intake in different growth phases control the correlation between amino acid and energy in growing-finishing pigs that are given random choice to feed. Pigs in their growing phase (weighing approximately up to 50 kg) show their innate capability of protein deposition outpacing their capability of absorbing enough feed matching their tissue needs for protein synthesis. Therefore, the reaction between amino acid intake and protein deposition and amino acid requirements with energy is clearly linear. In the pigs’ finishing period, however, energy intake surpasses their need for protein deposition. Their demands of amino acid for tissue synthesis are irrelevant to the energy intake.

Ⅲ. Different Energy and Protein Levels in Diet on Growth Performance, Blood Profiles, Pork Quality and Feed Cost in Growing-finishing Pig

ABSTRACT: This study was conducted to evaluate the optimal energy and protein level in feed of growing-finishing pigs for growth, blood profiles, pork quality and feed cost. This experiment was done by factorial design and factor 1 was two level of energy (3,150 or 3,300 kcal of ME/kg), and factor 2 was also two level of dietary protein in feed (90% of NRC CP requirements in 2012 or NRC CP requirements in 2012). Treatements were 1) LL : ME 3,150 kcal/kg + 90% of NRC 2012 CP diet; 2) LH : ME 3,150 kcal/kg + NRC 2012 CP diet; 3) HL : ME 3,300 kcal/kg + 90% of NRC 2012 CP diet; 4) HH : ME3,300 kcal/kg + NRC 2012 CP diet. Growth performance of growing-finishing pigs was improved when pigs were fed higher dietary energy and high protein treatment diet (HH) both in late growing phase (7th week) and the late finishing phase(13th week), respectively (P=0.03; P=0.05). Average daily gain (ADG) was increased when higher protein diets (LH and HH) were fed to growing-finishing pigs (P=0.03) and dietary protein was much more potent nutrient than dietary energy for growth of pigs during the whole experimental period. Average daily feed intake (ADFI) was also increased when pigs were fed higher protein diet particularly during growing phase (P=0.01) and this trend was maintained during finishing phase (P=0.03). However, Gain to feed ratio (G:F), was mainly affected by dietary energy (P=0.06) rather than dietary protein level (P=0.67). Blood urea nitrogen (BUN), total protein, creatinine and blood glucose were lowered when low energy and low protein diet (LL) was provided (P=0.01) resulted in an interaction (P=0.01). Although pH of pork was lowered when pigs were fed low protein treatment diet (P=0.03), but other measurements of pork quality, such as color, chemical analysis and TBARS, were not affected by dietary energy and protein level. Feed cost per weight gain was lowered when pigs were fed high energy and low protein treatment diet but feed cost per pig was increased when dietary protein level was increased (P=0.01). Although total feed cost to 110 kg was the lowest in low energy and low protein treatment (LL), days to market weight from 27.22 to 110kg was the shortest in high energy and high protein treatment (HH) among dietary treatments. Even though feed cost could be saved in LL treatment, days to market weight was delayed about 19 d compared to HH treatment subsequently LL treatment would not be efficient feed formulation for growing-finishing pigs. In conclusion, this experiment demonstrated that high protein diet resulted in improved growth performance in growing pigs but high energy (3,300 kcal of ME/kg) and low protein (90% of NRC(2012)) diet would be desirable feed formulation based upon feed cost, days to market weight and pork quality.

Keywords : Energy, Crude protein, Growing-finishing pig, Growth performance, Blood profiles, Pork quality, Feed cost

Introduction

Recently, global grain price tends to increase with various reasons. Extreme climate change, decrease of cultivation acreage and increase of meat consumption are also having a significant impact on global grain prices subsequently prices of feed ingredients will be increased continually in the future. In South Korea, it is known that feed cost comprised approximately 60 percent of the total cost of pig production and about 60 to 70 percent of ingredients in swine feed is consisted of corn and soybean. Over the last two decades, pig industry in Korea has been developed greatly and pork price has been maintained about 2~3 times higher than that of USA and EU. Therefore, swine producers in Korea are concerned about fast growing of pigs regardless of cost of feed or pork quality and are less interested in saving of production cost and improving productivity of farm. Moreover, many feed companies have been selling high-nutritive feed at high prices, and swine producers do not aware of the serious situation caused by feeding over-nutritive feed to pigs. Growing-finishing period is an important time to maximize the growth of pigs, in addition, pigs are generally consuming much more feed compared to other phase of pigs subsequently feed cost during this period is being comprised approximately 70% of total cost of feed of pigs. To save feed cost, swine producers need to avoid wasting of feed and provide efficient feed which contains adequate nutrients for normal growth of pigs. When swine feed is formulated efficiently, nutrients in feed will be well utilized in growing-finishing pigs subsequently growth rate of pigs has improved and days to market weight can be reduced. Not only price of swine feed, but also pollutants in environment will be great concerned when feed contained excessive nutrients. Among of nutrients, crude protein and energy contents in swine feed determine the price of feed, resulting in affecting net profit of swine farm. Therefore, this study was conducted to evaluate the optimal energy and protein level in feed of growing-finishing pigs for growth, blood profiles, pork quality and feed cost.

Materials and Methods

Experimental animals and management

A total of 140 finishing pigs ([Yorkshire × Landrace] × Duroc) with an average body weight of 27.22 ± 0.445 kg were used for 13 weeks feeding trial at Daewoo swine farm in Muan-gun, Jeollanam-do, Republic of Korea.

Experimental animals were allotted to one of four treatments, 5 replicates, 7 pigs per pen considering gender and body weight with RCB (randomized complete block) design.

Experimental period was consisted with 4 phases and early growing phaseis 1 - 4 week, late growing phase, is 5 - 7 week, early finishing phase is 8 - 10 week, and late finishing phase is 11 - 13 weeks, respectively. All pigs were housed in an automatically environment controlled room with fully-concrete floor facility (2.60 x 2.84m) during the whole experimental period. Each pen was equipped with a feeder and a nipple drinker to provide *ad-libitum* during experiment.

Experimental design and diets

The experimental period was classified into 1-4 weeks, 5-7 weeks, 8-10 weeks, and 11-13 weeks, and was designed to be 2 x 2 factorial design. Factor 1 is two levels of dietary energy (3,150 or 3,300 kcal of ME/kg), and factor 2 is also two levels of dietary protein (90 or 100% of CP requirements in NRC 2012). The experimental treatments are as followed (Table 8); 1) LL: ME 3,150 kcal/kg + low CP, 90% of CP of NRC 2012, 2) LH: ME 3,150 kcal/kg + CP of NRC 2012, 3) HL: ME 3,300 kcal/kg +

low CP, 90% of CP of NRC 2012, 4) HH: ME 3,300 kcal/kg + CP of NRC 2012. Experimental diets were formulated with corn-soybean meal base, and all other nutrients in experimental diets were met or exceeded the NRC requirements (2012). Formulae and chemical compositions of the experimental diets are shown in Tables 9, 10, 11, and 12.

Growth performance

Body weight (BW) and feed intake were measured in the beginning (initial) and at the end of each phase (4, 7, 10 and 13 week) to calculate the average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G:F), respectively.

Blood sampling and analysis

Blood samples were taken from the jugular vein of randomly selected 6 pigs in each treatment for measuring blood urea nitrogen (BUN), total protein, creatinine, and glucose. Blood collection was performed both at initial and at the end of each phase (4, 7, 10 and 13 week). Blood was collected in serum tubes (SSTTMⅡ Advance, BD Vacutainer, Becton Dickinson, Plymouth, UK) and quickly centrifuged for 15 min by 3,000 rpm at 4℃ (Eppendorf centrifuge 5810R, Germany). Then, the sera were transferred to 1.5 ml plastic tubes by pipette and stored at －20℃ until later analysis. BUN, total cholesterol, creatinine, and glucose concentration were analyzed with Kinetic UV assay test method using blood analyzer (Cobas 8000, Roche, Germany).

Carcass traits

At the end of experiment, a total of 16 pigs of 4 pigs from each treatment were slaughtered and pork samples were collected from nearby between 4th and 6th rib of carcass. Because of chilling procedure, 30 minutes after slaughter was regarded as initial time. The pH was measured at 0, 3, 6, 12 and 24 hour after initial time. The meat color was monitored at 3, 6, 12 and 24 hour after initial time. The pH was determined by pH meter (Model, Themo Orion, U.S.A) and meat color was analyzed by CIE color L*, a* and b* value using a CR300 (Minolta Camera Co., Japan). Proximate analysis of pork samples was done by the method of AOAC (2005)

Pork quality

Centrifuge method was used for measuring water holding capacity of pork (Abdullah and Najdawi, 2005). Pork samples were wrapped in filter tube, and heated in water bath at 80℃ for 20 min then, centrifuged for 10 min at 2,000 rpm and 10℃ (Eppendorf centrifuge 5810R, Germany). After centrifugation, the cooking loss was measured by packing of pork samples with polyethylene bag, heated in water bath until core temperature reached 72℃ and weighed before and after cooking. Additional samples were taken from core of longisimuss (0.5 inch in diameter) parallel to muscle fiber and used to measure the shear force (Warner Bratzler Shear, USA). Cooking loss, shear force, water holding capacity of pork sample were analyzed by Animal Origin Food Science lab in Seoul National University.

TBARS Assay

The extent of lipid oxidation was measured for the 2-thiobarbituric acid reactive substances (TBARS) value by using a spectrophotometer (X-ma 3100, Human Co. Ltd., Seoul, Korea). Each sample (5g) was homogenized with 15mL of DDW and 7.2% butylated hydroxyl toluene in ethanol at 9,600 rpm for 30 s (T25, Ika Works, Staufen, Germany). After homogenization, 2 mL of the homogenates were transferred to 15 mL falcon tubes. Then added 4 mL of 20 mM TBA in 15% TCA. The tubes were heated in a laboratory water bath at 90°C for 30 min, and centrifuged at 2,265 for 15 min (HM-150IV, Hanil Co. Ltd., Incheon, Korea). The samples were measured before and after cooking boiled in water bath at 90°C for 8 min. The absorbance of supernatant was measured at 532 nm. The TBARS value was expressed as mg MDA/kg.

Fatty acid composition

Lipids in pork sample (10 g) were extracted with 100 mL of chloroform/methanol (2.1, v/v) (Folch et al.,1957) and shaking incubator (25℃, 120 rpm) for 24 hours. Extracted lipids were filtered with filter paper (Whatman^{TM} No.4, Buckinghamshire, UK). 25 mL of 0.88 % NaCl was added in the filtered sample and centrifuging at 2,090×g for 10 min (Continent 512R, Hanil Co., Ltd., Incheon, Korea). The supernatant was separated and concentrated pork lipids using N_2 gas at 45℃. After concentrating the lipids, 0.1 g was weighted into 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. The samples were heated in the water bath at 85°C for 10 min and cooled to room temperature. After cooling, 2 mL of 14% BF3-methanol was added and repeated heating process one more time. After then, 2 mL of iso-octane and 1 mL saturated NaCl was added, centrifuged at 2,500 rpm for 3 min (Continent 512R, Hanil Co., Ltd., Incheon, Korea). Upper layer containing fatty acid methyl ester(FAME) was dehydrated with anhydrous sodium sulfate and transferred to a vial. Analyzed the vial using a gas chromatograph (HP 7890, Agilent Technologies, Santa Clara, CA, USA) with a split ratio (50:1). A capillary column (DB-23, 60 m x 250 µm x 0.25 µm, Agilent, Santa Clara, CA, USA) was used. The injector and detector temperatures were maintained at 250°C and 280°C, respectively. The column oven temperature were as follows: 50°C for 1 min, increased to 130°C at 25°C/min, 170°C at 8°C/min, then held at 215°C at 1.5°C/min. Nitrogen was used as a carrier gas at linear flow of 4 mL/min. Individual FAME was identified by comparison of the relative retention times of peaks from samples, with those of the external standards (37 FAME mix and CLA mix, Supelco, Bellefonte, PA, USA) calculated based on the Korean Food Standards Codex (MFDS, 2017).

Chemical Analyses

Diets were ground by a Cyclotec 1093 Sample Mill (Foss Tecator, Hillerod, Denmark) and ground diets were analyzed. All analyses were performed in duplicate samples and those processes were done again if results from duplicate samples varied more than 5% from the mean. Experimental diet was analyzed for contents of dry matter (procedure 930.15; AOAC, 1995), crude ash (procedure 942.05; AOAC, 1995), ether extract (procedure 920.39; AOAC, 1995), nitrogen by using the Kjeltec procedure with Kjeltec (KjeltecTM 2200, Foss Tecator, Sweden).

Economic analysis

As the experimental pigs were reared in the same environmental condition, economic analysis was calculated using the feed cost without considering other factors. The total feed cost (won) per body weight gain (kg) was calculated by using amount of the total feed intake and feed price. The feed cost per weight gain was calculated based on price of raw materials during the time of the experiment. The days to market weight (110 kg) were estimated from the body weight at the end of feeding trial and ADG of 13 weeks.

Statistical analysis

The experimental data was analyzed using 2 by 2 factorial procedure of SAS. For data on growth performance and economic analysis a pen was considered as an experimental unit, while individual pig was used as an unit for data on blood profile, pork quality and carcass traits. Effect of energy factor, protein factor, and interaction between two factors were declared significant at $P<0.05$ or highly significant at $P<0.01$.

Results and Discussion

Growth performance

The effect of energy level and protein level in feed on growth performance are presented in Table 13. Body weight was increased at 7th week (late growing phase) and 13th week(late finishing phase) by protein factor when it increased (P=0.03; P=0.05 respectively).

Average daily gain (ADG) was increased when higher protein diets (LH and HH) were provided to growing-finishing pigs (P=0.03) and dietary protein was much more potent nutrient than dietary energy for growth of pigs during the whole experimental period. Average daily feed intake (ADFI) was also increased when pigs were fed higher protein diet particularly during growing phase (P=0.01) and this trend was maintained during finishing phase (P=0.03). Gain to feed ratio (G:F), however, was mainly affected by dietary energy (P=0.06) rather than dietary protein level (P=0.67).

Protein and amino acids in feed affected the muscle development of pigs, and lack of protein and amino acids negatively influenced on growth performance and muscle development in pigs (Schinckel and de Lange, 1996). In addition, ADG and feed efficiency were increased significantly as the level of protein in growing-finishing feed increased (Kerr et al., 2003). Adequate CP level in the growing phase showed better growth and feed efficiency than pigs were fed feed from inappropriate CP level (Gilster and Wahlstrom, 1973; Easter and Baker, 1980). The increase in CP level resulted in improved ADG and feed efficiency (Cromwell et al., 1993; Chen et al., 1995).

However, muscle and fat depositions are not only affected by protein level but also energy-protein ratio (Wood et al., 2004). It was very known that protein deposition max was related with energy-protein ratio (Swine Nutrition, 1991). Also, ratio between energy-lysine can also influence on protein deposition because high-energy without appropriate lysine ratio can lead to low energy utilization (Noblet et al., 1987). Seve et al. (1986) also showed that imbalance of energy and protein could make slow protein synthesis and this study demonstrated that no effect by energy factor or interaction between energy and protein factors.

In conclusion, increase of protein level in feed resulted in significantly improving body weight, ADG and ADFI however, dietary energy was less effect than that of dietary protein.

Blood profiles

The effect of energy level and protein level on blood profiles in growing-finishing pigs is shown in Table 14. Blood urea nitrogen (BUN), total protein, creatinine and blood glucose were lowered when low energy and low protein diet (LL) was provided (P=0.01) resulted in an interaction (P=0.01).

BUN is a representative evaluation indicator of the efficiency of the use of amino acids in pigs and has been used as a response indicator to determine the protein requirements of animals or the single amino acid requirements (Hatori et al., 1994; Coma et al., 1995; Cai et al., 1996). Fuller et al. (1977) suggested that carbohydrates increased the accumulation of protein in the body. In this study, the increase in energy in feed raised the accumulation of protein in the body, which resulted in a decrease in BUN in the blood. In addition, previous studies have shown that pig's BUN was involved in the maintenance of ingested nitrogen in the body (Whang and Easter, 2000), and has a negative correlation with ADG and feed efficiency (Hann et al., 1995). These results are consistent with the results of higher BUN concentrations, such as reports from Chen et al. (1995, 1996) and Gomez et al. (1998). The reason for the high BUN concentration in the blood of pigs was that the protein was not fully utilized and released in the form of urea, which meant that protein utilization rate through feed was low.

In the total protein level in the blood, there were no significant differences in total protein in 4, 7, 10 week. However, total protein was decreased as energy level increase (P=0.01) however, it was increased as CP level increase (P=0.01), resulted in interaction between energy and CP level (P=0.01) in the 13 week (late finishing phase).

The total protein concentration in the blood is a complex compound of all kinds of proteins in the blood (Buzanovskii, 2017). Total protein in the blood plays important role to maintain normal osmotic pressure and pH in the blood. Diarrhea, vomiting, and dehydration could be occurred if the total protein concentration in the blood is excessively high (Brown and Otto. 2008).

The present study found that the total protein concentration in finishing pig blood increased significantly as energy levels increased but there were no symptoms such as vomiting or dehydration. Therefore, dietary energy levels in current experiment did not negatively influence on total protein in the blood.

The present study demonstrated that the concentration of creatinine is affected by dietary energy and CP level in feed (P=0.01). Creatinine is a nonprotein nitrogenous compound in the blood and is the final metabolite produced by non-enzymatic dehydration from the creatine of muscles (Zinellu et al., 2005). Since creatinine is produced as a muscle metabolite and is released into the blood and excreted into the urine subsequently the creatinine production is widely used as an indicator to estimate the total muscle mass of the body (Salazar, 2014). The concentration of creatinine in blood and urine is closely correlated with muscle mass (Baxmann, 2008). Creatinine is positively related with muscle percentage and performance (Doornenbal et al., 1986).

Blood glucose concentration was lowered when pigs were fed high protein treatment diets (LH and HH) presumably due to the fact that relative ration between energy and protein determined blood glucose. Although there were some significant differences by energy and protein treatment, dietary protein level influenced greater on BUN, total protein and blood glucose level than that of dietary energy.

pH and Meat color

The effects of dietary energy and protein levels on the pH changes in pork after slaughter are presented in Table 15. As a result, the final pH of pork in all treatments was between 5.2 and 5.9, but it was within normal range(RFN, Red Firm and Non-exudative).

The pH change of pork after slaughter can be seen as a very important factor of pork quality such as freshness, WHC, shear force, pork color, and tenderness (Brewer and McKeith, 1999; Binder et al., 2004). Bole et al (1993) reported that the pH level is closely related to the quality of pork, WHC and ternderness. Palansky and Nosal (1991) demonstrated that increasing pH resulted in reducing of cooking loss. The pH immediately after the slaughter is used as a prediction of PSE, and the final pH is recognized as a prediction of DFD.

Significant differences in energy and protein levels have occurred, but given that they are all within normal ranges, it is believed that the energy and protein levels in the treatment did not adversely affect the pH change of pork. In conclusion, it is believed that the energy and protein level of the feed will not have a negative effect on the pH change of pork after slaughter.

The effect of the energy level and protein level in the growing-finishing feed on the meat color is shown in Table 16. Bendall and Wismer (1962) reported that increasing yellowness and decreasing redness in pork resulted in decreasing freshness of pork. In this experiment, there was a significant decrease in Hunter value a, measured 6 hours after slaughter, as energy levels increase (P=0.01). However, there were no significant differences in all other analytical items. Therefore, the energy and protein level had no effect on the meat color in this experiment.

Pork quality

The effect of the energy and protein levels in the growing-finishing feed on the pork are presented in Table 17. There was significant decrease in crude fat content as energy increase (P=0.04). There was significant decrease in crude ash content as energy increase (P=0.03). In this experiment, there was no significant difference between moisture and crude protein level, depending on the energy level and protein level.

The composition of the carcass changes depending on the protein level fed by pigs. The shear force and water holding capacity are affected by the content of fat in the loin. The shear force decreases as the fat content increases. The water holding capacity is a measure of the ability of the meat to hold water due to internal and external environmental changes, determined by the microstructure of the meat or the change in the moisture content that occurs during cutting, and is known to be closely related to the pH change of the meat. In addition, shear force is a mechanically measured measure of the tenderness of meat, and is known to be highly associated with fat. Cooking loss is one of the indicators of indirect water holding capacity and is generally known to have inverse correlation with water holding capacity. In this study, there was significant increase in cooking loss as energy increase (P=0.01). In addition, shear force was significantly increased as energy levels increased (P=0.01). According to a study by Goerl et al (1995), as the fat content increases, water holding capacity is increased while the cooking loss is reduced, which improves the juice reduction, and weakens the shear force. However, further study is needed to clearly demonstrate energy and protein level in pork quality. Feeding high-protein feed improves the composition of the carcass (Davey, 1978) and improves the carcass (Davey 1978).

In conclusion, high energy affects negatively to cooking loss and shear force.

The effect of the energy level and protein level in the growing-finishing feed on the lipid oxidation of pork after slaughter are presented in Table 18. The results of this experiment showed significant differences in TBARS as CP level increase in the 5th day(P=0.05). However, there were no significant differences in all other analysis items. In addition, the TBARS value of all treatments were not reached 0.6 mg/kg

(Guo et al., 2003) which is the represent of lipid oxidation. Other studies have also reported that energy levels and protein levels do not show significant differences in lipid oxidation (Meng et al., 2010; Madeira et al., 2014).

Therefore, the energy and protein level in the growing-finishing feed did not have significant effect on the lipid oxidation of pork.

Fatty acid composition

The effect of the energy level and protein level in the growing-finishing feed on the fatty acid composition in pork after slaughter are presented in Table 19. Several studies have already shown that changes in diet affect fatty acids composition in pork (Miller et al., 1990; Larick et al., 1992). A prior study found that C18:3n3 is primarily oxidized in energy use, which leads to a reduction in storage of C18:3n3 in adipose cells (Leighton, Drury, Crawford, 1987). Several studies reported that the fatty acid content of the test feed was reflected in the loin of pork (Culp et al., 1980; Von Schacky and Weber., 1985; Hwang et al., 1988). According to the European Food Safety Administration (EFSA), safer foods have lower SFA content (EFSA, 2010). There was no significant difference in this experiment, but the HH treatment showed the lowest SFA content.

The fatty acid composition analysis resulted in a significant difference in the heneicosylic acid(c21:0) (P=0.01). However, there were no significant differences in all other fatty acids. Some studies have shown that protein-level adjustments did not show significant differences in MUFA (Bessa et al., 2013; Madeira et al., 2014). This resulted in similar results to this experiment.

Therefore, the energy and protein level in the growing-finishing feed did not have a negative effect on the formation of fatty acids.

Economic analysis

The effect of the energy level and protein level in the growing-finishing feed on economic analysis are presented in Table 20. To analyze economic analysis, feed per weight gain and total feed cost per pig were calculated using the total feed intake and feed cost of 1kg, and 110kg was estimated based on the weight and ADG at the end of the days to market. The feed cost per weight gain was significantly different at the early finishing phase (8-10 weeks). Feed cost per weight gain increased as energy and protein increase (P=0.01). There was no significant difference in feed cost per 1kg gain in early growing, late growing and late finishing phase. High energy and low protein treatment (HH) showed the lowest feed cost per weight gain.

In total feed costs, there were significant difference in protein level for the early growing phase (P=0.02), late growing phase (P=0.01) and growing-finishing phase (P=0.01). And feed cost tended to increase when protein level increase in the late finishing phase (P=0.06).

In this experiment, There were significant effect of energy and protein factors on feed cost per weight gain in early finishing phase because of significantly different G:F ratio. Also, the higher the protein level, the significantly higher the ADFI in the early growing phase, late growing phase, and growing-finishing phase. Consequently, the total feed cost was high according to the ADFI. And LL treatment showed lowest feed cost per pig.

Days to market weight from 27.22 to 110kg showed significant differences in protein content, and the higher the protein content, the shorter the market date by about 11 days. In addition, low energy and low protein treatment (LL) showed 124 days, while high energy and high protein treatment (HH) showed 105 days. Although total feed cost to 110 kg was the lowest in low energy and low protein treatment (LL), days to market weight from 27.22 to 110kg was the shortest in high energy and high protein treatment (HH) among dietary treatments.

Considering the rotation rate, adding another 70 days in order to reach 27kg each treatment took 194, 182, 185 and 175 days to market weight(110kg) and 1.9, 2.0, 2.0, 2.1 rotations/year. In estimated feed cost to 110kg, low energy and low protein treatment (LL) was the cheapest but the lowest rotation per year and in the feed cost per weight gain, high energy and low protein treatment (HL) was the lowest. In spite of the fact that feed cost could be saved in low energy and low protein treatment (LL), days to market weight was delayed about 19 days compared to high energy and high protein treatment (HH) concluding LL treatment would not be the efficient feed formulation for growing-finishing pigs.

Therefore, this experiment demonstrated that high protein diet resulted in improved growth performance in growing pigs but high energy (3,300 kcal of ME/kg) and low protein (90% of NRC(2012)) diet would be desirable feed formulation based upon feed cost, days to market weight and pork quality.

Conclusion

Growth performance in this experiment showed that the higher the protein level and the energy level in the feed during the late growing phase and the late finishing phase, the greater the body weight (P=0.03; P=0.05, respectively). The ADG increased as the protein level increased early growing phase, late growing phase and growing phase, late finishing phase and entire experimental phase (P=0.02; P=0.02; P=0.01; P=0.01; P=0.03, respectively). The ADFI increased significantly as the protein level increased early growing phase, late growing phase and growing phase and entire experimental phase (P=0.03; P=0.01; P=0.01; P=0.03). The blood profile showed that the BUN concentration increased as the protein level increased (P=0.01). There was a significant difference between the total proteins in the late finishing phase (P=0.01) but no significant difference in other phases. There were significant differences in creatinine by energy and protein levels, and glucose was significantly different in the 10th and 13th weeks. The pH of pork was significantly different at 12 hrs after slaughter (P=0.01) but the pH of all items was within the normal range and no significant differences occurred in the rest of the items. The color of pork showed significant differences in Hunter value a (P=0.01), but no significant differences occurred in all other items. In pork quality, the crude fat content appeared to be lowered as energy levels increased (P=0.03) and the cooking loss and shear force increased as energy levels increased (P=0.01; P=0.01, respectively). In carcass traits, the dressing rate showed low results as the protein level increased (P=0.01). Backfat thickness in carcass was decreased as energy content increased (P=0.04). The lipid oxidation showed a decrease in the TBARS value as the protein level increased on the 5th day of storage, but no significant difference was observed in all other items than (P=0.05), and no negative effect was present because the TBARS value was not reached at 0.6. Significant differences occurred in the formation of fatty acids in the heneicosylic acid (P=0.01). However, there were no significant differences in all other fatty acids. In the economic analysis, feed cost per weight gain increased as energy increased (P=0.01) and protein increased (P=0.01) at early finishing phase (8-10 weeks). The total feed cost increased as protein increased in early growing(1-4 week, P=0.02), late growing (5-7 week, P=0.01) and growing-finishing (0-13 weeks, P=0.01). A significant difference in protein level was found in the days to market weight and the higher the protein level, the shorter the days of market by about 11 days. Experiment of different energy level and protein level in growing-finishing feed showed that, the high protein level is better for the growth rate but low protein level is more economic.

Therefore, high levels of protein significantly increased body weight, ADG, and ADFI. In the energy level, high level of energy level showed negative effect on pork quality, but showed more economic in feed cost.

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

Table. 8 Experimental treatments

BW, kg	30~50 – 50~70 – 70~90 – 90~110		30~50 – 50~70 – 70~90 – 90~110	
ME, kcal	Low (3,150 kcal/kg)		High (3,300 kcal/kg)	
CP & Amino Acid	90% of NRC 2012	NRC 2012	90% of NRC 2012	NRC 2012
Treatment	LL	LH	HL	HH
CP, %	14.12 - 12.38 - 10.91 - 9.39	15.69-13.75 - 12.13-10.44	14.12-12.38 - 10.91-9.39	15.69-13.75 - 12.13-10.44
Lys(%)	1.01-0.87 - 0.76-0.64	1.12-0.97 - 0.84-0.71	1.01-0.87 - 0.76-0.64	1.12-0.97 - 0.84-0.71
Met(%)	0.29-0.25 - 0.23-0.19	0.32-0.28 - 0.25-0.21	0.29-0.25 - 0.23-0.19	0.32-0.28 - 0.25-0.21
Thr(%)	0.65-0.58 - 0.50-0.44	0.72-0.64 - 0.56-0.49	0.65-0.58 - 0.50-0.44	0.72-0.64 - 0.56-0.49
Trp(%)	0.17-0.15 - 0.14-0.12	0.19-0.17 - 0.15-0.13	0.17-0.15 - 0.14-0.12	0.19-0.17 - 0.15-0.13

Table 9. Formulae and chemical compositions of the experimental diet of early growing pigs (1-4 weeks).

Item	Treatment[1)]			
	LL	LH	HL	HH
Ingredient, %				
Ground corn	73.64	69.71	70.37	66.47
SBM	14.55	18.43	15.08	18.96
Wheat bran	7.90	7.90	7.90	7.90
Tallow	0.11	0.19	2.85	2.92
MDCP	1.34	1.28	1.36	1.29
Limestone	0.97	0.97	0.96	0.97
Salt	0.30	0.30	0.30	0.30
Vitamin premix[2)]	0.10	0.10	0.10	0.10
Mineral premix[3)]	0.10	0.10	0.10	0.10
L-Lysine-HCl, 78%	0.48	0.49	0.47	0.48
DL-met, 99%	0.06	0.07	0.06	0.07
L-Threonine, 99%	0.15	0.16	0.15	0.16
Tryptophan, 10%	0.30	0.30	0.30	0.28
Sum	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,150.00	3,150.00	3,300.00	3,300.00
CP	14.12	15.69	14.12	15.69
Lys	1.01	1.12	1.01	1.12
Met	0.29	0.32	0.29	0.32
Thr	0.65	0.72	0.65	0.72
Trp	0.17	0.19	0.17	0.19
Ca	0.66	0.66	0.66	0.66
Total P	0.56	0.56	0.56	0.56

1) LL : ME3,150 kcal/kg + 90% of NRC 2012 CP diet, LH : ME3,150 kcal/kg + NRC 2012 CP diet, HL : ME3,300 kcal/kg + 90% of NRC 2012 CP diet, HH : ME3,300 kcal/kg + NRC 2012 CP diet.

2) Provided the following quantities of vitamins per kg of complete diet : Vit A, 16,000IU; Vit D_3, 3,200IU; Vit. E, 35IU; Vit. K_3, 5mg; Rivoflavin, 6mg; Calcium pantothenic acid, 16mg; Niacin, 32mg; d–Biotin, 128ug; Vit.B_{12}, 20ug.

3) Provided the following quantities of minerals per kg of complete diet : Fe, 281mg; Cu, 288mg; Zn, 143mg; Mn, 49mg; I, 0.3mg; Se, 0.3mg.

4) Calculated value.

Table 10. Formulae and chemical compositions of the experimental diet of late growing pigs (5-7 weeks).

Item	Treatment[1)]			
	LL	LH	HL	HH
Ingredient, %				
Ground corn	77.74	74.55	84.10	80.69
SBM	10.10	13.50	11.64	15.02
Wheat bran	8.60	8.40	0.00	0.00
Tallow	0.04	0.05	0.55	0.61
MDCP	1.21	1.16	1.40	1.34
Limestone	0.87	0.87	0.79	0.79
Salt	0.30	0.30	0.30	0.30
Vitamin premix[2)]	0.10	0.10	0.10	0.10
Mineral premix[3)]	0.10	0.10	0.10	0.10
L-Lysine-HCl, 78%	0.45	0.47	0.44	0.45
DL-met, 99%	0.04	0.05	0.04	0.05
L-Threonine, 99%	0.15	0.15	0.14	0.15
Tryptophan, 10%	0.30	0.30	0.40	0.40
Sum	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,150.00	3,150.00	3,300.00	3,300.00
CP	12.38	13.75	12.38	13.75
Lys	0.87	0.97	0.87	0.97
Met	0.25	0.28	0.25	0.28
Thr	0.58	0.64	0.58	0.64
Trp	0.15	0.17	0.15	0.17
Ca	0.59	0.59	0.59	0.59
Total P	0.52	0.52	0.52	0.52

1) LL : ME3,150 kcal/kg + 90% of NRC 2012 CP diet, LH : ME3,150 kcal/kg + NRC 2012 CP diet, HL : ME3,300 kcal/kg + 90% of NRC 2012 CP diet, HH : ME3,300 kcal/kg + NRC 2012 CP diet.

2) Provided the following quantities of vitamins per kg of complete diet : Vit A, 16,000IU; Vit D_3, 3,200IU; Vit. E, 35IU; Vit. K_3, 5mg; Rivoflavin, 6mg; Calcium pantothenic acid, 16mg; Niacin, 32mg; d–Biotin, 128ug; Vit.B_{12}, 20ug.

3) Provided the following quantities of minerals per kg of complete diet : Fe, 281mg; Cu, 288mg; Zn, 143mg; Mn, 49mg; I, 0.3mg; Se, 0.3mg.

4) Calculated value.

Table 11. Formulae and chemical compositions of the experimental diet of early finishing pigs (8-10 weeks).

Item	Treatment[1)]			
	LL	LH	HL	HH
Ingredient, %				
Ground corn	81.13	78.22	88.26	85.33
SBM	6.30	9.35	7.89	10.95
Wheat bran	9.25	9.22	0.00	0.00
Tallow	0.00	0.01	0.33	0.34
MDCP	1.03	0.98	1.23	1.16
Limestone	0.79	0.80	0.70	0.72
Salt	0.30	0.30	0.30	0.30
Vitamin premix[2)]	0.10	0.10	0.10	0.10
Mineral premix[3)]	0.10	0.10	0.10	0.10
L-Lysine-HCl, 78%	0.44	0.44	0.43	0.43
DL-met, 99%	0.04	0.04	0.04	0.04
L-Threonine, 99%	0.12	0.14	0.12	0.13
Tryptophan, 10%	0.40	0.30	0.50	0.40
Sum	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,150.00	3,150.00	3,300.00	3,300.00
CP	10.91	12.13	10.91	12.13
Lys	0.76	0.84	0.76	0.84
Met	0.23	0.25	0.23	0.25
Thr	0.50	0.56	0.50	0.56
Trp	0.14	0.15	0.14	0.15
Ca	0.52	0.52	0.52	0.52
Total P	0.47	0.47	0.47	0.47

1) LL : ME3,150 kcal/kg + 90% of NRC 2012 CP diet, LH : ME3,150 kcal/kg + NRC 2012 CP diet, HL : ME3,300 kcal/kg + 90% of NRC 2012 CP diet, HH : ME3,300 kcal/kg + NRC 2012 CP diet.

2) Provided the following quantities of vitamins per kg of complete diet : Vit A, 16,000IU; Vit D_3, 3,200IU; Vit. E, 35IU; Vit. K_3, 5mg; Rivoflavin, 6mg; Calcium pantothenic acid, 16mg; Niacin, 32mg; d‐Biotin, 128ug; Vit.B_{12}, 20ug.

3) Provided the following quantities of minerals per kg of complete diet : Fe, 281mg; Cu, 288mg; Zn, 143mg; Mn, 49mg; I, 0.3mg; Se, 0.3mg.

4) Calculated value.

Table 12. Formulae and chemical compositions of the experimental diet of late finishing pigs (11-13 weeks).

Item	Treatment[1)]			
	LL	LH	HL	HH
Ingredient, %				
Ground corn	83.98	82.03	92.55	90.03
SBM	2.25	5.00	4.07	6.71
Wheat bran	10.70	9.91	0.00	0.00
Tallow	0.01	0.00	0.10	0.11
MDCP	0.88	0.85	1.10	1.05
Limestone	0.72	0.73	0.63	0.64
Salt	0.30	0.30	0.30	0.30
Vitamin premix[2)]	0.10	0.10	0.10	0.10
Mineral premix[3)]	0.10	0.10	0.10	0.10
L-Lysine-HCl, 78%	0.42	0.42	0.41	0.41
DL-met, 99%	0.02	0.03	0.02	0.02
L-Threonine, 99%	0.12	0.13	0.12	0.13
Tryptophan, 10%	0.40	0.40	0.50	0.40
Sum	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,150.00	3,150.00	3,300.00	3,300.00
CP	9.39	10.44	9.39	10.44
Lys	0.64	0.71	0.64	0.71
Met	0.19	0.21	0.19	0.21
Thr	0.44	0.49	0.44	0.49
Trp	0.12	0.13	0.12	0.13
Ca	0.16	0.46	0.16	0.46
Total P	0.43	0.43	0.43	0.43

1) LL : ME3,150 kcal/kg + 90% of NRC 2012 CP diet, LH : ME3,150 kcal/kg + NRC 2012 CP diet, HL : ME3,300 kcal/kg + 90% of NRC 2012 CP diet, HH : ME3,300 kcal/kg + NRC 2012 CP diet.

2) Provided the following quantities of vitamins per kg of complete diet : Vit A, 16,000IU; Vit D_3, 3,200IU; Vit. E, 35IU; Vit. K_3, 5mg; Rivoflavin, 6mg; Calcium pantothenic acid, 16mg; Niacin, 32mg; d‐Biotin, 128ug; Vit.B_{12}, 20ug.

3) Provided the following quantities of minerals per kg of complete diet : Fe, 281mg; Cu, 288mg; Zn, 143mg; Mn, 49mg; I, 0.3mg; Se, 0.3mg.

4) Calculated value.

Table 13. Effects of energy and protein levels on growth performance in growing-finishing pigs

Criteria	Treatment[1)]				SEM[2)]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy* Protein
Body weight, kg								
Initial	27.40	27.16	27.16	27.16	-	-	-	-
4th week	35.74	37.47	36.60	41.53	0.983	0.20	0.09	0.40
7th week	49.11	53.67	51.89	59.33	1.469	0.12	0.03	0.59
10th week	65.29	70.33	68.38	73.30	1.593	0.35	0.13	0.98
13rd week	82.80	90.69	87.94	95.07	1.938	0.20	0.05	0.92
ADG, g								
0-4 weeks	298	368	337	513	29.3	0.08	0.02	0.30
5-7 weeks	637	771	728	848	27.9	0.10	0.02	0.88
0-7 weeks	443	541	505	657	27.3	0.07	0.01	0.56
8-10 weeks	770	793	786	665	22.1	0.19	0.25	0.10
11-13 weeks	834	969	931	1,037	24.7	0.05	0.01	0.71
8-13 weeks	802	881	859	851	15.9	0.68	0.27	0.19
0-13 weeks	608	698	668	746	19.8	0.15	0.03	0.88
ADFI, g								
0-4 weeks	908	1,028	897	1,217	52.0	0.35	0.03	0.30
5-7 weeks	1,613	1,945	1,682	2,121	74.7	0.35	0.01	0.68
0-7 weeks	1,210	1,421	1,223	1,605	58.5	0.31	0.01	0.43
8-10 weeks	2,549	2,848	2,694	2,709	62.9	0.98	0.23	0.28
11-13 weeks	2,752	2,961	2,768	2,882	53.2	0.78	0.15	0.67
8-13 weeks	2,651	2,904	2,731	2,796	54.4	0.90	0.16	0.40
0-13 weeks	1,875	2,105	1,924	2,154	51.4	0.61	0.03	0.99
G:F ratio								
0-4 weeks	0.317	0.359	0.371	0.422	0.0162	0.07	0.14	0.87
5-7 weeks	0.394	0.400	0.433	0.403	0.0077	0.16	0.44	0.24
0-7 weeks	0.318	0.359	0.371	0.422	0.0162	0.07	0.14	0.87
8-10 weeks	0.304	0.279	0.292	0.246	0.0078	0.11	0.01	0.42
11-13 weeks	0.305	0.329	0.337	0.360	0.0082	0.05	0.14	0.99
8-13 weeks	0.304	0.304	0.315	0.305	0.0047	0.59	0.63	0.61
0-13 weeks	0.305	0.332	0.347	0.347	0.0047	0.06	0.67	0.69

1) LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

2) Standard error of means

Table 14. Effects of energy and protein levels on blood profiles in growing-finishing pigs

Criteria	Treatments[1]				SEM[2]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy* Protein
BUN, mg/dL								
Initial	-----------------5.10---------------				-	-	-	-
4th week	3.03	9.60	3.47	5.03	0.853	0.03	0.01	0.01
7th week	3.63	9.83	3.30	5.07	0.837	0.01	0.01	0.01
10th week	3.03	6.83	3.10	7.30	0.686	0.73	0.01	0.80
13rd week	4.17	6.50	5.03	7.03	0.345	0.01	0.01	0.01
Total protein, mg/dL								
Initial	----------------5.57----------------				-	-	-	-
4th week	6.77	6.70	5.90	5.67	0.265	0.10	0.78	0.88
7th week	6.53	6.90	5.93	5.63	0.262	0.10	0.95	0.53
10th week	6.57	6.80	6.10	6.67	0.143	0.31	0.19	0.57
13rd week	6.63	6.97	6.13	6.87	0.098	0.01	0.01	0.01
Creatinine, mg/dL								
Initial	-----------------1.04---------------				-	-	-	-
4th week	1.02	1.12	1.12	1.02	0.020	0.96	0.96	0.02
7th week	1.00	1.09	1.11	0.99	0.022	0.86	0.80	0.03
10th week	1.13	1.29	1.19	1.13	0.027	0.22	0.24	0.03
13rd week	1.03	1.09	1.45	1.17	0.048	0.01	0.01	0.01
Glucose, mg/dL								
Initial	-----------------92.67-------------				-	-	-	-
4th week	87.00	87.33	93.00	93.33	2.708	0.35	0.96	0.99
7th week	92.33	83.67	94.67	94.00	2.492	0.24	0.37	0.44
10th week	83.67	70.67	98.00	84.33	3.837	0.04	0.05	0.96
13rd week	92.00	71.00	90.33	75.67	2.750	0.03	0.01	0.01

[1] LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

[2] Standard error of means

Table 15. Effects of energy and protein levels on pH of pork in growing-finishing pigs

Criteria	Treatments[1]				SEM[2]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy* Protein
Time after slaughter								
0 hour	5.86	5.86	5.90	5.91	0.016	0.21	0.77	0.88
3 hour	5.75	5.76	5.79	5.79	0.024	0.55	0.91	0.98
6 hour	5.56	5.57	5.54	5.47	0.019	0.13	0.47	0.34
12 hour	5.25	5.54	5.47	5.79	0.054	0.01	0.01	0.71
24 hour	5.56	5.65	5.57	5.74	0.031	0.36	0.03	0.52

1) LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

2) Standard error of means.

Table 16. Effects of energy and protein levels on color of longissimus muscles in growing-finishing pigs

Criteria	Treatments[1]				SEM[2]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy* Protein
Hunter value[3], L								
3 hour	49.21	48.37	48.81	49.61	0.695	0.79	0.99	0.61
6 hour	51.18	49.13	51.84	50.77	0.568	0.33	0.19	0.68
12 hour	51.09	48.74	51.84	50.94	0.727	0.34	0.30	0.64
24 hour	52.08	50.72	51.95	52.04	0.529	0.62	0.59	0.54
Hunter value, a								
3 hour	7.60	7.07	7.06	6.23	0.295	0.28	0.29	0.81
6 hour	7.36	7.50	6.68	5.51	0.293	0.01	0.28	0.18
12 hour	7.84	8.30	7.44	7.31	0.228	0.16	0.72	0.54
24 hour	6.62	6.68	6.38	5.78	0.211	0.21	0.54	0.46
Hunter value, b								
3 hour	13.09	12.82	12.52	12.39	0.239	0.35	0.70	0.89
6 hour	13.86	13.34	13.41	12.78	0.202	0.19	0.22	0.79
12 hour	13.79	13.84	13.77	14.02	0.151	0.82	0.67	0.78
24 hour	13.94	13.37	13.59	13.32	0.143	0.52	0.18	0.62

[1] LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

[2] Standard error of means

[3] CIE L: luminance or brightness (vary from black to white), a: red and green component (+a:red, -a:green), b: yellow and blue component (+b:yellow, -b:blue)

Table 17. Effects of energy and protein levels on proximate analysis and physiochemical property of longissimus muscles in growing-finishing pigs

Criteria	Treatments[1]				SEM[2]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy*Protein
Proximate analysis, %								
Moisture	72.80	72.39	71.86	73.44	0.351	0.94	0.43	0.19
Crude protein	22.18	23.20	22.74	23.81	0.378	0.47	0.21	0.98
Crude fat	3.70	3.34	2.36	2.75	0.228	0.04	0.97	0.39
Crude ash	1.00	0.92	0.57	0.81	0.067	0.03	0.47	0.19
Physiochemical property								
WHC, %	66.88	65.06	62.40	66.76	0.827	0.38	0.42	0.07
Cooking loss, %	21.61	23.41	28.14	26.09	0.835	0.01	0.92	0.13
Shear force, kg	31.08	27.93	39.58	43.17	2.214	0.01	0.95	0.35
Carcass trait								
Carcass grade[3]	1.00	1.00	1.13	1.13	-	-	-	-
Dressing rate, %	74.61	73.29	74.11	72.35	0.328	0.21	0.01	0.69
Back-fat thickness, mm	24.50	20.25	19.00	19.00	0.884	0.04	0.18	0.18

[1] LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

[2] Standard error of means

[3] The grade of ccarcass was scored as follows: '1+'grade = 0.5 point, '1'grade = 1 point, '2'grade = 2 score (n=30). The lower the score, the higher the quality of the carcass

Table 18. Effects of energy and protein levels on TBARS assay in the longissimus muscles of growing-finishing pigs

Criteria	Treatments[1)]				SEM[2)]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy* Protein
TBARS, mgMA/kg								
1 day	0.34	0.30	0.32	0.33	0.009	0.77	0.25	0.16
3 day	0.33	0.32	0.34	0.32	0.011	0.77	0.52	0.98
5 day	0.34	0.32	0.37	0.33	0.009	0.24	0.05	0.54
7 day	0.33	0.32	0.36	0.36	0.013	0.22	0.76	0.90

1) LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

2) Standard error of means

Table 19. Effects of energy and protein levels on fatty acid composition of longissimus muscles from growing-finishing pigs

Criteria	Treatments[1]				SEM[2]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy* Protein
Fatty acid composition, %								
C14:0	1.56	1.46	1.64	1.36	0.129	0.98	0.52	0.76
C16:0	28.41	26.13	30.35	23.77	2.200	0.96	0.37	0.66
C16:1	3.28	3.09	3.15	2.66	0.277	0.66	0.58	0.80
C17:0	0.92	0.56	1.00	0.85	0.102	0.39	0.23	0.62
C18:0	14.52	14.10	16.82	12.30	1.176	0.92	0.33	0.42
C18:1 n-9	50.09	44.43	53.55	40.79	3.762	0.99	0.27	0.66
C18:2 n-6	8.28	8.55	9.75	7.84	0.524	0.73	0.47	0.34
C18:3 n-3	0.24	0.24	0.27	0.22	0.021	0.83	0.61	0.57
C20:0	0.22	0.23	0.28	0.18	0.019	0.87	0.26	0.19
C20:1	0.96	0.83	1.10	0.85	0.084	0.66	0.30	0.74
C20:2	0.39	0.41	0.51	0.40	0.027	0.37	0.42	0.23
C21:0	0.24	0.26	0.27	0.22	0.007	0.80	0.18	0.01
C20:4 n-6	1.51	1.57	1.65	1.55	0.026	0.27	0.64	0.15
SFA[3]	45.87	42.73	50.37	38.68	3.558	0.98	0.35	0.58
UFA[4]	64.74	59.12	70.00	54.31	4.433	0.98	0.27	0.60
MUFA[5]	54.33	48.34	57.81	44.30	4.086	0.97	0.28	0.67
PUFA[6]	10.42	10.77	12.19	10.01	0.583	0.69	0.47	0.32
UFA/SFA ratio	1.42	1.41	1.40	1.44	0.020	0.92	0.71	0.62

[1] LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

[2] Standard error of means

[3] SFA = saturated fatty acids

[4] UFA = unsaturated fatty acids

[5] MUFA = monosaturated fatty acids

[6] PUFA = polyunsaturated fatty acids

Table 20. Effects of energy and protein levels on feed cost in growing-finishing pigs

Criteria	Treatments[1]				SEM[2]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy *Protein
Feed cost per weight gain, won/kg								
0-4 week	732	645	682	585	32.1	0.40	0.17	0.94
5-7 week	740	740	683	757	13.7	0.44	0.18	0.17
8-10 week	924	1,024	983	1,189	28.9	0.01	0.01	0.20
11-13 week	888	846	817	782	21.3	0.13	0.38	0.94
0-13 week	830	830	801	815	11.2	0.36	0.77	0.77
Feed cost per pig, won/head								
0-4 week	5,745	6,628	5,917	8,267	359.2	0.15	0.02	0.24
5-7 week	9,831	12,031	10.408	13,497	488.9	0.21	0.01	0.58
8-10 week	14,777	16,995	16,560	16,587	394.2	0.53	0.10	0.25
11-13 week	15,484	16,998	15,992	16,957	319.8	0.71	0.06	0.66
0-13 week	45,838	52,652	48,477	55,307	1,365.7	0.28	0.01	0.99
Estimated feed cost to 110 kg, won								
	53,124	57,932	54,545	59,490	966.1	0.39	0.01	0.97
Days to market weight(110) from 27.22kg, days								
	124	112	115	105	2.6	0.11	0.03	0.78

[1] LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

[2] Standard error of means

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Ⅴ. Summary in Korean

본 연구는 육성-비육돈 사료 내 적절한 에너지 수준과 단백질 함량이 미치는 영향을 규명하기 위해서 수행되었으며, 사료 내 에너지 수준 (3,150 /3,300 kcal of ME/kg) 및 단백질 수준 (NRC 2012 요구량의 90 /100 %)에 따라 2 X 2 factorial로 구성했으며, 1) LL : ME3,150 kcal/kg + NRC 2012 CP의 90%, 2) LH : ME3,150 kcal/kg + NRC 2012 CP의 100%, 3) HL : ME3,300 kcal/kg + NRC 2012 CP의 90%, 4) HH : ME3,300 kcal/kg + NRC 2012 CP의 100%로 나누었다. 성장성적 분석 결과 HH 처리구에서 육성 후기(P=0.03)와 비육후기(P=0.05)에 개선되었다. 일당 증체량에서는 단백질 수준이 높을수록, 육성 비육돈에서 높았으며, 전체 실험 기간에서 에너지보다 단백질이 더 중요한 영양소임을 보여주었다. 일당사료섭취량 단백질 수준이 높을수록 육성 기간에 증가하였고(P=0.01), 비육기간까지 유지되었다(P=0.03). 하지만, G:F는 에너지 수준에 영향에 영향을 받았다(P=0.06). 혈액성상에 있어, LL처리구에서 BUN, 총단백질, 크레아티닌, 혈당이 낮게 유지되었으며(P=0.01), 상호작용이 일어났다(P=0.01). 돈육의 pH는 단백질 수준이 낮을수록 비록 감소했지만(P=0.03), 육색, 돈육의 일반성분, TBARS는 에너지와 단백질 수준에 영향을 받지 않았다. 경제성 분석에서는 1kg 증체당 사료비는 LL처리구가 가장 낮았으나, 총사료비용은 단백질 수준이 높을수록 증가하였다(P=0.01). 110kg 도달시까지 사료비용은 LL처리구가 가장 낮았으나, 27.22kg에서 110kg까지 출하일령은 처리구 중에서 HH가 가장 짧았다. 비록 사료 비용은 LL 처리구에서 절감할 수 있지만, HH 처리구 대비 출하일령이 19일이나 더 걸리기 때문에, 육성 비육돈 사료로서는 효율적이지 못함을 알 수 있었다. 따라서 본 실험은 사료 비용과 출하일령과 육질을 고려했을 때, 높은 에너지와 낮은 단백질의 사료가 육성-비육기의 사료로 바람직하다고 판단된다.

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A Thesis
For the Degree of Master of Science

Different Energy and Protein Levels in Diet on Growth Performance, Blood Profiles, Pork Quality and Feed Cost in Growing-finishing Pig

사료 내 에너지, 단백질 수준이 육성-비육돈의 성장성적, 혈액성상, 도체특성 및 경제성에 미치는 영향

August, 2020

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이 논문을 농학석사 학위논문으로 제출함

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서울대학교 대학원 농생명공학부

박 천 웅

박천웅의 농학석사 학위논문을 인준함

2020 년 7 월

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Summary

This study was conducted to evaluate the optimal energy and protein level in feed of growing-finishing pigs for growth, blood profiles, pork quality and feed cost. This experiment was done by a factorial design and factor 1 was two level of energy (3,150 or 3,300 kcal of ME/kg), and factor 2 was also two level of dietary protein in feed (90% of NRC CP requirements in 2012 or NRC CP requirements in 2012). Growth performance of growing-finishing pigs was improved when pigs were fed high dietary energy and high protein treatment diet (HH) both in late growing phase and the late finishing phase, respectively (P=0.03; P=0.05). Average daily gain (ADG) was increased when higher protein diets (LH and HH) were provided to growing-finishing pigs (P=0.03) and dietary protein was much more potent nutrient than dietary energy for growth of pigs during the whole experimental period. Average daily feed intake (ADFI) was also increased when pigs were fed higher protein diet particularly during growing phase (P=0.01) and this trend was maintained during finishing phase (P=0.03). Gain to feed ratio (G:F), however, was mainly affected by dietary energy (P=0.06) rather than dietary protein level (P=0.67). Blood urea nitrogen (BUN), total protein, creatinine and blood glucose were lowered when low energy and low protein diet (LL) was provided (P=0.01), resulted in an interaction (P=0.01). Although pH of pork was lowered when pigs were fed low protein treatment diet (P=0.03), but other measurements of pork quality, such as color, chemical analysis and TBARS, were not affected by dietary levels of energy and protein. Feed cost per weight gain was lowered when pigs were fed high energy and low protein treatment diet however, feed cost per pig was increased when dietary protein level was increased (P=0.01). Although total feed cost to 110kg of body weight was the lowest in low energy and low protein treatment (LL), days to market weight from 27.22 to 110kg was the shortest in high energy and high protein treatment (HH) among dietary treatments. Even though feed cost could be saved in LL treatment, days to market weight was delayed about 19 d compared to HH treatment subsequently LL treatment would not be efficient feed formulation for growing-finishing pigs. Consequently, this experiment demonstrated that high protein diet resulted in improved growth performance in growing pigs but high energy (3,300 kcal of ME/kg) and low protein (90% of NRC(2012)) diet would be desirable feed formulation based upon feed cost, days to market weight and pork quality.

Key words: Dietary energy and protein, Growing-finishing pig, Growth performance, Blood profiles, Pork quality, Feed cost

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List of Abbreviation

AA	Amino acid
AAFCO	Association of American Feed Control Officials
ADFI	Average daily feed intake
ADG	Average daily gain
AOAC	Association of official analytical chemists
ARG	Arginine
BF	Backfat
BUN	Blood urea nitrogen
BW	Body weight
CP	Crude protein
DE	Digestible energy
EE	Ether extract
FCR	Feed conversion ratio
FFA	Free fatty acid
G:F	Gain to feed
IMF	Intramuscular fat
KFSS	Korean feeding standard for swine
LYS	Lysine
ME	Metabolizable energy
MET	Methionine
MUFA	Mono unsaturated fatty acid

NRC	National research council
PUFA	Polyunsaturated fatty acid
RCBD	Randomized complete block design
SAS	Statistical analysis system
SBM	Soybean meal
SD	Standard deviation
SFA	Saturated fatty acid
TBARS	2-thiobarbituric acid reactive substances
THR	Threonine
TRP	Tryptophane
USFA	Unsaturated fatty acid
WHC	Water holding capacity

I. Introduction

Recently, global grain price tends to increase with various reasons. Extreme climate change, decrease of cultivation acreage and increase of meat consumption are also having a significant impact on global grain prices subsequently prices of feed ingredients will be increased continually in the future. In South Korea, it is known that feed cost comprised approximately 60 percent of the total cost of pig production and about 60 to 70 percent of ingredients in swine feed is consisted of corn and soybean. Over the last two decades, pig industry in Korea has been developed greatly and pork price has been maintained about 2~3 times higher than that of USA and EU. Therefore, swine producers in Korea are concerned about fast growing of pigs regardless of cost of feed or pork quality and are less interested in saving of production cost and improving productivity of farm. Moreover, many feed companies have been selling high-nutritive feed at high prices, and swine producers do not aware of the serious situation by feeding over-nutritive feed to pigs. Swine feed contained excessive nutrients not only increased Growing-finishing period is an important time to maximize the growth of pigs, in addition, pigs are generally consuming much more feed compared to other phase of pigs subsequently feed cost during this period is being comprised approximately 70% of total cost of feed of pigs. To save feed cost, swine producers need to avoid wasting of feed and formulate efficient feed which contains adequate nutrients for normal growth of pigs.

When swine feed is formulated efficiently, nutrients in feed will be well utilized in growing-finishing pigs subsequently growth rate of pigs has improved and days to market weight can be reduced. Not only price of swine feed, but also pollutants in environment will be great concerned when feed contained excessive nutrients. Among of nutrients, crude protein and energy contents in swine feed determine the price of feed, resulting in affecting net profit of swine farm. Consequently, this study was conducted to evaluate the optimal levels of energy and protein in swine diet on growth performance, blood profiles, carcass characteristics and feed cost in growing-finishing pigs.

II. Literature Review

1. Introduction

1.1 Genetic Improvement and Nutrient Requirement for Pigs

Genetic improvement of pigs, supported by constant breeding programs and genetic discoveries, has steadily been enhanced since its start in the early 20th century (especially in Northern Europe). In its initial phase, the focus was mainly on lean mass and feed efficiency of pigs. Studies have seen gradual advances in genotype or phenotype, so that enhancement of breed characteristics (such as type, color, and back fat thickness) was achieved, and daily gain and feed efficiency were constantly improved.

Since the beginning of animal domestication, humans have been aiming to breed animals best satisfying our interests. In its start, our goals concerned general features like size and color, and the matter of docility. Dickerson (1952, 1974) studies concerning crossbreeding of plants and poultry garnered attention from pig farms. The phenotypic trends of Dutch Landrace pigs and Dutch Yorkshire pigs from 1930 through 1990 is shown in Table 1. Merks (2000) reports 50-plus percent increase in daily gain, outstanding enhancement in feed efficiency, and approximately 50% of decrease in backfat thickness. Figure 1 shows main genetic trends through the century (including daily gain, backfat thickness, and litter size).

Table 1. Phenotypic trends in central test results in the Netherlands from 1930 until 1990

Race	Daily gain (g/d)	Feed efficiency (kg/kg)	Backfat thickness (mm)
Dutch landrace			
1930	500	3.5	45
1947	650	3.4	33
1972	788	2.6	26
1990	840	2.8	24
Great Yorkshire			
1930	550	3.4	48
1947	680	3.2	35
1972	815	2.5	27
1990	840	2.7	22

Sources:Merks,2000

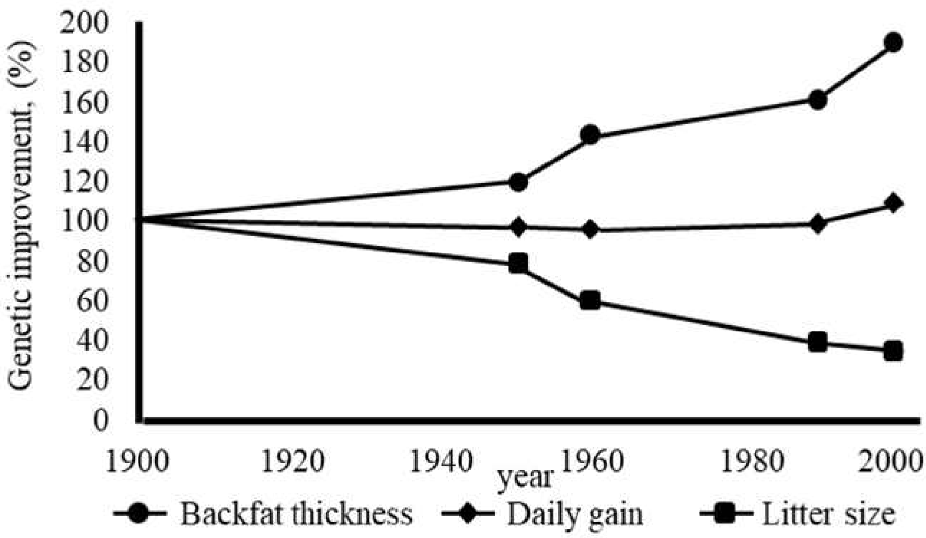

Figure 1. Schematic description of one century of genetic progress in pigs (Merks, 2000)

Advancement in the field of genetics (such as that of molecular genetics) continued into the last decade of 20th century, allowing improvement of sire and dam lines for swine reproduction systems.

Enhancement in growth performance and feed efficiency keeps proceeding, according to Knap (2009) and Torres et al. (2005). Intramuscular fat (IMF) content shows decrease in Brewer et al. (2001), as an outcome of breeding for leaner genotype.

The purpose of breeding programs was centered on daily gain, feed efficiency and litter size, and has evolved to also include characteristics like meat quality and vitality of piglets (Knol, 1998). There are also some studies involving gene-environment interaction (Andersen et al., 1998; Merks and Hanenberg, 1998) and inbreeding (Meuwissen, 1998).

Some scientists concentrated on the nutrient requirements of pigs. Ideal lysine/digestible energy (DE) ratio in growing pigs can be seen in Table 2, according to their genotype. Van Lunen and Cole (1996) observed that through genetic improvement, protein deposition and lysine requirements have increased. Naturally, it would be safe to assume that there will be steady increase of the nutrient requirements in pigs.

Table 2. Optimum lysine/digestible energy ratios in growing pigs by different genotype

Genotype	PD (g/day)	Weight (kg)	Lysine/DE ratio		
			Castrate	Gilt	Boar
Unimproved	100	<25	0.78	0.80	0.83
		25-55	0.73	0.75	0.78
Average	125	<25	0.85	0.85	0.88
		25-55	0.78	0.80	0.83
High	150	<25	0.88	0.90	0.93
		25-55	0.83	0.85	0.88
Hybrid	175	<25	1.20	1.20	1.20
		25-55	1.10	1.10	1.10

Sources: Van Lunen and Cole 1996

1.1.1 Nutrient requirement

Dietary energy is used in maintenance, accretion of protein and lipid, and heat loss of production (Van Milgen and Noblet, 2003). From pigs' birth to the point where they reach market weight, daily energy intake keeps increasing. The energy is firstly spent on maintenance, then on protein and lipid accretion (Lizardo et al., 2002). Spare energy will be accumulated as fat. The amount of energy for maintenance takes up about a third of their total energy intake, and the rest is spent on protein and lipid accretion (Black and Lange, 1995; NRC, 1998).

The interaction between energy intake and protein deposition decides the accretion of protein and lipid (through dietary energy) above the animal's maintenance needs. Bikker et al. (1995) states that the genotype and energy intake has influence on the effect of a dietary energy intake on body composition. Davies (1983) states that compared to pigs with low feeding level, pigs with high feeding level accumulated more fat and less muscle. Kanis (1988) and Bikker et al. (1995) suggested that increase in energy intake dropped the efficiency of lean tissue gain. Older pigs, according to Bikker et al. (1996) were shown to preserve more lipid per unit of extra energy than protein. Rao and McCracken (1991) reported an even increase of protein deposition up to 230 g/d, affected by the nitrogen balance of approximately 38 MJ of DE/d. Ellis et al. (1983) and Jorgensen et al. (1985) demonstrated that lowering the energy intake also increases the lean portion and decreases the fat portion in a pig's body. Raising the energy intake has been found to boost the ratio of lipid and protein deposition (LD : PD) (Campbell et al., 1983; De Greef et al., 1994; Bikker et al., 1995). Campbell and Taverner (1988) agreed to these influences of energy intake on body composition. Bikker et al. (1995) claimed that higher energy intake in growing female pigs lessened the protein deposition of lean tissue. De Greef et al. (1994), illustrated the increase of LD : PD as pigs' body weight increased, claimed that LD : PD increased in boars weighing 25 ~ 105 kg, regardless of high or low feeding level.

1.1.2 Nutrient Requirement of Pigs

In pig farming industry, two important factors for maximum result are growth rate and feed cost. Swine production aims to get more products from various feeds that provide proper nutrients. There are several nutrients crucial for synthesis of muscle, adipose tissue, bone, hair, skin and other body parts. They include energy, protein, amino acid, minerals, vitamins, water, etc. Nutrients also play great part in body maintenance, growth, reproduction and lactation.

Meanwhile, Wilson and Bayer (2000) claimed that feed ultimately affects 60% of the cost for producing market-weight pigs. Overfeeding nutrients is reported to have negative influence on the environment (Swine Nutrition 2nd Edition, 2001). Underfeeding is reported to affect pigs' 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). As these claims imply, nutrient concentration influences swine performance, and thus connected to cost of production. Accordingly, we need studies appraising changes in requirements of nutrients and resulting swine performance. The studies would enable us to enhance swine productivity and save feed cost.

1.2. Nutrient Requirement for Growing-Finishing Pigs

As nutrients intake is vital for growth, breeding and production of livestock animals, there has been continuous study on animal nutrition, in order to provide enough nutrients for animals without either excess or deficiency. As of pigs, there are enough information acquired through numbers of experiments (concerning pig's weight gain, feed efficiency, protein accretion rate, etc.). However, some differences exist depending on changing body weight and circumstances of animals. As a result, the standard of nutrient requirement for pigs was set by institutions worldwide (e.g. NRC of the USA (1998), ARC of the UK (1981), SCA of Australia (1987) and JRC of Japan (1993)). Rural Development Administration of South Korea also joined in by publishing the Korean Feeding Standard for Swine (2007).

Feed intake of growing-finishing swine depends on energy content in feed. Feed of high energy content leads to decrease in feed intake, increase in weight gain, and decrease in lean percentage following increased lipid accumulation. Daily energy requirement is obtained through the sum of the requirements for maintenance, protein and fat deposition, and thermo-regulation. Pigs of growing-finishing period need energy to grow and maintain bodily functions. Maintenance energy is fundamental in supporting life and body temperature and is gauged from heat production in fasting period. NRC (1998) suggests 110 $W^{0.75}$ kcal of DE daily or 106 $W^{0.75}$ kcal of metabolizable energy (ME) daily for pigs of all weights.

Because stage of growth, dietary energy and other nutrients influence fat and protein deposition, energy requirements for growth may vary. They are needed in synthesis of bone, tissue, organ, muscle and fat by protein and lipid deposition. Verstegen et al. (1987) stated that 10.6 Mcal of ME is needed for synthesis of a gram worth of protein, 12.5 Mcal of ME for synthesis of equal amount of fat. According to Wenk et al. (1980), protein took up 23% in a kilogram of muscle tissue; fat took up 80~95% in a kilogram of fat tissue. This shows that muscle synthesis requires more energy than fat deposition.

Table 3 shows standardized energy requirements for growing-finishing pigs set up by different institutions worldwide. NRC suggested 3,265 kcal/kg of ME (1998) as energy requirement of growing-finishing pigs (3,300 kcal/kg in its 2012 report). KFFS suggested 3,265 kcal/kg of ME (2007) as well (2012 report details the amount as follows: 3,350 kcal on 25 ~ 45 kg pigs, 3,300 kcal on 45 ~ 120 kg pigs). SCA (1987) and JRC (1993) shares similar information regarding pigs of growing-finishing phase. ARC (1981) shows lower energy requirement according to their own data of genotype, growth rate, lipid deposition and environmental factors.

Table 3. 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
EstimatedME[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	
EstimatedME[1], kcal/kg	2,983		2,983	
SCA, 1987	20 - 50		50 - 90	
DE. kcal/kg	3,346		3,346	
EstimatedME[1], kcal/kg	3,212		3,212	
JRC, 1993	30 - 70		70 - 110	
DE. kcal/kg	3,300		3,300	
EstimatedME[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)

Protein level in pigs in general represents 15~18% of their body mass, and 45~60% of it is shared to dissectible muscle or lean meat. Others spread to pigs' visceral organs, hair, bone, skin, blood and other tissues. Dietary protein replaces proteins lost in protein turnover, and is disposed as cells, amino acids, other nitrogenous compounds and unabsorbed enzyme secretions from the intestine ("metabolic fecal losses" or "endogenous fecal losses"), or urea from the kidney ("urinary losses"). In addition, amino acids found in protein are needed for the synthesis of non-protein compounds (hormones, neurotransmitters, immunoglobulins and other bioactive peptides). As seen in Table 4, which shows protein requirement for growing-finishing pigs, they require less protein as they mature. Quite a few researchers proposed that adequate amino acids balance is more effective for pigs' growth than protein level.

Table 4. Protein requirements for growing-finishing pigs

Item	Body weight (kg)			
NRC, 1998	20 - 50	50 - 80		80 - 120
Protein, %	18.0	15.5		13.2
NRC, 2012	25 - 50	50 - 75	75 - 100	100 - 135
Protein[1)],%	15.8	13.8	12.2	10.5
KFSS, 2007	25 - 50	50 - 80		80 - 120
Protein, %	18.0	16.0		13.0
KFSS, 2012	25 - 45	45 - 65	65 - 85	85 - 120
Protein, %	-	-	-	-
ARC, 1981	15 - 50		50 - 90	
Protein, %	15.6		11.2	
SCA, 1987	20 - 50		50 -90	
Protein, %	15.6		11.5	
JRC, 1993	30 - 70		70 - 110	
Protein, %	15.0		13.0	

[1)]Calculated from total nitrogen X 6.25

Main ingredients for swine feed like corn, barley and wheat can cover 30~60% of total amino acid requirements. Soybean meal is also an ample provision of pigs' requirements of protein and amino acid. The following 9 amino acids are indispensable amino acids that should be obtained through pigs' diet: lysine, methionine, threonine, tryptophan, histidine, isoleucine, leucine, phenylalanine and valine. Cysteine and tyrosine can only be synthesized from essential amino acids (from methionine and tyrosine, respectively), and these can be viewed as semi-essential. Lysine generally is considered the first-limiting amino acid in cereal-grain-based pig diets. Dietary amino acids requirement for swine is closely associated with protein accretion, energy intake and dietary energy density in their growing-finishing phase (NRC, 1998). The whole-body protein accretion rate differs according to genetic strain, gender, health and stock density, or to combination of these or other factors. However, the amount of lysine needed for growing-finishing pigs decreases linearly (Figure 2).

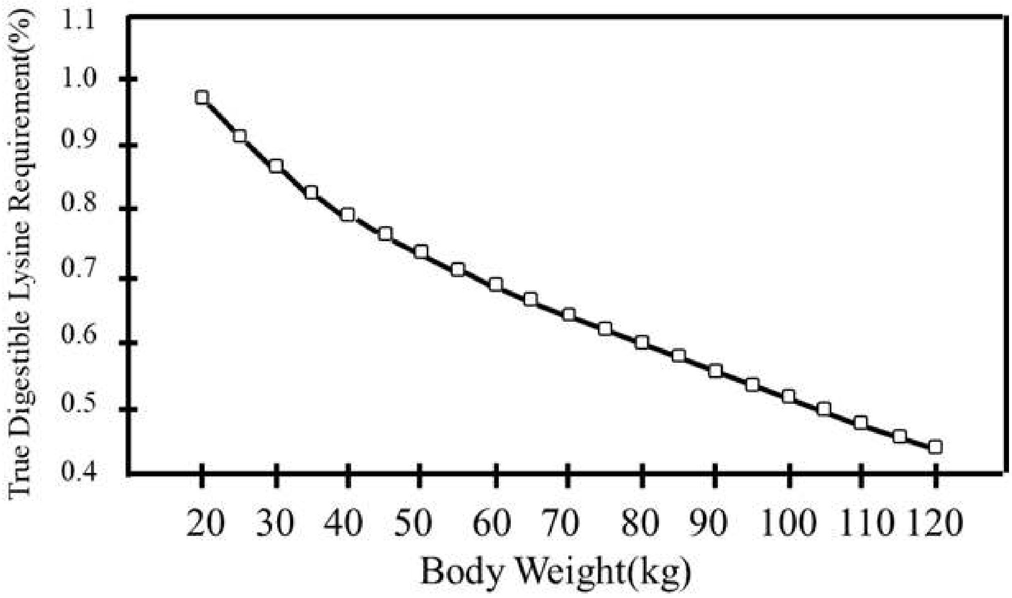

Figure 2. Lysine requirements (%, true ileal digestible basis) of pigs with a mean lean growth rate (NRC, 1998)

Institutes differ as to the requirement of lysine for growing-finishing pigs (Table 5). They all show linear decline of lysine requirement through pigs' growth. Nonetheless, these feeding standards show distinction, taking into account genetic strain, gender, health, growth rate, etc.

Table 5. Lysine requirements for growing-finishing pigs

Item	Body weight (kg)			
NRC, 1998	20 - 50	50 - 80		80 - 120
Lysine[1)], %	0.95	0.75		0.60
NRC, 2012	25 - 50	50 - 75	75 - 100	100 - 135
Lysine[1)], %	1.12	0.97	0.84	0.71
KFSS, 2007	25 - 50	50 - 80		80 - 120
Lysine[1)], %	0.98	0.82		0.64
KFSS, 2012	25 - 45	45 - 65	65 - 85	85 - 120
Lysine[1)], %	1.22	1.01	0.91	0.76
ARC, 1981	15 - 50		50 - 90	
Lysine[1)], %	1.10		0.78	
SCA, 1987	20 - 50		50 -90	
Lysine[1)], %	0.83		0.60	
JRC, 1993	30 - 70		70 - 110	
Lysine[1)], %	0.75		0.56	

[1)]Lysine requirement for total basis(%)

Dietary protein is vital source for the synthesis of body tissue, organ, hair, bone, skin, blood and other tissues. Moreover, some amino acids in protein are necessary for the synthesis of non-protein compounds; hormones, neurotransmitters, immunoglobulins to name a few, and other bioactive peptides.

Nutrient requirements decrease as pigs grow, and one way to provide appropriate nutrients for growing-finishing pigs is phase feeding. Phase feeding prevents the waste of nutrition, saves the cost for feedstuff, as well as curtails the emission of nitrogen.

Table 6 shows crude protein (CP) requirements for growing-finishing pigs set by the NRC. It shows that NRC (2012) has divided the phases of growing-finishing pigs into four, whereas in NRC (1998) the phases had been divided into three. CP requirements according to pigs' weight has lessened in NRC (2012) than in NRC (1998). This, along with many other reports, suggests that providing precise balance of amino acids is more effective for pigs' growth than protein level is.

Table 6. Crude protein requirements for growing-finishing pigs in NRC 1998 and 2012

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

[1]Calculated from total nitrogen X 6.25

1.3 Protein Deposition

1.3.1 Protein and Amino Acids

Proteins are primary nutrients for biological processes. They are macromolecules that make possible, virtually all molecular transformations and biochemical reactions.

Amino acids can combine into various chemical substances apart from proteins, including peptides, hormones, neurotransmitters, purine and pyrimidine nucleotides, creatine, carnitine, porphyrins, polyamines, and nitric oxide in an animal body (Wu and Morris, 1998). All natural proteins consist of 20 α-amino acids. These have a carbon that includes a primary amino group and a carboxyl group. Amino acids vary according to different structures of side chains contained in them. Since animal cells cannot utilize inorganic N (like urea or ammonia) to form amino acids when carbon skeletons are unavailable, essential amino acids must be included in the animal diets. Chung and Baker (1991) observed that piglets are fattened when provided a diet with crystalline amino acids as the only source of nitrogen. Easter and Baker (1976) observed that gilts go through normal pregnancy during the last 84-day phase of gestation when fed the same diet. Amino acids not only act as precursors of protein, but also of nitrogenous substances (such as nitric oxide, polyamines, creatine, dopamine, and catecholamines) that are crucial for whole-body homeostasis (Wu and Meiniger, 2002; Odenlund et al., 2009; Suryawan et al., 2009).

1.3.2 Protein Deposition

PDmax refers to the upper limit of protein deposition achieved or achievable by a pig. To get maximum results in growth rate and body weight gain (especially lean tissue growth), pigs' genotype and their PDmax were considered on the preferential basis. Energy usage for maintenance is followed by energy usage for protein accretion, which is followed by PDmax curve. PDmax curve is set up by numerous studies (Carr et al., 1977; Moughan and Verstegen, 1988; Thompson et al., 1996; De Greef et al., 1994; Van Lunen and Cole, 1998; Weatherup et al., 1998).

In Figure 3 is displayed the interrelationship between energy intake and body protein deposition. When body weight reaches certain amount, protein deposition slowly increases while energy intake approaches PDmax point (This is on the assumption that there are no factors hindering the protein deposition.) (Campbell and Taverner, 1988; Bikker et al., 1995, 1996; Quiniou et al., 1995, 1996). More energy intake from this point on results only in more lipid deposition. This will lead to fatter carcass and poorer feed efficiency. Pig farming is most efficient when energy intake is at PDmax level.

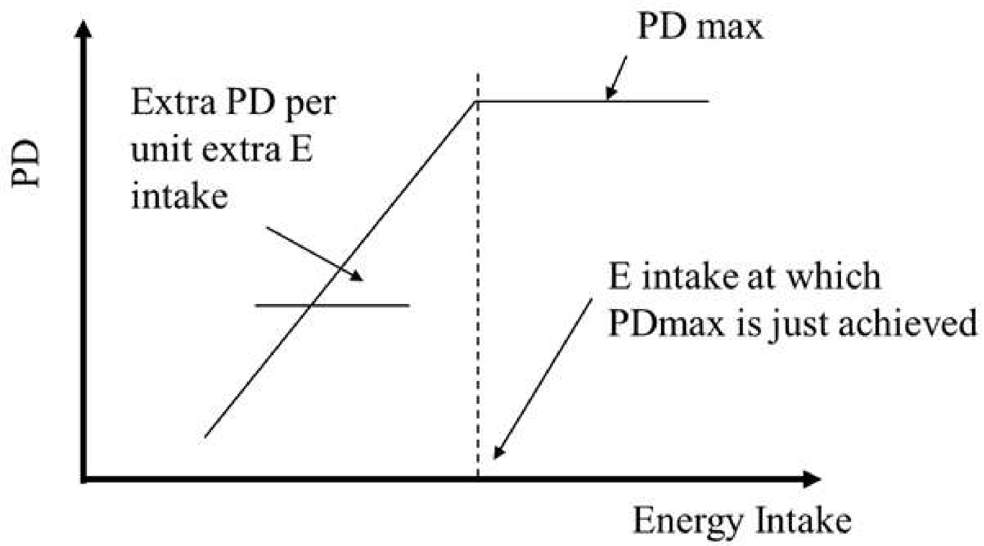

Figure 3. Relationship between energy intake and body protein deposition(PD) in growing pigs (Swine nutrition, 2nd edition)

PDmax point in growing-finishing pig is between 90~160 g/day (Carr et al., 1977; Moughan and Verstegen, 1988; Thompson et al., 1996). Recently, boars occasionally show PDmax of above 200 g/day (De Greef et al., 1994; Van Lunen and Cole, 1998; Weatherup et al., 1998). This shows that PDmax can be enhanced to a great extent, which is linked to great possibilities of lean growth through genetic selection. PDmax curve can be maintained or increased as energy intake in a 40 ~ 90 kg weighing pig, depending on pig’s genotype (Campbell and Taverner, 1988; De Greef et al., 1994; Quiniou et al., 1995; Bikker et al., 1996).

PDmax is highest in boars, then in gilts, and is lowest in castrates. When fully grown, there is approximately 5% difference in PDmax between gilts and castrates (Moughan and Verstegen, 1988; Stranks et al., 1988; Thompson et al., 1996), approximately 20 ~ 30% difference between boars and castrates (Moughan and Verstegen, 1988; Van Lunen and Cole, 1998).

1.4 Lipid Deposition

Protein deposition and lipid deposition occur simultaneously, but extra dietary energy is utilized first in protein deposition and then on lipid deposition.

Whittemore (1993) defined ‘target fat’ as the minimum amount of fat when animals would feel physiologically comfortable, so that available nutrients can be properly shared, and metabolism for reaching potential rate of lean tissue growth can be maximized. When remaining energy level for lipid deposition is lower than certain target fat level, achievement of protein deposition rates will be altered to achievement of target fat levels. This condition would set the physiological priority to restore fat levels to target fat level. Whittemore et al. (1988) explains the minimum amount of lipid (connected to the amount of protein deposition a growing pig can achieve) through the target fat level. This is because protein gains will be held back until target fat level is reached. Before lean-tissue growth rate reaches the full extent, the ratio of fat to lean will indicate the percentage of fat in the gain, which is the target level (Figure 4, Whittemore, 1993).

Kyriazakis and Emmans (1992) explained that the rate of lipid deposition is determined by the protein deposition rate that an animal may

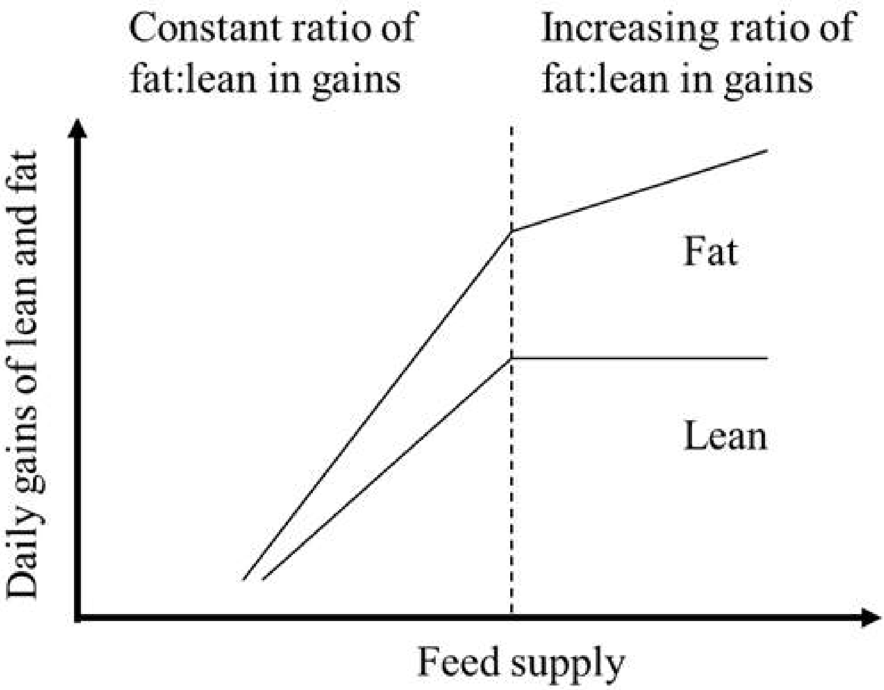

Figure 4. The ratio of lean to fat in gain (Whittemore, 1993)

achieve in its attempt to reach the normal level in a non-limiting environment. If the animal lacks in both protein and lipid level, each will aid the other in their balance. Increasing feed intake in the state of protein deficiency improves lipid retention rates (Kyriazakis and Emmans, 1992; Ferguson and Gous, 1997; Ferguson et al., 2000).

Whittemore (1998) explains, when animals become or are made overweight (through high quality diet, for example), they use remaining body fat to maintain their normal protein level, or they accumulate less lipid to restore by the lipid : protein ratio. Ferguson and Theeruth (2002) states that empty bodies of the pigs that are provided high-protein diet showed notably lower response from the lipid : protein ratio compared to those provided with low-protein diet, also agreed with Kyriazakis and Emmans (1991) and Ferguson and Gous (1997) reports. Pigs given feed of deficient protein are reported to acquire lipid rapidly compared to those given feed with appropriate amount of protein, and try meeting their potential protein growth rate (Kyriazakis et al., 1991; Ferguson and Gous, 1997).

2. Dietary Energy of Growing-Finishing pig

2.1 Effect of Dietary Energy Levels in Growing-Finishing Pigs

Dietary energy level is an important factor for having variety in feed intake. Controlling feed intake is dependent on energy density. Pettigrew and Moser (1991) explained that growing-finishing pigs generally showed less average daily feed intake (ADFI), more average daily gain (ADG) and gain to feed ratio (G : F) when provided with high dietary energy level. Few studies suggested that increasing energy in growing-finishing pigs' diet — although it did not have noteworthy effect on body weight and ADG — enhanced G : F (Baird et al., 1958; Clawson et al., 1962; Wagner et al., 1963). Chadd and Cole (1999), Smith et al. (1999) and De la Llata et al. (2001) however, represented that energy level too low for pigs lessened the energy intake and growth performance. Energy level too high on the other hand (according to Stahly et al. (1981), Southern et al. (1989), Williams et al. (1994) and Dunshea et al. (1998)), decreased ADG, ADFI and G : F. Cromwell et al. (1978) and Matthews et al. (2003) claimed different results altogether, stating different levels of energy on growing-finishing pigs do not affect growth rate and ADFI.

Stahly (1984) pointed to fat as a crucial component in growing-finishing pigs' diet, having high energy level. According to Young et al. (2003), adding 2.5% and 5% fat in the feed for growing-finishing pigs resulted in similar ADG and G : F. Haydon et al. (1989) claimed likewise, that 5% fat added for growing pigs did not produce any effect on their growth performance. However, adding 4.5% or 10% fat produced higher G : F and lower ADFI (Southern et al., 1989; Azain et al., 1991; Williams et al., 1994; Matthews et al., 2003). Some experiments achieved enhanced ADG and G : F in summer season by adding 5% fat in growing-finishing pigs' diet (Stahly and Cromwell, 1979; Stahly et al., 1981). De la Llata et al. (2001) reported enhanced ADG and G : F, reduced ADFI by adding 0%-6% of fat with 3.31~3.61 Mcal.

2.2 Dietary Energy Level and Fat Deposition

Pigs nowadays are leaner and require less feed intake. This means that growth rate can be enhanced by increasing energy intake, and pigs are less likely to become fatter (Young et al., 2003). Additionally, humans have achieved the desirable level of energy density in growing-finishing pigs' diet. Many countries have found diets using the available energy sources with least cost to satisfy the energy levels of pigs. Quite a few studies report that increasing energy density by including fat in growing-finishing pigs' diets generally enhances ADG and feed efficiency, while cutting down the ADFI. Pigs up to 59 kg go through an energy-dependent phase in growing phase (De la Llata et al., 2001). Bikker et al. (1996) noticed an energy-dependent phase in gilts from 45 ~ 85 kg and reasoned that protein deposition increased with more energy intake. Pigs from 93 ~ 120 kg were not in an energy-dependent phase, and therefore energy density of diet did not boost ADG. Smith et al. (1999) similarly observed added dietary fat had no effect on ADG from pigs weighing 73 ~ 104 kg. Put together, it can be said that dietary energy density is a crucial factor in protein or fat deposition. If pigs get more dietary energy than needed in growing phase, they will use leftover energy in lipid deposition or other body functions. If they get less than required, however, they will spend the energy not only in protein deposition but also in fat deposition. In finishing phase, dietary energy will be used in maintenance and protein deposition, and the excess will usually be spent in lipid deposition.

There are many studies demonstrating the relationship between dietary protein level and fat deposition in animals. Several reports that decrease in dietary protein level causes increase in fat deposition (Cromwell et al., 1978; Karlsson et al., 1993; Chiba et al., 2002). Teye et al. (2006) states that researchers have been applying CP diets containing unbalanced amino acids with net energy in order to bolster pigs' fat deposition (especially IMF). There are still some claims, however, of inclination for higher fat deposition with low-protein diets, even if the pigs are supplied balanced amino acids (Figueroa et al., 2002; Gomez et al., 2002b). Wood et al. (2013) study states that feeding low-protein diet, especially those with unbalanced amino acids content, boosted the IMF accumulation. This study, however, does not display much difference between low-protein diet group and control group in subcutaneous or intermuscular fat deposition.

Several studies explain the reason behind fat deposition when low-protein diets are provided. The gap between lipogenesis and lipolysis rates decides fat deposition. The reactions are controlled by metabolic enzymes and functional genes in the growth, and the following development process of muscle tissue (Wang et al., 2012). Jurie et al. (2007) suggested that fatty acid transport in muscle tissue also regulates IMF deposition.

Chen et al. (2008) discovered a beneficial link between IMF deposition and expression level of SREBP-1 messenger RNA (mRNA) in muscle tissue of pigs. Some other studies also discovered a connection between stearoyl-CoA desaturase (SCD) protein expression and the amount of total fatty acids in muscle of pigs that are provided a low-protein diet (Doran, 2006). Wang et al. study (2012) claimed that low-CP diet increases the mRNA and protein expression of SREBP-1c, ACC, FAS and SCD. mRNA and protein expression level of lipolytic genes including HSL and CPT-1 were seen to decrease in the low-protein diet group. Furthermore, a positive connection between an elevated IMF content in pigs that are fed low-protein diet and activation of PPAR-ɣ and H-FABP mRNA expression is also suggested (Guo et al., 2011). According to Zhao et al. (2010), pigs fed low-protein diet showed increase in subcutaneous fat deposition. This result was induced primarily by up-regulation of lipogenic genes for pigs weighing 60 ~ 100 kg, down-regulation of lipolytic genes for pigs weighing 60 kg, and up-regulation of lipolytic genes for those weighing 100 kg.

Dietary protein level affects muscular fatty acid composition. Wang et al. (2012) claimed that pigs with low-protein diet showed higher concentration of C18:2, C18:3 and poly-unsaturated fatty acid (PUFA) than pigs with high-protein diet. The difference of fatty acid composition between low-protein/high-protein diet may come from the variance of SCD. According to Cohen and Jeffrey (2004), SCD is accountable for the generation of mono-unsaturated fatty acids, which catalyzes its substrates palmitic (16:0) and stearic acid (18:0) to produce palmitoleic (16:1) and oleic acid (18:1). Wang et al. (2012) demonstrated that pigs fed low-protein diet showed higher mRNA and protein expressions of SCD than those of high-protein diet. Additionally, Wood et al. (2013) pointed out that oleic acid is the central outcome from de novo fat synthesis in pigs and deduced that its concentration is heightened as the pig gets fatter.

Meanwhile, there are studies displaying considerably lower PUFA and higher IMF content in pigs with low-protein diet (Teye et al., 2006; Alonso et al., 2010). Lambe et al. (2013) claimed that the CT scans of growing pigs showed no meaningful differences in total fat deposition.

2.3 Effect of Dietary Energy Level on Growth Performance

High dietary energy diet for growing-finishing pigs generally enhances ADG, G : F and carcass fatness, and diminishes ADFI (Pettigrew and Moser, 1991).

Young et al. (2003) demonstrates that through quadratic effect of added fat, adding 2.5% fat in the diet caused 2% enhancement in ADG; adding 5% fat resulted in 2.1% increase in ADG. Feed efficiency also was almost coinciding among 2.5% and 5% added fat levels. Following these results, adding 5% or 10% fat in growing-finishing pig’s diet increased G : F and decreased ADFI (Southern et al., 1989; Azain et al., 1991; Williams et al., 1994). Furthermore, growing-finishing pigs bred in high temperature conditions showed enhanced ADG and G : F when fed diet of high energy level with 5% added fat, without difference in carcass leanness (Stahly and Cromwell, 1979; Stahly et al., 1981). Increasing fat percentage with 3.31 ~ 3.61 mcal (De La Llata et al., 2001) or energy density (Smith et al., 1999) also proved effective in boosting ADG and G : F while decreasing ADFI.

Feeding increasing choice white grease have been observed to garner similar effects in growing-finishing pigs (Stahly and Cromwell, 1979; Stahly et al., 1981). Campbell and Taverner (1986) and Southern et al. (1989) also reported enhancement of ADG in pigs provided with added fat.

Few researches report important advancement in feed efficiency by adding energy, albeit seeing no noteworthy effect on growth rate (Baird et al., 1958; Clawson et al., 1962; Wagner et al., 1963).

Smith et al. (1999) introduces an experiment of adding 0%, 1.5%, 3%, 4.5% and 6% CWG in the diet of growing-finishing pigs (energy density ranging 3.31 ~ 3.56 mcal/kg of ME in growing diets, 3.32 ~ 3.56 mcal/kg of ME in finishing diets). As energy density increased, ADG and ADFI were lessened, and feed efficiency saw improvement during the course of experimental phase (44.5 ~ 104.3 kg). Tribble et al. (1979), Stahly et al. (1981) and Southern et al. (1989) coincided with the outcome.

Apple et al. (2004) conducted an experiment centered on energy density in finishing phase (3.30 mcal/kg and 3.48 mcal/kg). During the final week of finishing phase, pigs fed 3.48 mcal/kg showed higher ADG then those fed 3.30 mcal/kg, although no such important variation was seen in other phases. Le Dividich et al. (1987) and Matthews et al. (2003) describes no noteworthy result on ADG despite having increased the energy density of late-finishing diets. Williams et al. (1994) and Dunshea et al. (1998) failed to find any interactions between energy density and growth rate in pigs. Again, Seerley et al. (1978), Campbell and Taverner (1986) and Southern et al. (1989) reported to have seen the effect of increased dietary energy on feed efficiency.

Contrary to previous reports, there are claims of no relationship between dietary energy level and growth performance of growing-finishing pigs. Cromwell et al. (1978) and Matthews et al. (2003) stated no influence of higher dietary energy level on growth performance and feed intake, respectively. Matthews et al. (2003) elaborated that high-ME diet (added 200 kcal by 4.5% fat to control diet) did not affect ADG in pigs' early growing phase (although ADFI was increased and G : F was decreased). The ME level in diet did not have noteworthy influence on the growth performance during other phases (late-grower, early-finisher, late-finisher and overall phases). Haydon et al. (1989) also concurred with aforementioned reports that 5% added fat did not affect growth performance.

2.4 Effect of Dietary Energy Level on Carcass Characteristics

Energy level is closely related to carcass fat level in pigs that are provided ad libitum access to feed.

Stein and Easter (1996) experimented with finishing pigs (weighing 55 ~ 112 kg), feeding them diet with 2,700 ~ 3,500 kcal/kg of ME. When dietary energy increased from 3,300 kcal/kg to 3,500 kcal/kg of ME, feed intake lessened. At lower energy density in diet, no change was observed in feed intake. Dietary energy below 3,300 kcal/kg of ME increased carcass lean content. It can be concluded from this experiment that low dietary energy density helps increasing the carcass lean content. Factors pointed out to increase carcass fatness in growing-finishing pigs include added fat (Pettigrew and Moser, 1991), dietary ME (Seerley et al., 1978; Coffey et al., 1982; Myer et al., 1992) and energy intake (Nossamen et al., 1991; Ellis et al., 1996; Wood et al., 1996). Cromwell et al. (1978) and Ellis et al. (1996) observed increased LM area following increased dietary energy intake. Myer et al. (1992) and Matthews et al. (2003) reported few instances when energy density didn't affect LM area. Other studies claimed that marbling and IMF content was increased by higher dietary energy density (Cromwell et al., 1978; Le Dividich et al., 1987) or energy intake (Ellis et al., 1996; Wood et al., 1996; Lebret et al., 2001). Drew et al. (1971) experimented with the diet of 10% added fat and discovered that IMF content was higher in longissimus (22.4% vs 14.6%) and gluteus medius (14.7% vs 11.1%). According to Wagner et al. (1963), when IMF was augmented in high-energy diet, no difference could be observed in nitrogen content of the meat. It induced thicker carcass backfat, lower lean cut yield, and notably higher dressing yield. Additionally, increase in energy level produced higher dressing yield ― matching the claims of Bowland and Berg (1959) ― and decrease in energy level produced lower lean cut yield ― also proposed by Mulholland et al. (1960). Sewell and Cartoon (1959) study, on the other hand, claimed no relationship between energy level in diets and total yield of lean cuts.

Cromwell et al. (1978) states that dietary fat has no influence on carcass characteristics except for lower yield of lean cuts. Similarly, Matthews et al. (2003) explained that no difference in carcass traits were made by ME level in diet. According to them, carcass temperature (45 min.) and CIE L value showed some increase in pigs given high-ME diets, but shear force was decreased. According to Apple et al. (2004), energy density in finishing pigs' diets did not affect hot carcass weights and dressing percent. In fact, dietary energy density (3.30 or 3.48 Mcal) did not affect any quality traits (e.g., muscle pH, drip loss, meat color, marbling, firmness, moisture, protein, lipid, ash, cooking loss and shear force). Other researches also concur that dietary energy level is insignificant regarding ultimate LM pH, drip loss percentage (Matthew et al., 2003), meat color and firmness (Coffey et al., 1982; Matthews et al., 2003), marbling scores and intramuscular lipid content (Seerley et al., 1978; Coffey et al., 1982; Myer et al., 1992), and cooking loss (Matthews et al., 2003; Lebret et al. 2001).

Backfat thickness is strongly related to carcass fatness in regard to pork quality and can be an indirect indication of pork quality. Cromwell et al. (1978) claimed that pigs produced more carcass backfat when provided with diet that was higher in energy level. This outcome many other researchers agree to, such as Heitman (1956), Kennington et al. (1958) and Boenker et al. (1960). Smith et al. (1999) measured 10th rib fat depth or longissimus muscle area with real-time ultrasound before slaughter and saw no effect of energy density. After slaughter, however, backfat thickness showed a variance according to different dietary energy density. These discrepancies between the real-time ultrasound and commercial plant fat depths might be coming from the skinning procedure during the slaughter process. Apple et al. (2004), comparing with pigs fed low-energy diets (3.30 mcal/kg), stated that pigs' fat thickness − measured with ultrasound − was greater on d14 and 28 in pigs fed high-energy diets (3.48 mcal/kg). However, dietary energy level did not affect scanned LM area or live weight.

There have been many studies claiming low-protein diet elevates the IMF deposition (Teye et al., 2006; Alonso et al., 2010; Wood et al., 2013). According to Fernandez et al. (1999), increase of IMF content in muscle may be of good influence on meat quality (such as tenderness, flavor, juiciness, and the nutritional value of meat). Various studies agree with this relationship between the meat quality and IMF content in meat that was fed a low-protein diet (Cisneros, Ellis, Baker, Easter and McKeith, 1996; Teye et al., 2006). Font-i-Furnols et al. (1987) went on to report that pork with high IMF content won favor from consumers. Dikeman (1987) stated that IMF activates saliva secretion and improves the juiciness by coating the inside of the mouth. Accordingly, pig farms strived to gain pork with enough IMF content that, not only guarantees taste but also assuages health-related issues concerning high-fat pork (Fortin et al., 2005). (According to Zhang et al. (2007), high consumption of saturated fatty acids heightens the plasma cholesterol level, which may bring cardiovascular disease.)

As of meat color, increase of Hunter L* value in pork fed low-protein diet contributes to visual aspects, giving it more lightness (Suárez-Belloch et al., 2016; Teye et al., 2006). Also, Hunter b* value has been reported to have connection with marbling (Suárez-Belloch et al., 2016). Goerl et al. (1995) observed that low-protein diet increases the Hunter b* value of pork.

Glycolytic potential refers to the potential amount of all muscular substrates that will be utilized in generating lactate after butchery (Monin and Sellier, 1985). It is another crucial factor, considering the effect muscle glycogen content at slaughter has on the rate and the extent of post-mortem pH drop (Henckel et al., 2000). According to Huff-Lonergan and Lonergan (2005), glycogen contained in muscle produces lactic acid during glycolysis, resulting in lower pH level. Ruusunen et al. (2007) observed higher glycolytic potential in pigs fed low-protein diet than in pigs fed high-protein diet. Katsumata et al. (2003) study shares similar point, claiming higher glycogen content in the low-lysine group than the high-lysine group.

3. Dietary Protein and AA in Growing-Finishing Pig

3.1 Protein and amino acid requirements for swine diets

3.1.1 Transition of Protein and Amino Acid Requirements in NRC

Table 7 is the change of protein and amino acid requirements set by NRC. Growth phase is more detailed in 2012 model than in 1998 model. This elaboration can aid in pig farmers' saving the feed cost and decreasing excess nutrient composition of the feed. 2012 model displays higher ME as well, from 3,265 kcal to 3,300 kcal. Moreover, it shows lower CP requirement and higher amino acids requirement compared to its previous report; this comes from preventing lack of limiting amino acids (or imbalance of them). Any deficiency of essential amino acids caused by low-CP diet is suggested that they be filled out by crystalline amino acids.

Table 7. Nutrient requirements of growing-finishing pig (NRC)

NRC, 1998	BW, kg	5-10	10-20	20-50	50-80		80-120
	ME, kcal	3,265	3,265	3,265	3,265		3,265
	CP, %	23.7	20.9	18	15.5		13.2
	Lys, %	1.35	1.15	0.95	0.75		0.6
	Met, %	0.35	0.3	0.25	0.2		0.16
NRC, 2012	BW, kg	7-11	11-25	25-50	50-75	75-100	100-135
	ME, kcal	3,400	3,350	3,300	3,300	3,300	3,300
	CP, %[1)]	20.6	18.9	15.7	13.8	12.1	10.4
	Lys, %	1.53	1.4	1.12	0.97	0.84	0.71
	Met, %	0.44	0.4	0.32	0.28	0.25	0.21

[1)]Calculated from total nitrogen X 6.25

3.1.2 Transition of Ideal Amino Acid Profile

Lack of limiting amino acids may hinder protein synthesis in the body. However, they are essential amino acids that can easily be insufficient in the feed. Mainly, the first limiting amino acid is lysine.

Mitchell (1964) report was first of many researches that specified the ‘ideal amino acids profiles.’ It indicates amino acids profiles that are adequate for animals’ performance, so that all amino acids are equally limiting. ARC (1981), based on the pig carcass, displayed the ideal amino acid ratio of essential amino acids. Wu (2010) however, claimed that their report centers only on the essential amino acid composition of the animal body. Similarly, Wu (2014) claimed that ARC’s ideal protein concept fails to consider the relative contribution of maintenance to the total amino acid pigs need. It goes on to assert that ARC did not include arginine, glycine and all synthesizable amino acids.

Wang and Fuller (1989) provided another ideal amino acid profile. They took account of the requirements for both maintenance and tissue protein accretion. Their study featured high content of glutamate in the diet, a reinforcement for non-specific nitrogen source. Non-specific nitrogen source was thought to make up for lack of non-essential amino acids.

Baker made an attempt to assess the amino acid requirements of pigs between 1990 and 2000. Chung and Baker (1992) produced the ideal amino acid profile that includes arginine, glycine, histidine and proline. Their report does not take into account other synthesizable amino acids. They don’t elaborate on the reason for using arginine, glycine, histidine and proline proportions to lysine. Whether glutamate is an effective precursor or not, and the influence of high glutamate content on metabolism is also not explained thoroughly. NRC and Baker (2000) does not include proline or glycine in ideal amino acids profiles.

Meanwhile, NRC (2012) increased the requirement of amino acid for pigs, while keeping the ratio among amino acids unchanging. This made the need of limiting amino acids increased. Plus, lower CP level brought about new limiting amino acids such as valine.

3.1.3 Effects of Dietary CP Levels in Growing-finishing Pigs

Growing-finishing pigs, when fed enough CP level in diet, showed higher ADG, G : F and carcass leanness (Gilster and Wahlstrom, 1973; Kornegay et al., 1973; Easter and Baker, 1980). According to Cromwell et al. (1978), diets with dietary CP level from 12 ~ 16% caused greater weight gain and G : F. Cromwell et al. (1993) and Chen et al. (1995) saw similar response in ADG and G : F when fed higher CP content diet. Cromwell et al. (1978) also noticed no influence on growth performance when dietary CP level ranges from 16 ~ 20%. Wagner et al. (1963) observed that boosting the CP level from 13% to 25% caused enhancement in ADG.

Kerr et al. (1995) study states that when fed low-CP diets (15-12-11%), pigs should be supplemented with lysine, tryptophan and threonine. Pigs with high-CP diets (19-16-14%) showed no such need. Growing-finishing pigs mostly showed low ADG and G : F when fed low-CP diets without amino acids supplementation. Also, compared to those fed high-CP diets, their carcasses displayed smaller longissimus muscle, thicker average backfat, and lower percentage of muscle overall (Gilster and Wahlstrom, 1973; Kornegay et al., 1973; Easter and Baker, 1980). Cromwell et al. (1996) and Tuitoek et al. (1997) claimed that decreased CP level (2-3%) with amino acids supplementation did not have negative influences on ADG and G : F of growing-finishing pigs. Plus, CP level lower than 3% did not decrease ADG and G : F in growing-finishing pigs (Hahn et al., 1995; Kerr et al., 1995). Hansen and Lewis (1993) and Gomez et al. (2002b) show different results.

3.2 Dietary Protein and AA Metabolism

3.2.1 Lysine Metabolism

Numerous studies established for decades that dietary supply of protein, or its components, amino acids are crucial to the pigs' growth and development of muscles. About 20 natural amino acids exist that are utilized in protein biosynthesis (called standard proteinogenic amino acids). Not all amino acids are essential dietary components, since through de novo synthesis pigs can acquire approximately 10 of them. 'Essential amino acids' refer to those that pigs cannot acquire on their own (or at least not enough for their metabolic needs) and need to be provided from outside sources (Fuller et al., 1987). Lysine is the first and main limiting one among these essential amino acids, it being the most lacking amino acids in almost every swine diets based on cereal grains (Lewis, 2001; NRC, 2012). This reason puts lysine in a predominant position in nutritional management of the pigs (Figure 5).

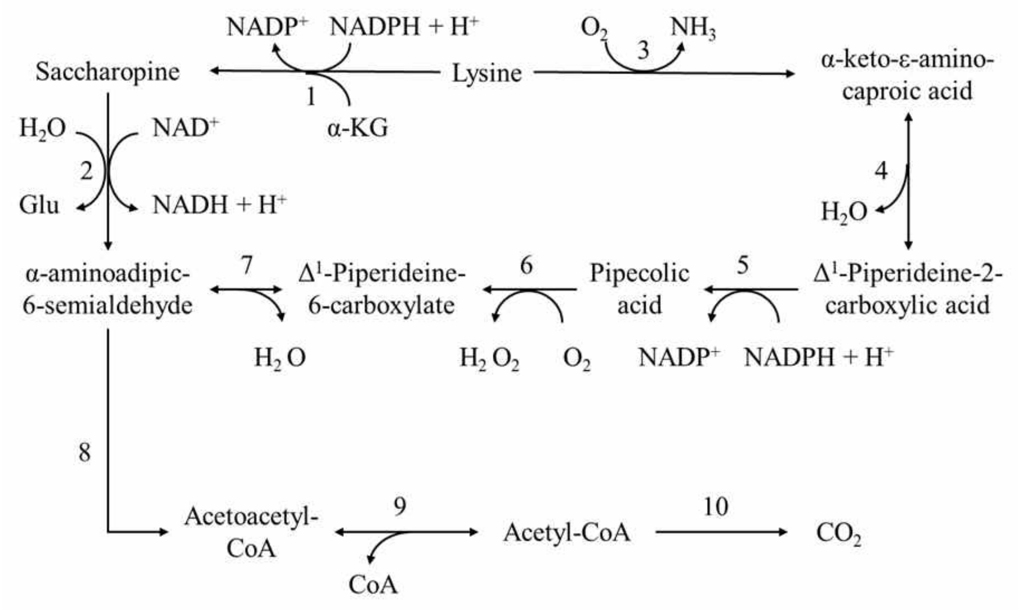

Figure 5. Lysine catabolism in monogastric animals. (Chung, 2018)

Papes et al. (1999) and Gatrell et al. (2013) stated that the main pathway of lysine catabolism is the saccharopine pathway in liver. By the catalysis of lysine-ketoglutarate reductase, lysine is initially combined with α-ketoglutarate to produce saccharopine. Then, saccharopine is transformed to α-aminoadipic-6-semialdehyde and glutamate by saccharopine reductase. Saccharopine reductase (also called saccharopine dehydrogenase), like lysine-ketoglutarate reductase, is a part of a polypeptide, bifunctional aminoadipate δ-semialdehyde synthase (Gatrell et al., 2013). Through several more phases, the α-aminoadipate-6-semialdehyde will then be transformed to acetyl-coenzyme A (Wu, 2013). This pathway is a rare reaction, because ε-amino group is carried to α-ketoglutarate and then to the general nitrogen pool. Oxidizing acetyl-coenzyme A generates CO2 and energy through the citric acid cycle.

1) Physiological Functions of Lysine

Lysine, apart from metabolic functions, plays a part in physiological functions of monogastric animals as well. Lysine influences metabolism of nutrients, hormone production, and immunity of animals (Wu, 2010a; Wu, 2013). Peptide-bound lysine is also where post-translational modification and epigenetic regulation of gene expression happens. In order to utilize lysine properly for animals, scientists and farmers need to be well-acquainted with these functions that lysine can provide.

2) Lysine Mechanism and Perspectives

Wittmann and Becker (2007) mentions that late 1980s saw an introduction of commercial feed-grade crystalline lysine in animal feed industry. Animal nutritionists should take into deep consideration the replenishment of dietary lysine, since the lack of lysine impedes animals' health maintenance and growth performance. (Oversupply of lysine, on the other hand, is harmless.)

Dietary supplementation of crystalline lysine is proved to aid in muscle protein accretion and whole-body growth of pigs. Researchers found out that lysine supplementation helps in nitrogen retention and protein accretion, as well as the growth performance of the animals (Sharda et al., 1976; Fuller et al., 1987; Salter et al., 1990; Shelton et al., 2011). Additionally, Salter et al. (1990) attributed the increase of muscle protein accretion to the increase in the rate of protein synthesis, as opposed to the decrease in the rate of protein degradation.

The metabolic/molecular mechanisms in which dietary lysine controls muscle mass accumulation in pigs was not clarified (Wu, 2010b; Rezaei et al., 2013). Then, Liao et al. (2015) discovered the metabolic and physiological roles of lysine, concerning swine muscle growth and development. Relevant studies have been scarce concerning pigs, and so much of the knowledge amassed up to now have been dependent on studies of other monogastric animals, including humans.

3.2.2 Methionine Metabolism

There are metabolic relationships between methionine and cysteine that are now academically accepted (Figure 6). Methionine, by adenosine triphosphate, can be turned into S-adenosyl methionine. This methionine-derivative gives its methyl group to various acceptors (Finkelstein, 1990). S-adenosyl-L-homocysteine is formed, and then is hydrolyzed to homocysteine and adenosine. Homocysteine holds a pivotal place, since it can be recycled into methionine, or be condensed with serine, forming cystathionine and then cysteine. The fact that the conversion of homocysteine into cysteine is irreversible is noteworthy (Bauchart-Thevret et al., 2009). Overall, these metabolic pathways show that methionine can be transformed into cysteine, but not so vice versa. De-/re-methylation process between methionine and homocysteine in the activated methyl cycle needs B-vitamin coenzymes (Finkelstein, 1998).

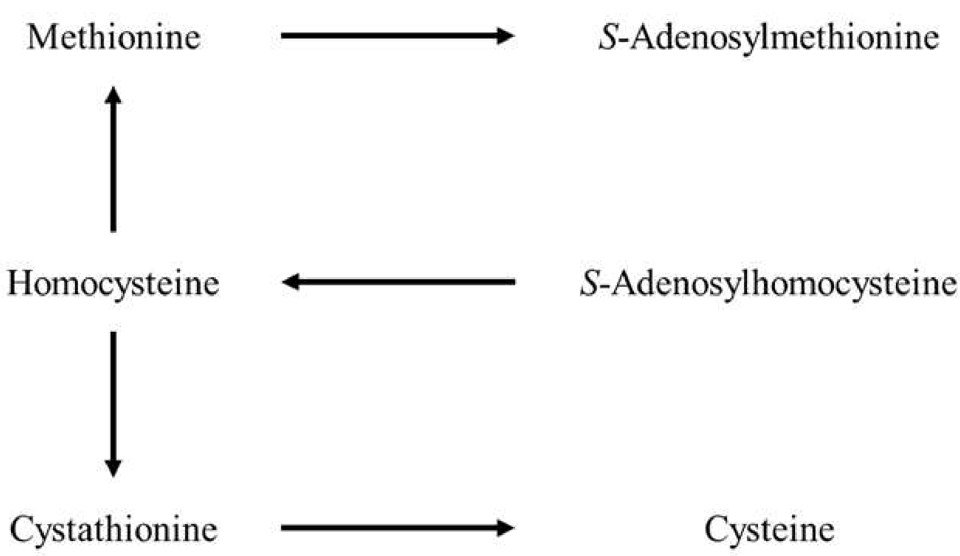

Figure 6. Metabolic pathways of sulfur amino acids. (Chung, 2018)

3.2.3 Tryptophan Metabolism

Another essential amino acid is tryptophan. It is a crucial component for its biological roles, main one being its connection to metabolic pathways involved in tryptophan catabolism. Tryptophan is a precursor for the synthesis of serotonin, a neurotransmitter related to mood, stress response, sleep and appetite regulation. From the perspective of quantity, the rate of tryptophan usage in creating serotonins is very low. This is because the tryptophan transport and availability in the brain might be limiting for the synthesis of brain serotonin. Diets with low tryptophan lower feed intake. The mechanism concerning this effect of low tryptophan diets is generally linked with the relationship between tryptophan and serotonin. Adding the fact that tryptophan is one of the essential amino acids that can only be gained from outer source, it can be suggested that deficiency of tryptophan limits protein synthesis, accretion and growth rate.

3.2.4 Threonine Metabolism

Portal-drained viscera is known to oxidize some essential amino acids (Van Goudoever et al., 2000; Riedijk et al., 2007). However, it cannot be said that the essential amino acids will doubtlessly be catabolized inside the intestinal tissues. Threonine catabolism through L-threonine 3-dehydrogenase pathway is a small factor within the visceral tissues, not influenced by intestines (Le Floc'h and Sève, 2005; Schaart et al., 2005). Schaart et al. (2005) states that splanchnic oxidation (measured by 13CO2 production from 13C-labeled threonine) takes up 2% of intestinal utilization of threonine, 13% of whole-body threonine oxidation.

These results imply that protein synthesis controls the dietary threonine utilization by the intestinal mucosa of pigs (Le Floc'h and Sève, 2005; Schaart et al., 2005), probably by being included into mucins. According to Montagne et al. (2004), mucins are polymeric glycoproteins featuring heavily in mucus layer that coats the epithelium of the gastrointestinal tract, or all epithelia of mammals. Most mucins are secreted, and some of them are membrane-bound. Secreted mucins are important in the inborn immune defense of mucosa. Lots of threonine can be found in the core protein of the major intestinal mucins. Faure et al. (2002) study involving rats reports that the fractional synthesis rate of mucin glycoproteins stayed comparatively same following the length of intestine (range 112 ~ 138%/d). However, it was considerably higher compared to the total mucosal protein synthesis rate, notably in the ileum (77%/d) and colon (44%/d).

Around 11% of endogenous protein in ileal digesta of pigs consists of mucins, 30% of them being threonine (Lien et al., 1997). When amino acids from proteins that are secreted internally reach the large intestine, they are lost by the animal. Similarly, secretion of mucins, erosion of the mucus, and recovery of mucins following endogenous ileal losses are susceptible to many factors, be it dietary or anti-nutritional (Montagne et al., 2004). The need for threonine seems to receive huge influence from secretion, recycling, or loss of intestinal mucins, triggering the energy needs of the organism. In 12-hour feeding phase and 12-hour fasting period, intestinal recycling of amino acids from secretory proteins are crucial regulatory mechanism for systemic availability of dietary amino acids (Van der Schoor et al., 2002). Noteworthy threonine recycling from mucosal protein in the portal circulation, however, was absent. This indicates either that these proteins can cope with digestion or that recycled threonine are re-absorbed directly into mucosal protein.

3.3 Dietary Protein Level and Protein Deposition

Synthesis of body tissue, organ, etc. essentially needs dietary protein as its source. Protein intake, however, is not a primary factor to pigs' growth. Their growth depends on energy intake and usage of that energy. The energy took in by the pigs is used in maintenance, body protein deposition and fat deposition. Most of them will constantly be spent on maintenance. The remainder then goes to body protein deposition, and then finally, the surplus will be utilized in body fat deposition.

Body protein deposition, a significant factor in utilization of energy in pigs, is regulated by PDmax. PDmax level is generally consistent in pigs weighing up to approximately 80 ~ 90 kg (Moughan and Verstegan, 1988;

Quiniou et al., 1995). Mathematical models like Gompertz function can illustrate the decrease in PDmax level following pigs' growth; pigs provided high-protein diet can utilize appropriate amount of protein that meets PDmax requirement. The remainder will either be secreted or utilized in other bodily functions and energy production. Therefore, protein intake higher than PDmax requirement is crucial to maximum growth of pigs.

3.4. Effect of Dietary Protein Level on Carcass Characteristics

Many studies claimed that adequate amount of dietary protein for pigs contribute to enhancement of carcass characteristics.

Cromwell et al. (1978) states that increase in protein level caused increase in longissimus area and lean cut yield. Backfat did not seem to be influenced by protein level, but pigs provided low-protein diet showed highest IMF content in longissimus, and vice versa. Difference in shear values of loin was insignificant, only to the point where pigs fed low-protein diets produced marginally lower numbers than those with high-protein diets. Flavor and overall satisfaction scores also showed minimal contrast (Pigs fed low-protein diets showed slightly higher scores). Roasts prepared from pigs with low-protein diets performed greater in tenderness and juiciness, owing to the higher IMF content. Along with Wagner et al. (1963), Wyllie et al. (1969) and Drews et al. (1971), the study also states that dietary protein level has considerable effect on the IMF content of longissimus.

Wagner et al. (1963) states that increase in protein level causes carcass backfat, dressing percentage and IMF content to decrease, and the percent yield of lean cuts to increase. However, tissue nitrogen content showed no sign of noteworthy change by increasing protein level. Figueroa et al. (2002) observed that decreasing dietary protein level from 16% to 12% increased backfat and decreased longissimus muscle area.

Apple et al. (2004) (along with Cromwell et al. (1978), Goerl et al. (1995) and Kerr et al. (1995)) states that increasing dietary CP decreased LM marbling and IMF. The study concurs with Goodband et al. (1990) and Goerl et al. (1995) that it has no influence on proportion of ash in the longissimus muscle. Increasing CP level caused increase in LM are and lean yield.

Kerr et al. (1995) states that decrease in dietary CP increases the firmness and marbling of the longissimus muscle. Decrease in dietary CP also brought about the decrease of longissimus muscle area and overall percentage of muscle in pigs. Pigs that were provided low-CP diet (reduced CP level by 4% compared to control group) showed increase in average backfat thickness, 10th rib fat thickness, leaf fat weight and total fat in the longissimus muscle. Increase of carcass fat and decrease of longissimus muscle occurred concurrently when pigs were fed low-CP diet. Also, compared to pigs with high-CP diet, pigs with low-CP diet (with supplementation in amino acids) showed tendency for higher fatness. (This result is also claimed by Stahly et al. (1981), Fuller et al. (1984, 1986), Noblet et al. (1987), Schoenherr (1992) and Tuitoek et al. (1993)). There are two possible reason for this increase in carcass fatness; (1) Carcass quality is responsive to nitrogen content in the diet rather than amino acid from CP. (2) Low-CP level diets may possess higher net energy value. This allows the leftover energy that are related with low-CP/amino acids supplemented diets to be accumulated as fat.

Hansen and Lewis (1993), having experimented with growing-finishing pigs, states that the 10th backfat thickness showed curvilinear reaction to dietary protein level, proposing the possibility that subcutaneous fat would increase at dietary protein level over 23%. Increase in dietary protein also resulted in curvilinear reaction from longissimus muscle area and carcass lean percentage. Dietary protein level of 11% to about 19% caused longissimus muscle to increase almost linearly in pigs. However, longissimus muscle decreased when dietary protein level was boosted up to 23%. When protein level went over 19%, it ended up abating possible advances in carcass lean percentage. In conclusion, both lack and excess of dietary protein proved to be of adverse circumstance for carcass quality of growing-finishing pigs.

4. Dietary Energy and Protein Intake

4.1 Dietary Energy Level and Voluntary Feed Intake

One of the many theories concerning regulating factors of voluntary feed intake of pig points to dietary energy intake. According to this theory, pigs take energy according to their near or past energy needs. This will affect their meal size and time between meals. Gastric distension and emptying also have been pointed out to be a regulating factor of pigs' feed intake (Martin et al., 1989).

Both ARC (1981) and NRC (1998) points to DE content in diet and live body weight as main factors of voluntary feed intake in pigs. However, differences of up to 20 ~ 30% in voluntary feed intake are discovered according to different pig genotypes (Forbes et al., 1989; Schinckel, 1994) and gender (Schinckel, 1994).

Figure 7 shows the possible link between energy density of diet, levels of feed and energy intake according to Cole et al. (1971). There was a theoretical range of dietary energy levels that researchers thought the pigs can adapt their feed intake for maintaining constant energy intake. The physiological control of feed intake, however, is likely to be associated, not with maintenance of energy intake but with other mechanisms. These mechanisms include full gut capacity with diets of low nutrient density and a lack of gut capacity with diets of high nutrient density (Cole et al., 1971).

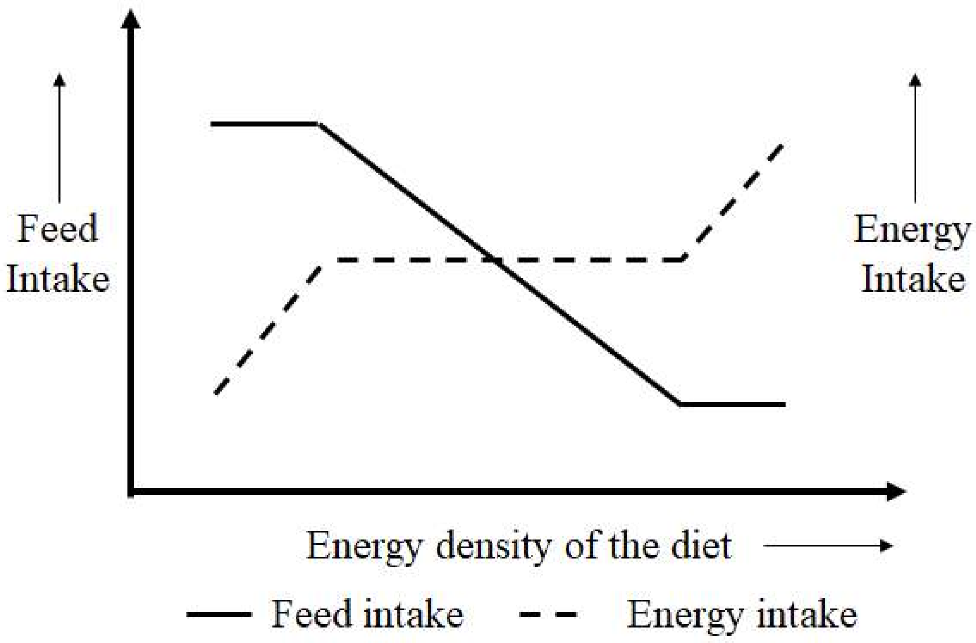

Figure 7. Schematic representation of the relationship between feed and energy intakes and the energy density of the diet. (Cole et al., 1971).

There are numerous factors of functional importance that can influence these relationships to decide the feed intake of pigs provided a specific diet. They include the size, genotype, sex, previous nutrition of the animal, dietary concentration of protein and other nutrients, and the sources of energy in the diet (especially concerning the type of fat or fiber). According to Giles et al. (1998), pigs weighing below 20 kg were not capable of increasing feed intake, in order to adapt to decreasing dietary energy density (roughly under 16 MJ/kg of DE concentration). Pigs weighing between 20 ~ 50 kg were able to increase feed intake with DE concentration of 14 MJ/kg, those weighing above 70 kg with 10 MJ/kg.

4.2 Dietary Protein Level and Protein Intake

The level of other essential nutrients in the diet can have effect on the voluntary feed intake of pigs, especially in the perspective of deficiencies or imbalances. Several studies point out that lacking protein or essential amino acids in diets can decrease the feed intake of growing-finishing pigs (Rogerson and Campbell, 1982; Hahn et al., 1995). Imbalance of adequate amino acids shares similar effect (Henry et al., 1992; Henry, 1995; Hahn and Baker, 1995). Friesen et al. (1994) contrarily claimed an increase in feed intake by dietary protein deficiency.

Protein level in diet and the amount of voluntary feed intake decides the content of protein intake. Studies below show nutrient factors (energy and protein) that are crucial to protein intake.

According to Kyriazakis and Emmans (1992), only the rate of protein supply at low levels of protein intake determines the rate of protein deposition. Energy supply at high levels of protein intake determines the protein deposition. Poultry performance have been reported to be affected by the ratio of protein to energy in the diet (Baldini and Rosenberg, 1955; Leong et al., 1955; Matterson et al., 1955; Scott and Staheli, 1955; Lockhart, 1955; Combs and Romoser, 1955). The effects of protein and energy content in pigs' feed on performance and carcass characteristics are also claimed by numerous researches (Bowland and Berg, 1959; Noland and Scott, 1960; Pond et al., 1960; Constain and Morgan, 1961).

Devilat et al. (1970) and Davey (1978) experimented with choice feeding method, in which pigs are given choice between two isoenergetic diets with different protein level and can choose according to their needs. This plan is built upon a hypothesis that pigs can control their feed intake to match their nutrient requirements. It has been suggested by Kyriazakis (1989) and Kyriazakis et al. (1990) that individually housed pigs can distinguish their diets between different protein levels, and they likely will choose feed intake adequate for their needs. Bradford and Gous (1991) study also imply similar remark, stating that choice feeding appears to be more beneficial to commercial swine farm than phase feeding is. Braude (1967) contradicts and claimed that pigs are often incapable of selecting certain diet that matches their requirements, and so that choice feeding method is not much better than single feeding. Gourley et al. (1993), Owen et al. (1994) and Nam and Aherne (1995) joins this refutation, concurring with pigs' inability to make a choice among isoenergetic diets with different protein level.

4.3 Dietary Energy Level and Protein Intake

A high-energy diet tends to contain high concentration of other nutrients, and vice versa. It is unpractical, however, to lessen the concentration of various nutrients even in lower energy diets.

The process of forming ingested amino acids into body protein requires energy. About 30 ~ 50% of energy is utilized in the anabolism of lean tissue for growing pigs. Meanwhile, dietary amino acids can also be utilized as a source of energy. It will maintain a lot of body functions and support the synthesis of body lipid after the nutrients are degraded into carbon and hydrogen. The synthesis of protein from pigs' feed shows 30 ~ 60% efficiency. Accordingly, there is a significance in the energy yield from the deamination of amino acids that are not accumulated in pigs' body or milk. Deaminated amino acids not linked with protein can also be effective precursors for other bodily activities (e.g. the formation of fatty tissues). However, main functions of proteins through feed are supply of amino acid elements in swine protein deposition (in growth or milk) and maintenance of tissues.

Henry (1988) claims that provision of amino acids matching the energy density of diet is crucial to maintaining the ratio of amino acid and energy steadily. Some studies like Carr et al. (1977) and Whittemore and Fawcett (1976) suggested that the ratio of available lysine/MJ of DE did not display linearly during the whole of pigs' life span. However, others like Chiba et al. (1991) implied linear response from linkage between energy intake and the rate of protein deposition (for growing pigs weighing up to 50 kg).

Pigs' altering amino acid/energy needs, and their extent of feed intake in different growth phases control the correlation between amino acid and energy in growing-finishing pigs that are given random choice to feed. Pigs in their growing phase (weighing approximately up to 50 kg) show their innate capability of protein deposition outpacing their capability of absorbing enough feed matching their tissue needs for protein synthesis. Therefore, the reaction between amino acid intake and protein deposition and amino acid requirements with energy is clearly linear. In the pigs' finishing period, however, energy intake surpasses their need for protein deposition. Their demands of amino acid for tissue synthesis are irrelevant to the energy intake.

Ⅲ. Different Energy and Protein Levels in Diet on Growth Performance, Blood Profiles, Pork Quality and Feed Cost in Growing-finishing Pig

ABSTRACT: This study was conducted to evaluate the optimal energy and protein level in feed of growing-finishing pigs for growth, blood profiles, pork quality and feed cost. This experiment was done by factorial design and factor 1 was two level of energy (3,150 or 3,300 kcal of ME/kg), and factor 2 was also two level of dietary protein in feed (90% of NRC CP requirements in 2012 or NRC CP requirements in 2012). Treatements were 1) LL : ME 3,150 kcal/kg + 90% of NRC 2012 CP diet; 2) LH : ME 3,150 kcal/kg + NRC 2012 CP diet; 3) HL : ME 3,300 kcal/kg + 90% of NRC 2012 CP diet; 4) HH : ME3,300 kcal/kg + NRC 2012 CP diet. Growth performance of growing-finishing pigs was improved when pigs were fed higher dietary energy and high protein treatment diet (HH) both in late growing phase (7th week) and the late finishing phase(13th week), respectively (P=0.03; P=0.05). Average daily gain (ADG) was increased when higher protein diets (LH and HH) were fed to growing-finishing pigs (P=0.03) and dietary protein was much more potent nutrient than dietary energy for growth of pigs during the whole experimental period. Average daily feed intake (ADFI) was also increased when pigs were fed higher protein diet particularly during growing phase (P=0.01) and this trend was maintained during finishing phase (P=0.03). However, Gain to feed ratio (G:F), was mainly affected by dietary energy (P=0.06) rather than dietary protein level (P=0.67). Blood urea nitrogen (BUN), total protein, creatinine and blood glucose were lowered when low energy and low protein diet (LL) was provided (P=0.01) resulted in an interaction (P=0.01). Although pH of pork was lowered when pigs were fed low protein treatment diet (P=0.03), but other measurements of pork quality, such as color, chemical analysis and TBARS, were not affected by dietary energy and protein level. Feed cost per weight gain was lowered when pigs were fed high energy and low protein treatment diet but feed cost per pig was increased when dietary protein level was increased (P=0.01). Although total feed cost to 110 kg was the lowest in low energy and low protein treatment (LL), days to market weight from 27.22 to 110kg was the shortest in high energy and high protein treatment (HH) among dietary treatments. Even though feed cost could be saved in LL treatment, days to market weight was delayed about 19 d compared to HH treatment subsequently LL treatment would not be efficient feed formulation for growing-finishing pigs. In conclusion, this experiment demonstrated that high protein diet resulted in improved growth performance in growing pigs but high energy (3,300 kcal of ME/kg) and low protein (90% of NRC(2012)) diet would be desirable feed formulation based upon feed cost, days to market weight and pork quality.

Keywords : Energy, Crude protein, Growing-finishing pig, Growth performance, Blood profiles, Pork quality, Feed cost

Introduction

Recently, global grain price tends to increase with various reasons. Extreme climate change, decrease of cultivation acreage and increase of meat consumption are also having a significant impact on global grain prices subsequently prices of feed ingredients will be increased continually in the future. In South Korea, it is known that feed cost comprised approximately 60 percent of the total cost of pig production and about 60 to 70 percent of ingredients in swine feed is consisted of corn and soybean. Over the last two decades, pig industry in Korea has been developed greatly and pork price has been maintained about 2~3 times higher than that of USA and EU. Therefore, swine producers in Korea are concerned about fast growing of pigs regardless of cost of feed or pork quality and are less interested in saving of production cost and improving productivity of farm. Moreover, many feed companies have been selling high-nutritive feed at high prices, and swine producers do not aware of the serious situation caused by feeding over-nutritive feed to pigs. Growing-finishing period is an important time to maximize the growth of pigs, in addition, pigs are generally consuming much more feed compared to other phase of pigs subsequently feed cost during this period is being comprised approximately 70% of total cost of feed of pigs. To save feed cost, swine producers need to avoid wasting of feed and provide efficient feed which contains adequate nutrients for normal growth of pigs. When swine feed is formulated efficiently, nutrients in feed will be well utilized in growing-finishing pigs subsequently growth rate of pigs has improved and days to market weight can be reduced. Not only price of swine feed, but also pollutants in environment will be great concerned when feed contained excessive nutrients. Among of nutrients, crude protein and energy contents in swine feed determine the price of feed, resulting in affecting net profit of swine farm. Therefore, this study was conducted to evaluate the optimal energy and protein level in feed of growing-finishing pigs for growth, blood profiles, pork quality and feed cost.

Materials and Methods

Experimental animals and management

A total of 140 finishing pigs ([Yorkshire × Landrace] × Duroc) with an average body weight of 27.22 ± 0.445 kg were used for 13 weeks feeding trial at Daewoo swine farm in Muan-gun, Jeollanam-do, Republic of Korea.

Experimental animals were allotted to one of four treatments, 5 replicates, 7 pigs per pen considering gender and body weight with RCB (randomized complete block) design.

Experimental period was consisted with 4 phases and early growing phaseis 1 - 4 week, late growing phase, is 5 - 7 week, early finishing phase is 8 - 10 week, and late finishing phase is 11 - 13 weeks, respectively. All pigs were housed in an automatically environment controlled room with fully-concrete floor facility (2.60 x 2.84m) during the whole experimental period. Each pen was equipped with a feeder and a nipple drinker to provide *ad-libitum* during experiment.

Experimental design and diets

The experimental period was classified into 1-4 weeks, 5-7 weeks, 8-10 weeks, and 11-13 weeks, and was designed to be 2 x 2 factorial design. Factor 1 is two levels of dietary energy (3,150 or 3,300 kcal of ME/kg), and factor 2 is also two levels of dietary protein (90 or 100% of CP requirements in NRC 2012). The experimental treatments are as followed (Table 8); 1) LL: ME 3,150 kcal/kg + low CP, 90% of CP of NRC 2012, 2) LH: ME 3,150 kcal/kg + CP of NRC 2012, 3) HL: ME 3,300 kcal/kg +

low CP, 90% of CP of NRC 2012, 4) HH: ME 3,300 kcal/kg + CP of NRC 2012. Experimental diets were formulated with corn-soybean meal base, and all other nutrients in experimental diets were met or exceeded the NRC requirements (2012). Formulae and chemical compositions of the experimental diets are shown in Tables 9, 10, 11, and 12.

Growth performance

Body weight (BW) and feed intake were measured in the beginning (initial) and at the end of each phase (4, 7, 10 and 13 week) to calculate the average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G:F), respectively.

Blood sampling and analysis

Blood samples were taken from the jugular vein of randomly selected 6 pigs in each treatment for measuring blood urea nitrogen (BUN), total protein, creatinine, and glucose. Blood collection was performed both at initial and at the end of each phase (4, 7, 10 and 13 week). Blood was collected in serum tubes (SSTTMⅡ Advance, BD Vacutainer, Becton Dickinson, Plymouth, UK) and quickly centrifuged for 15 min by 3,000 rpm at 4℃ (Eppendorf centrifuge 5810R, Germany). Then, the sera were transferred to 1.5 ml plastic tubes by pipette and stored at －20℃ until later analysis. BUN, total cholesterol, creatinine, and glucose concentration were analyzed with Kinetic UV assay test method using blood analyzer (Cobas 8000, Roche, Germany).

Carcass traits

At the end of experiment, a total of 16 pigs of 4 pigs from each treatment were slaughtered and pork samples were collected from nearby between 4th and 6th rib of carcass. Because of chilling procedure, 30 minutes after slaughter was regarded as initial time. The pH was measured at 0, 3, 6, 12 and 24 hour after initial time. The meat color was monitored at 3, 6, 12 and 24 hour after initial time. The pH was determined by pH meter (Model, Themo Orion, U.S.A) and meat color was analyzed by CIE color L*, a* and b* value using a CR300 (Minolta Camera Co., Japan). Proximate analysis of pork samples was done by the method of AOAC (2005)

Pork quality

Centrifuge method was used for measuring water holding capacity of pork (Abdullah and Najdawi, 2005). Pork samples were wrapped in filter tube, and heated in water bath at 80℃ for 20 min then, centrifuged for 10 min at 2,000 rpm and 10℃ (Eppendorf centrifuge 5810R, Germany). After centrifugation, the cooking loss was measured by packing of pork samples with polyethylene bag, heated in water bath until core temperature reached 72℃ and weighed before and after cooking. Additional samples were taken from core of longisimuss (0.5 inch in diameter) parallel to muscle fiber and used to measure the shear force (Warner Bratzler Shear, USA). Cooking loss, shear force, water holding capacity of pork sample were analyzed by Animal Origin Food Science lab in Seoul National University.

TBARS Assay

The extent of lipid oxidation was measured for the 2-thiobarbituric acid reactive substances (TBARS) value by using a spectrophotometer (X-ma 3100, Human Co. Ltd., Seoul, Korea). Each sample (5g) was homogenized with 15mL of DDW and 7.2% butylated hydroxyl toluene in ethanol at 9,600 rpm for 30 s (T25, Ika Works, Staufen, Germany). After homogenization, 2 mL of the homogenates were transferred to 15 mL falcon tubes. Then added 4 mL of 20 mM TBA in 15% TCA. The tubes were heated in a laboratory water bath at 90°C for 30 min, and centrifuged at 2,265 for 15 min (HM-150IV, Hanil Co. Ltd., Incheon, Korea). The samples were measured before and after cooking boiled in water bath at 90°C for 8 min. The absorbance of supernatant was measured at 532 nm. The TBARS value was expressed as mg MDA/kg.

Fatty acid composition

Lipids in pork sample (10 g) were extracted with 100 mL of chloroform/methanol (2.1, v/v) (Folch et al.,1957) and shaking incubator (25℃, 120 rpm) for 24 hours. Extracted lipids were filtered with filter paper (Whatman^{TM} No.4, Buckinghamshire, UK). 25 mL of 0.88 % NaCl was added in the filtered sample and centrifuging at 2,090×g for 10 min (Continent 512R, Hanil Co., Ltd., Incheon, Korea). The supernatant was separated and concentrated pork lipids using N_2 gas at 45℃. After concentrating the lipids, 0.1 g was weighted into 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. The samples were heated in the water bath at 85°C for 10 min and cooled to room temperature. After cooling, 2 mL of 14% BF3-methanol was added and repeated heating process one more time. After then, 2 mL of iso-octane and 1 mL saturated NaCl was added, centrifuged at 2,500 rpm for 3 min (Continent 512R, Hanil Co., Ltd., Incheon, Korea). Upper layer containing fatty acid methyl ester(FAME) was dehydrated with anhydrous sodium sulfate and transferred to a vial. Analyzed the vial using a gas chromatograph (HP 7890, Agilent Technologies, Santa Clara, CA, USA) with a split ratio (50:1). A capillary column (DB-23, 60 m x 250 µm x 0.25 µm, Agilent, Santa Clara, CA, USA) was used. The injector and detector temperatures were maintained at 250°C and 280°C, respectively. The column oven temperature were as follows: 50°C for 1 min, increased to 130°C at 25°C/min, 170°C at 8°C/min, then held at 215°C at 1.5°C/min. Nitrogen was used as a carrier gas at linear flow of 4 mL/min. Individual FAME was identified by comparison of the relative retention times of peaks from samples, with those of the external standards (37 FAME mix and CLA mix, Supelco, Bellefonte, PA, USA) calculated based on the Korean Food Standards Codex (MFDS, 2017).

Chemical Analyses

Diets were ground by a Cyclotec 1093 Sample Mill (Foss Tecator, Hillerod, Denmark) and ground diets were analyzed. All analyses were performed in duplicate samples and those processes were done again if results from duplicate samples varied more than 5% from the mean. Experimental diet was analyzed for contents of dry matter (procedure 930.15; AOAC, 1995), crude ash (procedure 942.05; AOAC, 1995), ether extract (procedure 920.39; AOAC, 1995), nitrogen by using the Kjeltec procedure with Kjeltec (KjeltecTM 2200, Foss Tecator, Sweden).

Economic analysis

As the experimental pigs were reared in the same environmental condition, economic analysis was calculated using the feed cost without considering other factors. The total feed cost (won) per body weight gain (kg) was calculated by using amount of the total feed intake and feed price. The feed cost per weight gain was calculated based on price of raw materials during the time of the experiment. The days to market weight (110 kg) were estimated from the body weight at the end of feeding trial and ADG of 13 weeks.

Statistical analysis

The experimental data was analyzed using 2 by 2 factorial procedure of SAS. For data on growth performance and economic analysis a pen was considered as an experimental unit, while individual pig was used as an unit for data on blood profile, pork quality and carcass traits. Effect of energy factor, protein factor, and interaction between two factors were declared significant at $P<0.05$ or highly significant at $P<0.01$.

Results and Discussion

Growth performance

The effect of energy level and protein level in feed on growth performance are presented in Table 13. Body weight was increased at 7th week (late growing phase) and 13th week(late finishing phase) by protein factor when it increased (P=0.03; P=0.05 respectively).

Average daily gain (ADG) was increased when higher protein diets (LH and HH) were provided to growing-finishing pigs (P=0.03) and dietary protein was much more potent nutrient than dietary energy for growth of pigs during the whole experimental period. Average daily feed intake (ADFI) was also increased when pigs were fed higher protein diet particularly during growing phase (P=0.01) and this trend was maintained during finishing phase (P=0.03). Gain to feed ratio (G:F), however, was mainly affected by dietary energy (P=0.06) rather than dietary protein level (P=0.67).

Protein and amino acids in feed affected the muscle development of pigs, and lack of protein and amino acids negatively influenced on growth performance and muscle development in pigs (Schinckel and de Lange, 1996). In addition, ADG and feed efficiency were increased significantly as the level of protein in growing-finishing feed increased (Kerr et al., 2003). Adequate CP level in the growing phase showed better growth and feed efficiency than pigs were fed feed from inappropriate CP level (Gilster and Wahlstrom, 1973; Easter and Baker, 1980). The increase in CP level resulted in improved ADG and feed efficiency (Cromwell et al., 1993; Chen et al., 1995).

However, muscle and fat depositions are not only affected by protein level but also energy-protein ratio (Wood et al., 2004). It was very known that protein deposition max was related with energy-protein ratio (Swine Nutrition, 1991). Also, ratio between energy-lysine can also influence on protein deposition because high-energy without appropriate lysine ratio can lead to low energy utilization (Noblet et al., 1987). Seve et al. (1986) also showed that imbalance of energy and protein could make slow protein synthesis and this study demonstrated that no effect by energy factor or interaction between energy and protein factors.

In conclusion, increase of protein level in feed resulted in significantly improving body weight, ADG and ADFI however, dietary energy was less effect than that of dietary protein.

Blood profiles

The effect of energy level and protein level on blood profiles in growing-finishing pigs is shown in Table 14. Blood urea nitrogen (BUN), total protein, creatinine and blood glucose were lowered when low energy and low protein diet (LL) was provided (P=0.01) resulted in an interaction (P=0.01).

BUN is a representative evaluation indicator of the efficiency of the use of amino acids in pigs and has been used as a response indicator to determine the protein requirements of animals or the single amino acid requirements (Hatori et al., 1994; Coma et al., 1995; Cai et al., 1996). Fuller et al. (1977) suggested that carbohydrates increased the accumulation of protein in the body. In this study, the increase in energy in feed raised the accumulation of protein in the body, which resulted in a decrease in BUN in the blood. In addition, previous studies have shown that pig's BUN was involved in the maintenance of ingested nitrogen in the body (Whang and Easter, 2000), and has a negative correlation with ADG and feed efficiency (Hann et al., 1995). These results are consistent with the results of higher BUN concentrations, such as reports from Chen et al. (1995, 1996) and Gomez et al. (1998). The reason for the high BUN concentration in the blood of pigs was that the protein was not fully utilized and released in the form of urea, which meant that protein utilization rate through feed was low.

In the total protein level in the blood, there were no significant differences in total protein in 4, 7, 10 week. However, total protein was decreased as energy level increase (P=0.01) however, it was increased as CP level increase (P=0.01), resulted in interaction between energy and CP level (P=0.01) in the 13 week (late finishing phase).

The total protein concentration in the blood is a complex compound of all kinds of proteins in the blood (Buzanovskii, 2017). Total protein in the blood plays important role to maintain normal osmotic pressure and pH in the blood. Diarrhea, vomiting, and dehydration could be occurred if the total protein concentration in the blood is excessively high (Brown and Otto. 2008).

The present study found that the total protein concentration in finishing pig blood increased significantly as energy levels increased but there were no symptoms such as vomiting or dehydration. Therefore, dietary energy levels in current experiment did not negatively influence on total protein in the blood.

The present study demonstrated that the concentration of creatinine is affected by dietary energy and CP level in feed (P=0.01). Creatinine is a nonprotein nitrogenous compound in the blood and is the final metabolite produced by non-enzymatic dehydration from the creatine of muscles (Zinellu et al., 2005). Since creatinine is produced as a muscle metabolite and is released into the blood and excreted into the urine subsequently the creatinine production is widely used as an indicator to estimate the total muscle mass of the body (Salazar, 2014). The concentration of creatinine in blood and urine is closely correlated with muscle mass (Baxmann, 2008). Creatinine is positively related with muscle percentage and performance (Doornenbal et al., 1986).

Blood glucose concentration was lowered when pigs were fed high protein treatment diets (LH and HH) presumably due to the fact that relative ration between energy and protein determined blood glucose. Although there were some significant differences by energy and protein treatment, dietary protein level influenced greater on BUN, total protein and blood glucose level than that of dietary energy.

pH and Meat color

The effects of dietary energy and protein levels on the pH changes in pork after slaughter are presented in Table 15. As a result, the final pH of pork in all treatments was between 5.2 and 5.9, but it was within normal range(RFN, Red Firm and Non-exudative).

The pH change of pork after slaughter can be seen as a very important factor of pork quality such as freshness, WHC, shear force, pork color, and tenderness (Brewer and McKeith, 1999; Binder et al., 2004). Bole et al (1993) reported that the pH level is closely related to the quality of pork, WHC and ternderness. Palansky and Nosal (1991) demonstrated that increasing pH resulted in reducing of cooking loss. The pH immediately after the slaughter is used as a prediction of PSE, and the final pH is recognized as a prediction of DFD.

Significant differences in energy and protein levels have occurred, but given that they are all within normal ranges, it is believed that the energy and protein levels in the treatment did not adversely affect the pH change of pork. In conclusion, it is believed that the energy and protein level of the feed will not have a negative effect on the pH change of pork after slaughter.

The effect of the energy level and protein level in the growing-finishing feed on the meat color is shown in Table 16. Bendall and Wismer (1962) reported that increasing yellowness and decreasing redness in pork resulted in decreasing freshness of pork. In this experiment, there was a significant decrease in Hunter value a, measured 6 hours after slaughter, as energy levels increase (P=0.01). However, there were no significant differences in all other analytical items. Therefore, the energy and protein level had no effect on the meat color in this experiment.

Pork quality

The effect of the energy and protein levels in the growing-finishing feed on the pork are presented in Table 17. There was significant decrease in crude fat content as energy increase (P=0.04). There was significant decrease in crude ash content as energy increase (P=0.03). In this experiment, there was no significant difference between moisture and crude protein level, depending on the energy level and protein level.

The composition of the carcass changes depending on the protein level fed by pigs. The shear force and water holding capacity are affected by the content of fat in the loin. The shear force decreases as the fat content increases. The water holding capacity is a measure of the ability of the meat to hold water due to internal and external environmental changes, determined by the microstructure of the meat or the change in the moisture content that occurs during cutting, and is known to be closely related to the pH change of the meat. In addition, shear force is a mechanically measured measure of the tenderness of meat, and is known to be highly associated with fat. Cooking loss is one of the indicators of indirect water holding capacity and is generally known to have inverse correlation with water holding capacity. In this study, there was significant increase in cooking loss as energy increase (P=0.01). In addition, shear force was significantly increased as energy levels increased (P=0.01). According to a study by Goerl et al (1995), as the fat content increases, water holding capacity is increased while the cooking loss is reduced, which improves the juice reduction, and weakens the shear force. However, further study is needed to clearly demonstrate energy and protein level in pork quality. Feeding high-protein feed improves the composition of the carcass (Davey, 1978) and improves the carcass (Davey 1978).

In conclusion, high energy affects negatively to cooking loss and shear force.

The effect of the energy level and protein level in the growing-finishing feed on the lipid oxidation of pork after slaughter are presented in Table 18. The results of this experiment showed significant differences in TBARS as CP level increase in the 5th day(P=0.05). However, there were no significant differences in all other analysis items. In addition, the TBARS value of all treatments were not reached 0.6 mg/kg

(Guo et al., 2003) which is the represent of lipid oxidation. Other studies have also reported that energy levels and protein levels do not show significant differences in lipid oxidation (Meng et al., 2010; Madeira et al., 2014).

Therefore, the energy and protein level in the growing-finishing feed did not have significant effect on the lipid oxidation of pork.

Fatty acid composition

The effect of the energy level and protein level in the growing-finishing feed on the fatty acid composition in pork after slaughter are presented in Table 19. Several studies have already shown that changes in diet affect fatty acids composition in pork (Miller et al., 1990; Larick et al., 1992). A prior study found that C18:3n3 is primarily oxidized in energy use, which leads to a reduction in storage of C18:3n3 in adipose cells (Leighton, Drury, Crawford, 1987). Several studies reported that the fatty acid content of the test feed was reflected in the loin of pork (Culp et al., 1980; Von Schacky and Weber., 1985; Hwang et al., 1988). According to the European Food Safety Administration (EFSA), safer foods have lower SFA content (EFSA, 2010). There was no significant difference in this experiment, but the HH treatment showed the lowest SFA content.

The fatty acid composition analysis resulted in a significant difference in the heneicosylic acid(c21:0) (P=0.01). However, there were no significant differences in all other fatty acids. Some studies have shown that protein-level adjustments did not show significant differences in MUFA (Bessa et al., 2013; Madeira et al., 2014). This resulted in similar results to this experiment.

Therefore, the energy and protein level in the growing-finishing feed did not have a negative effect on the formation of fatty acids.

Economic analysis

The effect of the energy level and protein level in the growing-finishing feed on economic analysis are presented in Table 20. To analyze economic analysis, feed per weight gain and total feed cost per pig were calculated using the total feed intake and feed cost of 1kg, and 110kg was estimated based on the weight and ADG at the end of the days to market. The feed cost per weight gain was significantly different at the early finishing phase (8-10 weeks). Feed cost per weight gain increased as energy and protein increase (P=0.01). There was no significant difference in feed cost per 1kg gain in early growing, late growing and late finishing phase. High energy and low protein treatment (HH) showed the lowest feed cost per weight gain.

In total feed costs, there were significant difference in protein level for the early growing phase (P=0.02), late growing phase (P=0.01) and growing-finishing phase (P=0.01). And feed cost tended to increase when protein level increase in the late finishing phase (P=0.06).

In this experiment, There were significant effect of energy and protein factors on feed cost per weight gain in early finishing phase because of significantly different G:F ratio. Also, the higher the protein level, the significantly higher the ADFI in the early growing phase, late growing phase, and growing-finishing phase. Consequently, the total feed cost was high according to the ADFI. And LL treatment showed lowest feed cost per pig.

Days to market weight from 27.22 to 110kg showed significant differences in protein content, and the higher the protein content, the shorter the market date by about 11 days. In addition, low energy and low protein treatment (LL) showed 124 days, while high energy and high protein treatment (HH) showed 105 days. Although total feed cost to 110 kg was the lowest in low energy and low protein treatment (LL), days to market weight from 27.22 to 110kg was the shortest in high energy and high protein treatment (HH) among dietary treatments.

Considering the rotation rate, adding another 70 days in order to reach 27kg each treatment took 194, 182, 185 and 175 days to market weight(110kg) and 1.9, 2.0, 2.0, 2.1 rotations/year. In estimated feed cost to 110kg, low energy and low protein treatment (LL) was the cheapest but the lowest rotation per year and in the feed cost per weight gain, high energy and low protein treatment (HL) was the lowest. In spite of the fact that feed cost could be saved in low energy and low protein treatment (LL), days to market weight was delayed about 19 days compared to high energy and high protein treatment (HH) concluding LL treatment would not be the efficient feed formulation for growing-finishing pigs.

Therefore, this experiment demonstrated that high protein diet resulted in improved growth performance in growing pigs but high energy (3,300 kcal of ME/kg) and low protein (90% of NRC(2012)) diet would be desirable feed formulation based upon feed cost, days to market weight and pork quality.

Conclusion

Growth performance in this experiment showed that the higher the protein level and the energy level in the feed during the late growing phase and the late finishing phase, the greater the body weight (P=0.03; P=0.05, respectively). The ADG increased as the protein level increased early growing phase, late growing phase and growing phase, late finishing phase and entire experimental phase (P=0.02; P=0.02; P=0.01; P=0.01; P=0.03, respectively). The ADFI increased significantly as the protein level increased early growing phase, late growing phase and growing phase and entire experimental phase (P=0.03; P=0.01; P=0.01; P=0.03). The blood profile showed that the BUN concentration increased as the protein level increased (P=0.01). There was a significant difference between the total proteins in the late finishing phase (P=0.01) but no significant difference in other phases. There were significant differences in creatinine by energy and protein levels, and glucose was significantly different in the 10th and 13th weeks. The pH of pork was significantly different at 12 hrs after slaughter (P=0.01) but the pH of all items was within the normal range and no significant differences occurred in the rest of the items. The color of pork showed significant differences in Hunter value a (P=0.01), but no significant differences occurred in all other items. In pork quality, the crude fat content appeared to be lowered as energy levels increased (P=0.03) and the cooking loss and shear force increased as energy levels increased (P=0.01; P=0.01, respectively). In carcass traits, the dressing rate showed low results as the protein level increased (P=0.01). Backfat thickness in carcass was decreased as energy content increased (P=0.04). The lipid oxidation showed a decrease in the TBARS value as the protein level increased on the 5th day of storage, but no significant difference was observed in all other items than (P=0.05), and no negative effect was present because the TBARS value was not reached at 0.6. Significant differences occurred in the formation of fatty acids in the heneicosylic acid (P=0.01). However, there were no significant differences in all other fatty acids. In the economic analysis, feed cost per weight gain increased as energy increased (P=0.01) and protein increased (P=0.01) at early finishing phase (8-10 weeks). The total feed cost increased as protein increased in early growing(1-4 week, P=0.02), late growing (5-7 week, P=0.01) and growing-finishing (0-13 weeks, P=0.01). A significant difference in protein level was found in the days to market weight and the higher the protein level, the shorter the days of market by about 11 days. Experiment of different energy level and protein level in growing-finishing feed showed that, the high protein level is better for the growth rate but low protein level is more economic.

Therefore, high levels of protein significantly increased body weight, ADG, and ADFI. In the energy level, high level of energy level showed negative effect on pork quality, but showed more economic in feed cost.

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

Table. 8 Experimental treatments

BW, kg	30~50 – 50~70 – 70~90 – 90~110		30~50 – 50~70 – 70~90 – 90~110	
ME, kcal	Low (3,150 kcal/kg)		High (3,300 kcal/kg)	
CP & Amino Acid	90% of NRC 2012	NRC 2012	90% of NRC 2012	NRC 2012
Treatment	LL	LH	HL	HH
CP, %	14.12 - 12.38 - 10.91 - 9.39	15.69-13.75 - 12.13-10.44	14.12-12.38 - 10.91-9.39	15.69-13.75 - 12.13-10.44
Lys(%)	1.01-0.87 - 0.76-0.64	1.12-0.97 - 0.84-0.71	1.01-0.87 - 0.76-0.64	1.12-0.97 - 0.84-0.71
Met(%)	0.29-0.25 - 0.23-0.19	0.32-0.28 - 0.25-0.21	0.29-0.25 - 0.23-0.19	0.32-0.28 - 0.25-0.21
Thr(%)	0.65-0.58 - 0.50-0.44	0.72-0.64 - 0.56-0.49	0.65-0.58 - 0.50-0.44	0.72-0.64 - 0.56-0.49
Trp(%)	0.17-0.15 - 0.14-0.12	0.19-0.17 - 0.15-0.13	0.17-0.15 - 0.14-0.12	0.19-0.17 - 0.15-0.13

Table 9. Formulae and chemical compositions of the experimental diet of early growing pigs (1-4 weeks).

Item	Treatment[1)]			
	LL	LH	HL	HH
Ingredient, %				
Ground corn	73.64	69.71	70.37	66.47
SBM	14.55	18.43	15.08	18.96
Wheat bran	7.90	7.90	7.90	7.90
Tallow	0.11	0.19	2.85	2.92
MDCP	1.34	1.28	1.36	1.29
Limestone	0.97	0.97	0.96	0.97
Salt	0.30	0.30	0.30	0.30
Vitamin premix[2)]	0.10	0.10	0.10	0.10
Mineral premix[3)]	0.10	0.10	0.10	0.10
L-Lysine-HCl, 78%	0.48	0.49	0.47	0.48
DL-met, 99%	0.06	0.07	0.06	0.07
L-Threonine, 99%	0.15	0.16	0.15	0.16
Tryptophan, 10%	0.30	0.30	0.30	0.28
Sum	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,150.00	3,150.00	3,300.00	3,300.00
CP	14.12	15.69	14.12	15.69
Lys	1.01	1.12	1.01	1.12
Met	0.29	0.32	0.29	0.32
Thr	0.65	0.72	0.65	0.72
Trp	0.17	0.19	0.17	0.19
Ca	0.66	0.66	0.66	0.66
Total P	0.56	0.56	0.56	0.56

1) LL : ME3,150 kcal/kg + 90% of NRC 2012 CP diet, LH : ME3,150 kcal/kg + NRC 2012 CP diet, HL : ME3,300 kcal/kg + 90% of NRC 2012 CP diet, HH : ME3,300 kcal/kg + NRC 2012 CP diet.

2) Provided the following quantities of vitamins per kg of complete diet : Vit A, 16,000IU; Vit D_3, 3,200IU; Vit. E, 35IU; Vit. K_3, 5mg; Rivoflavin, 6mg; Calcium pantothenic acid, 16mg; Niacin, 32mg; d - Biotin, 128ug; Vit.B_{12}, 20ug.

3) Provided the following quantities of minerals per kg of complete diet : Fe, 281mg; Cu, 288mg; Zn, 143mg; Mn, 49mg; I, 0.3mg; Se, 0.3mg.

4) Calculated value.

Table 10. Formulae and chemical compositions of the experimental diet of late growing pigs (5-7 weeks).

Item	Treatment[1)]			
	LL	LH	HL	HH
Ingredient, %				
Ground corn	77.74	74.55	84.10	80.69
SBM	10.10	13.50	11.64	15.02
Wheat bran	8.60	8.40	0.00	0.00
Tallow	0.04	0.05	0.55	0.61
MDCP	1.21	1.16	1.40	1.34
Limestone	0.87	0.87	0.79	0.79
Salt	0.30	0.30	0.30	0.30
Vitamin premix[2)]	0.10	0.10	0.10	0.10
Mineral premix[3)]	0.10	0.10	0.10	0.10
L-Lysine-HCl, 78%	0.45	0.47	0.44	0.45
DL-met, 99%	0.04	0.05	0.04	0.05
L-Threonine, 99%	0.15	0.15	0.14	0.15
Tryptophan, 10%	0.30	0.30	0.40	0.40
Sum	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,150.00	3,150.00	3,300.00	3,300.00
CP	12.38	13.75	12.38	13.75
Lys	0.87	0.97	0.87	0.97
Met	0.25	0.28	0.25	0.28
Thr	0.58	0.64	0.58	0.64
Trp	0.15	0.17	0.15	0.17
Ca	0.59	0.59	0.59	0.59
Total P	0.52	0.52	0.52	0.52

1) LL : ME3,150 kcal/kg + 90% of NRC 2012 CP diet, LH : ME3,150 kcal/kg + NRC 2012 CP diet, HL : ME3,300 kcal/kg + 90% of NRC 2012 CP diet, HH : ME3,300 kcal/kg + NRC 2012 CP diet.

2) Provided the following quantities of vitamins per kg of complete diet : Vit A, 16,000IU; Vit D_3, 3,200IU; Vit. E, 35IU; Vit. K_3, 5mg; Rivoflavin, 6mg; Calcium pantothenic acid, 16mg; Niacin, 32mg; d–Biotin, 128ug; Vit.B_{12}, 20ug.

3) Provided the following quantities of minerals per kg of complete diet : Fe, 281mg; Cu, 288mg; Zn, 143mg; Mn, 49mg; I, 0.3mg; Se, 0.3mg.

4) Calculated value.

Table 11. Formulae and chemical compositions of the experimental diet of early finishing pigs (8-10 weeks).

Item	Treatment[1)]			
	LL	LH	HL	HH
Ingredient, %				
Ground corn	81.13	78.22	88.26	85.33
SBM	6.30	9.35	7.89	10.95
Wheat bran	9.25	9.22	0.00	0.00
Tallow	0.00	0.01	0.33	0.34
MDCP	1.03	0.98	1.23	1.16
Limestone	0.79	0.80	0.70	0.72
Salt	0.30	0.30	0.30	0.30
Vitamin premix[2)]	0.10	0.10	0.10	0.10
Mineral premix[3)]	0.10	0.10	0.10	0.10
L-Lysine-HCl, 78%	0.44	0.44	0.43	0.43
DL-met, 99%	0.04	0.04	0.04	0.04
L-Threonine, 99%	0.12	0.14	0.12	0.13
Tryptophan, 10%	0.40	0.30	0.50	0.40
Sum	100.00	100.00	100.00	100.00
Chemical composition[4)]				
ME, kcal/kg	3,150.00	3,150.00	3,300.00	3,300.00
CP	10.91	12.13	10.91	12.13
Lys	0.76	0.84	0.76	0.84
Met	0.23	0.25	0.23	0.25
Thr	0.50	0.56	0.50	0.56
Trp	0.14	0.15	0.14	0.15
Ca	0.52	0.52	0.52	0.52
Total P	0.47	0.47	0.47	0.47

1) LL : ME3,150 kcal/kg + 90% of NRC 2012 CP diet, LH : ME3,150 kcal/kg + NRC 2012 CP diet, HL : ME3,300 kcal/kg + 90% of NRC 2012 CP diet, HH : ME3,300 kcal/kg + NRC 2012 CP diet.

2) Provided the following quantities of vitamins per kg of complete diet : Vit A, 16,000IU; Vit D_3, 3,200IU; Vit. E, 35IU; Vit. K_3, 5mg; Rivoflavin, 6mg; Calcium pantothenic acid, 16mg; Niacin, 32mg; d–Biotin, 128ug; Vit.B_{12}, 20ug.

3) Provided the following quantities of minerals per kg of complete diet : Fe, 281mg; Cu, 288mg; Zn, 143mg; Mn, 49mg; I, 0.3mg; Se, 0.3mg.

4) Calculated value.

Table 12. Formulae and chemical compositions of the experimental diet of late finishing pigs (11-13 weeks).

Item	Treatment[1]			
	LL	LH	HL	HH
Ingredient, %				
Ground corn	83.98	82.03	92.55	90.03
SBM	2.25	5.00	4.07	6.71
Wheat bran	10.70	9.91	0.00	0.00
Tallow	0.01	0.00	0.10	0.11
MDCP	0.88	0.85	1.10	1.05
Limestone	0.72	0.73	0.63	0.64
Salt	0.30	0.30	0.30	0.30
Vitamin premix[2]	0.10	0.10	0.10	0.10
Mineral premix[3]	0.10	0.10	0.10	0.10
L-Lysine-HCl, 78%	0.42	0.42	0.41	0.41
DL-met, 99%	0.02	0.03	0.02	0.02
L-Threonine, 99%	0.12	0.13	0.12	0.13
Tryptophan, 10%	0.40	0.40	0.50	0.40
Sum	100.00	100.00	100.00	100.00
Chemical composition[4]				
ME, kcal/kg	3,150.00	3,150.00	3,300.00	3,300.00
CP	9.39	10.44	9.39	10.44
Lys	0.64	0.71	0.64	0.71
Met	0.19	0.21	0.19	0.21
Thr	0.44	0.49	0.44	0.49
Trp	0.12	0.13	0.12	0.13
Ca	0.16	0.46	0.16	0.46
Total P	0.43	0.43	0.43	0.43

[1] LL : ME3,150 kcal/kg + 90% of NRC 2012 CP diet, LH : ME3,150 kcal/kg + NRC 2012 CP diet, HL : ME3,300 kcal/kg + 90% of NRC 2012 CP diet, HH : ME3,300 kcal/kg + NRC 2012 CP diet.

[2] Provided the following quantities of vitamins per kg of complete diet : Vit A, 16,000IU; Vit D_3, 3,200IU; Vit. E, 35IU; Vit. K_3, 5mg; Rivoflavin, 6mg; Calcium pantothenic acid, 16mg; Niacin, 32mg; d - Biotin, 128ug; Vit.B_{12}, 20ug.

[3] Provided the following quantities of minerals per kg of complete diet : Fe, 281mg; Cu, 288mg; Zn, 143mg; Mn, 49mg; I, 0.3mg; Se, 0.3mg.

[4] Calculated value.

Table 13. Effects of energy and protein levels on growth performance in growing-finishing pigs

Criteria	Treatment[1)]				SEM[2)]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy* Protein
Body weight, kg								
Initial	27.40	27.16	27.16	27.16	-	-	-	-
4th week	35.74	37.47	36.60	41.53	0.983	0.20	0.09	0.40
7th week	49.11	53.67	51.89	59.33	1.469	0.12	0.03	0.59
10th week	65.29	70.33	68.38	73.30	1.593	0.35	0.13	0.98
13rd week	82.80	90.69	87.94	95.07	1.938	0.20	0.05	0.92
ADG, g								
0-4 weeks	298	368	337	513	29.3	0.08	0.02	0.30
5-7 weeks	637	771	728	848	27.9	0.10	0.02	0.88
0-7 weeks	443	541	505	657	27.3	0.07	0.01	0.56
8-10 weeks	770	793	786	665	22.1	0.19	0.25	0.10
11-13 weeks	834	969	931	1,037	24.7	0.05	0.01	0.71
8-13 weeks	802	881	859	851	15.9	0.68	0.27	0.19
0-13 weeks	608	698	668	746	19.8	0.15	0.03	0.88
ADFI, g								
0-4 weeks	908	1,028	897	1,217	52.0	0.35	0.03	0.30
5-7 weeks	1,613	1,945	1,682	2,121	74.7	0.35	0.01	0.68
0-7 weeks	1,210	1,421	1,223	1,605	58.5	0.31	0.01	0.43
8-10 weeks	2,549	2,848	2,694	2,709	62.9	0.98	0.23	0.28
11-13 weeks	2,752	2,961	2,768	2,882	53.2	0.78	0.15	0.67
8-13 weeks	2,651	2,904	2,731	2,796	54.4	0.90	0.16	0.40
0-13 weeks	1,875	2,105	1,924	2,154	51.4	0.61	0.03	0.99
G:F ratio								
0-4 weeks	0.317	0.359	0.371	0.422	0.0162	0.07	0.14	0.87
5-7 weeks	0.394	0.400	0.433	0.403	0.0077	0.16	0.44	0.24
0-7 weeks	0.318	0.359	0.371	0.422	0.0162	0.07	0.14	0.87
8-10 weeks	0.304	0.279	0.292	0.246	0.0078	0.11	0.01	0.42
11-13 weeks	0.305	0.329	0.337	0.360	0.0082	0.05	0.14	0.99
8-13 weeks	0.304	0.304	0.315	0.305	0.0047	0.59	0.63	0.61
0-13 weeks	0.305	0.332	0.347	0.347	0.0047	0.06	0.67	0.69

1) LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

2) Standard error of means

Table 14. Effects of energy and protein levels on blood profiles in growing-finishing pigs

Criteria	Treatments[1)]				SEM[2)]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy* Protein
BUN, mg/dL								
Initial	-----------------5.10---------------				-	-	-	-
4th week	3.03	9.60	3.47	5.03	0.853	0.03	0.01	0.01
7th week	3.63	9.83	3.30	5.07	0.837	0.01	0.01	0.01
10th week	3.03	6.83	3.10	7.30	0.686	0.73	0.01	0.80
13rd week	4.17	6.50	5.03	7.03	0.345	0.01	0.01	0.01
Total protein, mg/dL								
Initial	----------------5.57----------------				-	-	-	-
4th week	6.77	6.70	5.90	5.67	0.265	0.10	0.78	0.88
7th week	6.53	6.90	5.93	5.63	0.262	0.10	0.95	0.53
10th week	6.57	6.80	6.10	6.67	0.143	0.31	0.19	0.57
13rd week	6.63	6.97	6.13	6.87	0.098	0.01	0.01	0.01
Creatinine, mg/dL								
Initial	-----------------1.04---------------				-	-	-	-
4th week	1.02	1.12	1.12	1.02	0.020	0.96	0.96	0.02
7th week	1.00	1.09	1.11	0.99	0.022	0.86	0.80	0.03
10th week	1.13	1.29	1.19	1.13	0.027	0.22	0.24	0.03
13rd week	1.03	1.09	1.45	1.17	0.048	0.01	0.01	0.01
Glucose, mg/dL								
Initial	-----------------92.67-------------				-	-	-	-
4th week	87.00	87.33	93.00	93.33	2.708	0.35	0.96	0.99
7th week	92.33	83.67	94.67	94.00	2.492	0.24	0.37	0.44
10th week	83.67	70.67	98.00	84.33	3.837	0.04	0.05	0.96
13rd week	92.00	71.00	90.33	75.67	2.750	0.03	0.01	0.01

1) LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

2) Standard error of means

Table 15. Effects of energy and protein levels on pH of pork in growing-finishing pigs

Criteria	Treatments[1)]				SEM[2)]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy* Protein
Time after slaughter								
0 hour	5.86	5.86	5.90	5.91	0.016	0.21	0.77	0.88
3 hour	5.75	5.76	5.79	5.79	0.024	0.55	0.91	0.98
6 hour	5.56	5.57	5.54	5.47	0.019	0.13	0.47	0.34
12 hour	5.25	5.54	5.47	5.79	0.054	0.01	0.01	0.71
24 hour	5.56	5.65	5.57	5.74	0.031	0.36	0.03	0.52

1) LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

2) Standard error of means.

Table 16. Effects of energy and protein levels on color of longissimus muscles in growing-finishing pigs

Criteria	Treatments[1]				SEM[2]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy*Protein
Hunter value[3], L								
3 hour	49.21	48.37	48.81	49.61	0.695	0.79	0.99	0.61
6 hour	51.18	49.13	51.84	50.77	0.568	0.33	0.19	0.68
12 hour	51.09	48.74	51.84	50.94	0.727	0.34	0.30	0.64
24 hour	52.08	50.72	51.95	52.04	0.529	0.62	0.59	0.54
Hunter value, a								
3 hour	7.60	7.07	7.06	6.23	0.295	0.28	0.29	0.81
6 hour	7.36	7.50	6.68	5.51	0.293	0.01	0.28	0.18
12 hour	7.84	8.30	7.44	7.31	0.228	0.16	0.72	0.54
24 hour	6.62	6.68	6.38	5.78	0.211	0.21	0.54	0.46
Hunter value, b								
3 hour	13.09	12.82	12.52	12.39	0.239	0.35	0.70	0.89
6 hour	13.86	13.34	13.41	12.78	0.202	0.19	0.22	0.79
12 hour	13.79	13.84	13.77	14.02	0.151	0.82	0.67	0.78
24 hour	13.94	13.37	13.59	13.32	0.143	0.52	0.18	0.62

1) LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

2) Standard error of means

3) CIE L: luminance or brightness (vary from black to white), a: red and green component (+a:red, -a:green), b: yellow and blue component (+b:yellow, -b:blue)

Table 17. Effects of energy and protein levels on proximate analysis and physiochemical property of longissimus muscles in growing-finishing pigs

Criteria	Treatments[1)]				SEM[2)]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy* Protein
Proximate analysis, %								
Moisture	72.80	72.39	71.86	73.44	0.351	0.94	0.43	0.19
Crude protein	22.18	23.20	22.74	23.81	0.378	0.47	0.21	0.98
Crude fat	3.70	3.34	2.36	2.75	0.228	0.04	0.97	0.39
Crude ash	1.00	0.92	0.57	0.81	0.067	0.03	0.47	0.19
Physiochemical property								
WHC, %	66.88	65.06	62.40	66.76	0.827	0.38	0.42	0.07
Cooking loss, %	21.61	23.41	28.14	26.09	0.835	0.01	0.92	0.13
Shear force, kg	31.08	27.93	39.58	43.17	2.214	0.01	0.95	0.35
Carcass trait								
Carcass grade[3)]	1.00	1.00	1.13	1.13	-	-	-	-
Dressing rate, %	74.61	73.29	74.11	72.35	0.328	0.21	0.01	0.69
Back-fat thickness, mm	24.50	20.25	19.00	19.00	0.884	0.04	0.18	0.18

[1)] LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

[2)] Standard error of means

[3)] The grade of ccarcass was scored as follows: ‘1+’grade = 0.5 point, ‘1’grade = 1 point, ‘2’grade = 2 score (n=30). The lower the score, the higher the quality of the carcass

Table 18. Effects of energy and protein levels on TBARS assay in the longissimus muscles of growing-finishing pigs

Criteria	Treatments[1)]				SEM[2)]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy* Protein
TBARS, mgMA/kg								
1 day	0.34	0.30	0.32	0.33	0.009	0.77	0.25	0.16
3 day	0.33	0.32	0.34	0.32	0.011	0.77	0.52	0.98
5 day	0.34	0.32	0.37	0.33	0.009	0.24	0.05	0.54
7 day	0.33	0.32	0.36	0.36	0.013	0.22	0.76	0.90

1) LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

2) Standard error of means

Table 19. Effects of energy and protein levels on fatty acid composition of longissimus muscles from growing-finishing pigs

Criteria	Treatments[1)				SEM[2)	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy*Protein
Fatty acid composition, %								
C14:0	1.56	1.46	1.64	1.36	0.129	0.98	0.52	0.76
C16:0	28.41	26.13	30.35	23.77	2.200	0.96	0.37	0.66
C16:1	3.28	3.09	3.15	2.66	0.277	0.66	0.58	0.80
C17:0	0.92	0.56	1.00	0.85	0.102	0.39	0.23	0.62
C18:0	14.52	14.10	16.82	12.30	1.176	0.92	0.33	0.42
C18:1 n-9	50.09	44.43	53.55	40.79	3.762	0.99	0.27	0.66
C18:2 n-6	8.28	8.55	9.75	7.84	0.524	0.73	0.47	0.34
C18:3 n-3	0.24	0.24	0.27	0.22	0.021	0.83	0.61	0.57
C20:0	0.22	0.23	0.28	0.18	0.019	0.87	0.26	0.19
C20:1	0.96	0.83	1.10	0.85	0.084	0.66	0.30	0.74
C20:2	0.39	0.41	0.51	0.40	0.027	0.37	0.42	0.23
C21:0	0.24	0.26	0.27	0.22	0.007	0.80	0.18	0.01
C20:4 n-6	1.51	1.57	1.65	1.55	0.026	0.27	0.64	0.15
SFA[3)	45.87	42.73	50.37	38.68	3.558	0.98	0.35	0.58
UFA[4)	64.74	59.12	70.00	54.31	4.433	0.98	0.27	0.60
MUFA[5)	54.33	48.34	57.81	44.30	4.086	0.97	0.28	0.67
PUFA[6)	10.42	10.77	12.19	10.01	0.583	0.69	0.47	0.32
UFA/SFA ratio	1.42	1.41	1.40	1.44	0.020	0.92	0.71	0.62

1) LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

2) Standard error of means

3) SFA = saturated fatty acids

4) UFA = unsaturated fatty acids

5) MUFA = monosaturated fatty acids

6) PUFA = polyunsaturated fatty acids

Table 20. Effects of energy and protein levels on feed cost in growing-finishing pigs

Criteria	Treatments[1)]				SEM[2)]	P-value		
	LL	LH	HL	HH		Energy	Protein	Energy *Protein
Feed cost per weight gain, won/kg								
0-4 week	732	645	682	585	32.1	0.40	0.17	0.94
5-7 week	740	740	683	757	13.7	0.44	0.18	0.17
8-10 week	924	1,024	983	1,189	28.9	0.01	0.01	0.20
11-13 week	888	846	817	782	21.3	0.13	0.38	0.94
0-13 week	830	830	801	815	11.2	0.36	0.77	0.77
Feed cost per pig, won/head								
0-4 week	5,745	6,628	5,917	8,267	359.2	0.15	0.02	0.24
5-7 week	9,831	12,031	10.408	13,497	488.9	0.21	0.01	0.58
8-10 week	14,777	16,995	16,560	16,587	394.2	0.53	0.10	0.25
11-13 week	15,484	16,998	15,992	16,957	319.8	0.71	0.06	0.66
0-13 week	45,838	52,652	48,477	55,307	1,365.7	0.28	0.01	0.99
Estimated feed cost to 110 kg, won								
	53,124	57,932	54,545	59,490	966.1	0.39	0.01	0.97
Days to market weight(110) from 27.22kg, days								
	124	112	115	105	2.6	0.11	0.03	0.78

1) LL : corn-SBM based diet with ME 3,150kcal/kg + low CP, LH : corn-SBM based diet with ME 3,150kcal/kg + high CP, HL : corn-SBM based diet with ME 3,300kcal/kg + low CP, HH : corn-SBM based diet with ME 3,300kcal/kg + high CP.

2) Standard error of means

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Ⅴ. Summary in Korean

본 연구는 육성-비육돈 사료 내 적절한 에너지 수준과 단백질 함량이 미치는 영향을 규명하기 위해서 수행되었으며, 사료 내 에너지 수준 (3,150 /3,300 kcal of ME/kg) 및 단백질 수준 (NRC 2012 요구량의 90 /100 %)에 따라 2 X 2 factorial로 구성했으며, 1) LL : ME3,150 kcal/kg + NRC 2012 CP의 90%, 2) LH : ME3,150 kcal/kg + NRC 2012 CP의 100%, 3) HL : ME3,300 kcal/kg + NRC 2012 CP의 90%, 4) HH : ME3,300 kcal/kg + NRC 2012 CP의 100%로 나누었다. 성장성적 분석 결과 HH 처리구에서 육성 후기(P=0.03)와 비육후기(P=0.05)에 개선되었다. 일당 증체량에서는 단백질 수준이 높을수록, 육성 비육돈에서 높았으며, 전체 실험 기간에서 에너지보다 단백질이 더 중요한 영양소임을 보여주었다. 일당사료섭취량 단백질 수준이 높을수록 육성 기간에 증가하였고(P=0.01), 비육기간까지 유지되었다(P=0.03). 하지만, G:F는 에너지 수준에 영향에 영향을 받았다(P=0.06). 혈액성상에 있어, LL처리구에서 BUN, 총단백질, 크레아티닌, 혈당이 낮게 유지되었으며(P=0.01), 상호작용이 일어났다(P=0.01). 돈육의 pH는 단백질 수준이 낮을수록 비록 감소했지만(P=0.03), 육색, 돈육의 일반성분, TBARS는 에너지와 단백질 수준에 영향을 받지 않았다. 경제성 분석에서는 1kg 증체당 사료비는 LL처리구가 가장 낮았으나, 총사료비용은 단백질 수준이 높을수록 증가하였다(P=0.01). 110kg 도달시까지 사료비용은 LL처리구가 가장 낮았으나, 27.22kg에서 110kg까지 출하일령은 처리구 중에서 HH가 가장 짧았다. 비록 사료 비용은 LL 처리구에서 절감할 수 있지만, HH 처리구 대비 출하일령이 19일이나 더 걸리기 때문에, 육성 비육돈 사료로서는 효율적이지 못함을 알 수 있었다. 따라서 본 실험은 사료 비용과 출하일령과 육질을 고려했을 때, 높은 에너지와 낮은 단백질의 사료가 육성-비육기의 사료로 바람직하다고 판단된다.

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