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Effect of Low Protein Levels with L-Valine Supplemented in Weaning Diet on Growth Performance, Fecal Score, Blood Profiles, Nutrients Digestibility, Carcass Characteristics and Economic Analysis in Weaning to Finishing Pigs

자돈 사료 내 단백질 수준과 발린의 첨가가 자돈 및 육성비육돈의 성장성적, 분변지수, 혈액성상, 영양소 소화율, 도체특성 및 경제성에 미치는 영향

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지도교수 **김 유 용**

이 논문을 농학석사 학위논문으로 제출함

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서울대학교 대학원 농생명공학부

한 영 걸

한영걸의 농학석사 학위논문을 인준함

2018 년 2 월

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Summary

Supplying adequate nutrients to livestock not only can lower production costs, but also reduce the economic losses and environmental burdens caused by excess nutrients. The Korea government has enacted laws to regulate environmental pollution resulted by livestock manure. In this context, NRC (2012) revised and adjusted the protein requirement to a lower level compared to previous NRC requirement (1998). However, there is a lack of verification that it can be applied to the domestic swine industry. So the process of verifying whether changes in the protein requirements suggested by the NRC (2012) is indeed appropriate for domestic situation is needed. Therefore, this study was conducted to evaluate optimal crude protein levels with L-valine supplementation in weaning pig diet considering subsequent growth performance, fecal score, blood profiles, nutrient digestibility, carcass characteristics and economic analysis from weaning to finishing pigs. A total of 160 weaning pigs ([Yorkshire×Landrace]×Duroc), with an average body weight of 7.86±1.05kg, were used for 22 weeks feeding trial. Pigs were allotted into one of five treatments by body weight and sex in 4 replicates with 8 pigs per pen in a randomized complete block (RCB) design. The treatments were included 1) Corn-SBM based diet with L-valine supplementation + protein content suggested by NRC (1998) (HP), 2) Basal diet + protein content suggested by NRC (1998) - 1% (MHP), 3) Basal diet + protein content suggested by NRC (1998) - 1.5%, 4) Basal diet + protein content suggested by NRC (2012) and 5) Corn-SBM based diet without L-valine supplementation + protein content suggested by NRC (2012). In feeding trial, reducing crude protein (CP) level showed negative effect on body weight (BW) and average daily gain (ADG) during early growing phase ($P<0.01$). However, there was no significant impact of reducing CP level on BW and ADG at the end of experiment. Also, average daily feed intake

(ADFI) decreased as dietary CP level decreased in 7-10 week (linear, $P<0.05$). On the other hand, L-valine supplementation in weaning diet increased BW in 22 week, ADG in 7-14 week and ADFI 11-14 week ($P<0.01$, $P<0.01$ and $P<0.05$, respectively). There was no significant difference in fecal score, but fecal consistency tended to decrease as dietary CP level decreased (linear, $P<0.10$). Likewise L-valine supplementation in weaning diet had no significant effect on fecal score. In blood analysis, there was a positive effect of reducing CP level and L-valine supplementation in weaning diet on BUN concentration in both weaning and growing-finishing period ($P<0.01$; linear, $P<0.05$). Nutrient digestibility and nitrogen balance was not affected by dietary treatments. In carcass characteristics, pH and water holding capacity (WHC) were decreased linearly as dietary CP level decreased (linear, $P<0.05$). However, crude fat, Hunter L* and b* value showed linear response as dietary CP level decreased (linear, $P<0.05$). The fatty acid composition of *longissimus muscle* was changed by feeding CP diet leading to increased MUFA concentration (linear, $P<0.05$). When pigs were fed low CP diet, feed cost per weight gain, total feed cost and days to market weight were diminished compared to higher CP treatment groups ($P<0.05$). Moreover, L-valine supplementation resulted in improving days to market weight. Consequently, lowering dietary CP level did not show any detrimental impact on growth performance and increase amino acids availability, crude fat content and MUFA concentration in muscle. Moreover, decreased dietary CP level reduce BUN concentration, feed cost per weight gain, total feed cost, pH and WHC in muscle. On the other hand, supplementation of L-valine in weaning diet resulted in improved growth performance, BUN concentration and numerically decreased days to market weight during growing and finishing period. Although much lower CP level diet was provided during weaning period compared to NRC (1998), there was no detrimental effect on the whole growth performance of pigs. When pigs

were fed lowered dietary CP treatment diet, it is desirable to consider supplementing L-valine in weaning pigs' diet.

Key words: Protein level, Nitrogen excretion, Carcass characteristics, Growth performance, Weaning to finishing pig

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List of Abbreviation

AA	Amino acid
ACC	Acetyl-CoA carboxylase
ADG	Average daily gain
ADFI	Average daily feed intake
AOAC	Association of official analytical chemists
ARC	Agricultural research council
BCFA	Branched chain fatty acid
BUN	Blood urea nitrogen
BW	Body weight
CP	Crude protein
CPT-1	Carnitine palmitoyltransferase-1
CRD	Completely randomized design
DE	Digestible energy
DM	Dry matter
EAA	Essential amino acid
ETEC	Enterotoxigenic *Escherichia coli*
FAME	Fatty acid methyl ester
FAS	Fatty acid synthase
FFA	Free fatty acid
FTA	Free trade agreement
H-FABP	Heart fatty-acid binding protein
HSL	Hormone sensitive lipase

IMF	Intramuscular fat
LDL	Low-density lipoprotein
ME	Metabolizable energy
MUFA	Monounsaturated fatty acid
NE	Net energy
NRC	National research council
PD	Protein deposition
PPARg	Peroxisome proliferator-activated receptor g
PWD	Post weaning diarrhea
PUFA	Polyunsaturated fatty acid
RCB	Randomized complete block
SAS	Statistical analysis system
SBM	Soybean meal
SCD	Stearoyl-CoA desaturase
SFA	Saturated fatty acid
SREBP-1c	Sterol regulatory element-binding protein 1c
VFA	Volatile fatty acid
WHC	Water holding capacity

I. Introduction

Due to competition between producing animal feed and bio-fuel as ethanol, the world grain price has been soared noticeably. Moreover, severe climate change and abnormal climate such as drought and flood, have influenced on world grain market. Thus for some years ahead, the price of imported feed ingredient will become more costly. In Korea, it is obvious that the feed cost comprise approximately 50~60% of total cost for pig production. Feed cost and pig production cost are much higher than those of other countries because feed industry completely relies on imported feed ingredients. Additionally, shipping charge and storage cost affect negatively on feed cost and pig production cost. Moreover, since FTA with other countries such as EU and USA, the imported pork have been increased dramatically and it occupied more than 30% in total pork market of South Korea. It has led to intense competition between imported pork and domestic pork. Therefore, in order to compete with imported pork, pig producers in South Korea need to reduce production cost as well as to improve feed efficiency or find appropriate nutrient requirement of animals.

The disposal of livestock manure has become a big problem in the South Korea society because of bad smell, the amount and nutrient composition of the manure exceeding the capacity of the land and causing eutrophication. In this context, Korea government have begun to strength regulation of the effluent water standard from livestock manure. According to ministry of agriculture food and rural affairs, they suggested the emission legislation that total nitrogen content in effluent water from swine farm will be reduced from current 500ppm to 250ppm until 2019 gradually.

Low crude protein (CP) diet would be countermeasure in order to reduce production cost and total nitrogen content in livestock manure. Generally, reduction of CP level in swine diet could save feed cost because protein sources are more expensive than energy sources. Moreover, reduction of CP level could decrease surplus nitrogen source excreted through manure. Consequently, NRC (2012) suggested lower CP level than that of NRC (1998) without retardation of swine growth. However, Korean livestock feeding standard (2012) did not suggest optimal CP levels for Korean swine farms. So the process of verifying whether changes in the protein requirements suggested by the NRC (2012) is indeed appropriate for domestic situation is needed. Therefore, this study was conducted to evaluate optimal crude protein levels with L-valine supplementation in weaning pig diet considering growth performance, fecal score, blood profiles, nutrient digestibility subsequent carcass characteristics and economic analysis of weaning to finishing pigs.

II. Literature Review

1. Introduction

1.1 Genetic improvement and nutrient requirement for pigs

Breeding programmes and improved knowledge of genetics have led to gradually enhanced genetic improvement in pigs. Genetic improvement by breeding in pigs started early 20^{th} century, specially in Northern Europe. In the early stage the purpose of these programmes was focussed only on lean mass and feed efficiency. Advance in genotype or phenotype was achieved especially for breed characteristics like type and colour and later also backfat thickness, daily gain and consequently improved feed efficiency.

Since mankind began to domesticate farm animals, we have been striving to get progeny from the animals that appeared best fit for the goal we had in mind. In the early stage, docility and breed characteristics like colour and size were favoured. The research of Dickerson (1952, 1974) on crossbreeding in plants and poultry also arouse the attention of pig breeders. In Table 1 the phenotypic trends in central test results from 1930 until 1990 in the Netherlands is presented for Dutch Landrace and Dutch Yorkshire. According to Merks (2000), Daily gain was enhanced by more than 50%, the feed efficiency was improved unusually and backfat thickness was decreased by about 50%. In Figure 1, it schematized the primary genetic trends in 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 (Merks, 2000)

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

In the last decade of 20th century, improved knowledge of genetics such as molecular genetics led to increased genetic advance in both sire and dam lines for reproduction and production characteristics. Knap (2009) and Torres et al. (2005) also suggested that feed efficiency and growth performance were improved and getting better as time goes. According to Brewer et al. (2001), breeding for leaner genotype has resulted in decreased intramuscular fat (IMF) content.

Breeding goals are now focussed not only on economically lucrative traits like daily gain, feed efficiency and litter size but also increasingly on traits such as meat quality (drip loss, colour) and vitality of piglets (Knol, 1998). Moreover some researchers conducted study to overcome genotype x environment interaction (Andersen et al., 1998;Merks and Hanenberg, 1998) and inbreeding (Meuwissen, 1998).

In the meantime, other researchers were attention to the change of nutrient requirement of pigs. Table 2. showed optimum lysine/digestible energy ratio in growing pigs by genotype. van Lunen

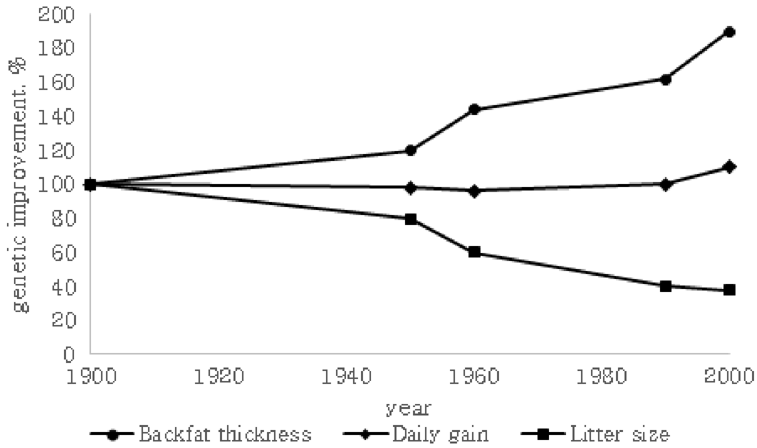

Figure 1. Schematic description of one century of genetic progress in pigs (Merks, 2000)

and Cole (1996) reported that protein deposition and lysine requirements have changed as a result of genetic improvements. Pigs with improved genotype showed higher protein deposition capacity and higher lysine requirement. Therefore, the nutrient requirement of pigs is expected to increase steadily in the future.

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

1.2 Scale of livestock industry and Situation of environmental regulation in Korea

In Korea, the consumption of meat has increased sharply with the improvement of economic growth and national income in the 1970s. Thus the size of the livestock industry has changed into large scale or enterprise-scale with government plan focussing only on development regardless of the environment. In addition, since the Uruguay Round (UR) negotiations, government support for livestock industry has increased due to the market opening pressure of the livestock sector.

The number of livestock breeding livestock in Korea has increased rapidly over all kinds of breeds. On the other hand, the number of farm households is sharply decreasing over all kinds of species. This shows that the scale and concentration of livestock breeding is ongoing.

Table 3. The number of livestock animals and farms (KOSTAT, 2016)

	1970	1980	1990	1995	2000	2010	2016
Pig							
The number of livestock, thousand	1,126	1,784	4,528	6,461	8,214	9,881	10,367
The number of farms, thousand	884	503	133	46	24	7.3	4.6
Average number of livestock per farm	1.3	3.5	34	140.5	344.5	1,354	2,254

These modern livestock industry featuring factory farm and a densely raising farm is called by industrial agriculture. Industrial agriculture is characterized by non-natural and it is increasing environmental burden such as air pollution caused by methane and carbon dioxide and water pollution caused by total nitrogen and heavy metal (Song, 2017). Thus ministry of environment has strengthened relevant legislation. According to legislation about livestock manure, it could restrict the number of livestock in a densely populated area. Moreover, effluent standards of purification facility in livestock industry was consolidated to prevent water pollution by livestock manure and it was presented in Table 4. In particular, the regulation of total-nitrogen has been greatly strengthened. So we have to prepare a plan to reduce total-nitrogen in manure.

Table 4. The change of effluent standards of purification facility in livestock industry (Ministry of environment, 2015)

	item	The special zone		Other region	
		Current	Amendment	Current	Amendment
Object of permission	BOD	50	40	150	120
	SS	50	40	150	120
	T-N	250	120	850	250
	T-P	50	40	200	100
Object of report	BOD	150	120	350	150
	SS	150	120	350	150
	T-N	850	250	-	400
	T-P	200	100	-	100

As the level of restriction is strengthened, the legislation about livestock manure, which intends to manage and utilize livestock manure efficiently, has become a severe law that more strongly regulates the livestock industry than any related laws.

2 Protein and amino acid requirements for swine diets

2.1 Transition of protein and amino acid requirements in NRC

The change of protein and amino acid requirements in NRC is showed in Table 5. NRC (2012) has some characteristics comparison with NRC (1998). Firstly, it was divided growth phase more detail than NRC (1998). Detailed phase feeding could help pig producer to save feed cost and reduce surplus nutrient composition in the feed. Secondly, it showed higher metabolizable energy from 3,265 to 3,300 kcal. Finally, it had lower CP requirement but higher amino acids requirement. Low CP levels might cause lack of limiting amino acids or amino acids unbalance. That’s why NRC (2012) suggested higher amino acids requirements. The shortage of essential amino acids caused by low CP diet could be alleviated through supplementing crystalline amino acids.

Table 5. 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	18.0	15.5		13.2
	Lys,%	1.35	1.15	0.95	0.75		0.60
	Met,%	0.35	0.30	0.25	0.20		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	1.40	1.12	0.97	0.84	0.71
	Met,%	0.44	0.40	0.32	0.28	0.25	0.21

[1] The value of CP is calculated from N by multiplying by 100/16 (or 6.25). (Swine Nutrition 2nd Edition, 2001)

2.2 Transition of ideal amino acid profile

Limiting amino acid is an essential amino acid that is easily deficient in the feed, which prevents protein synthesis in the body. The first limiting amino acid is mainly lysine. Mitchell (1964) firstly mentioned about ideal amino acid profile. The ideal amino acids profiles refer to an amino acid profile that exactly meets the animal's requirement so that all amino acids are equally limiting for performance. Agricultural research council (ARC; 1981) presented ideal amino acid ratio of essential amino acids based on their concentration in the pig carcass. However, Wu (2010) mentioned that ARC's ideal amino acid conceptual foundation based only on the essential amino acids (EAA) composition of the animal body. In the same context, Wu (2014) pointed out ARC's ideal protein concept did not take into consideration the relative contribution of maintenance to the total amino acids needs of the pigs. Moreover, ARC did not include arginine, glycine and all synthesizable amino acids. Since then, Wang and Fuller (1989) suggested other ideal amino acids profile featuring high content of glutamate. They took into consideration the requirements for both maintenance and tissue protein accretion. Glutamate was supplemented in the diet to provide non-specific nitrogen source. Non-specific nitrogen source was thought to be used to compensate for shortage of non-essential amino acids. Between 1990 and 2000, Baker tried to evaluate amino acid requirements of pigs. Chung and Baker (1992) designed ideal amino acids profile including arginine, glycine, histidine and proline. However, they did not take into consideration other synthesizable amino acids and not explain the reason for the rationale for the use of arginine, glycine, histidine and proline proportions to lysine. Also, the explanation whether glutamate is effective precursor was insufficient and the influence of high content of glutamate on metabolism other amino acids was left out. Since then, NRC and Baker (2000) were not aware of the needs of pigs for proline or glycine. So they were omitted in ideal amino acids profile.

On the other hand, the ratio among amino acids was consistent but the requirement of amino acid for pigs in NRC (2012) was increased. So the need of limiting amino acids was increased. Moreover, lower CP level in NRC (2012) resulted in the emergence of new limiting amino acid such as valine.

Table 6. Amino acid profile (relative to lysine) of ideal protein for 10-20 kg growing pig

	ARC (1981)	Wang-Fuller (1989)	Chung-Baker (1992)	NRC (1998)	Baker (2000)	NRC (2012)
Lysine	100	100	100	100	100	100
Arginine	-	-	42	42	42	42
Glycine	-	-	100	-	-	-
Histidine	33	-	32	32	32	34
Isoleucine	55	60	60	54	60	58
Leucine	100	110	100	102	100	100
Met + Cys	50	63	60	57	60	59
Phe + Tyr	96	120	95	94	95	100
Proline	-	-	33	-	-	-
Tryptophan	15	18	18	19	17	19
Threonine	60	72	35	62	65	65
Valine	70	75	68	68	68	70
Glutamate	-	826	878	-	-	-

2.3 Valine deficiency of low protein diet in weaning period

Trend for lowering CP level in diet resulted in increase of limiting amino acids such as lysine, methionine and threonine and so on. Valine come into the picture. Lysine is first-limiting and tryptophan, threonine, methionine and valine are equally second-limiting in a reduced protein (13.5% CP) corn-soybean meal-based diet with 8% whey for 10kg pigs (Mavromichalis et al., 1998). According to report of Gloaguen et al. (2011), feeding a valine-deficient diet to piglets had an negative influence on feed intake, thereby affected growth performance. In a similar vein, Goto et al. (2010) conducted animal experiment with rats. they reported that the intracerebroventricular administration of valine to rats fed a valine-free diet restored the cerebrospinal fluid concentration of valine and increased feed intake. As shown in Figure 2, Dever and Hinnebusch (2005) suggested a possible mechanism for anorexia due to valine-deficiency.

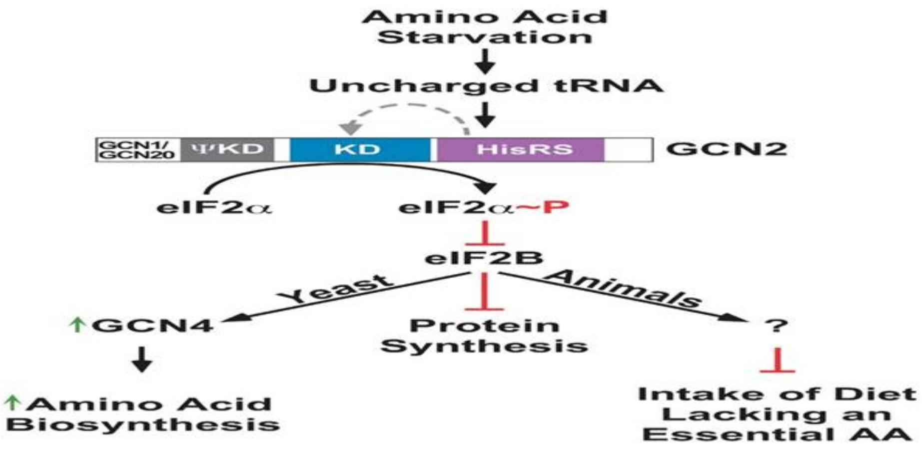

Figure 2. Mechanism for anorexia due to valine-deficiency (Dever and Hinnebusch, 2005)

3. Impact of low protein diet on gastrointestinal tract

3.1 Protein fermentation

Both intestinal beneficial and pathogenic bacterium inhabit a pig's gastrointestinal tract. They may directly influence on intestinal nutrient requirements and have relevance to the availability of dietary nutrients for growth (Burrin and Stoll, 2003). According to the report of Stein and Nyachoti (2003), The population and activity of microflora in the foregut rely on diet type and age. Cranwell and Moughan (1989) gave a report that undigested nutrients like protein and carbohydrates in the intestinal lumen supply a fine source of substrates for microbial fermentation and proliferation. Macfarlane et al. (1992) suggested that protein fermentation is most pronounced in the distal large intestinal tract where carbohydrate can become a limiting factor for microbial fermentation and is followed by increased production of branched-chain fatty acid (BCFA). Also, Pluske et al. (2002) indicated that microbial fermentation of undigested protein source could aggravate diarrhea by contributing to production of potentially toxic and osmotically active byproducts such as indole, phenols and ammonia and so on. Thus Nyachoti et al. (2006) conducted experiment feeding low CP diet and reported that low CP diets help maintain gut health by lowering toxic metabolites caused by microbial fermentation. They observed that significant linear reductions of volatile fatty acid (VFA) and linear reduction of ammonia in ileal digesta. Therefore, they commented that feeding low protein diet with AA supplementation could minimize microbial proliferation in the gut and also their byproducts caused by microbial fermentation. Thus it makes pigs have better opportunity utilizing dietary nutrients for growth. These findings were in accordance with report of Htoo et al. (2007) and Opapeju et al. (2008) that observed lower concentration of ammonia N in the colon digesta fed by low CP diet. Additionally, Heo et al. (2008) imply feeding a low CP diet after weaning mitigate indices of protein fermentation and post weaning diarrhea (PWD) without adverse effects on production compared with high CP diet.

3.2 Microbial population

Opapeju et al. (2009) demonstrated that pigs fed the 22.5% CP diet had greater microbial abundance and diversity in their colon digesta compared with those fed the 17.6% CP diet 7 d after enterotoxigenic *Escherichia coli* (ETEC) challenge. This study showed that pigs fed the 17.6% CP diet had a greater prevalence of bacteria in the order *Clostridiales* particularly family *Lachnospiraceae* and genus *Roseburia* and tended to have a lesser prevalence of family *Clostridiaceae* and genus *Clostridium* that preferentially ferment protein in their colon digesta compared with those fed the 22.5% CP diet. According to Louis et al. (2007), the *Roseburia/Eubacterium rectale* group preferentially ferments carbohydrates rather than protein. In addtion, *Roseburia/Eubacterium rectale* are known as a butyrate producing bacteria preferred energy source for intestinal epithelial cells (Bergman, 1990). Thus, Opapeju et al. (2009) indicate that a low CP diet has the potential to increase the prevalence of butyrate-producing bacteria in the hindgut. These observation were accordance with research of Macfarlane and Macfarlane (1995) that demonstrate that low CP diet showed a direct effect on reduction of substrate availability for protein fermenters like pathogen bacteria. Besides, Konstantinov et al. (2004) suggest that increase in microbial richness and diversity has been associated with increased ecosystem stability and resistance to pathogen invasion.

On the other hand, Naychoti et al. (2006) reported that low CP diet with AA-supplementation had no effect on gastrointestinal microbial populations. The author explained that the study was conducted in a clean experimental facility and the caution should be needed in translating the result to a commercial situation. Because bacterial load in the gut microbial population can be affected by sanitary conditions in the environment where pigs are kept. Indeed, Göransson et al. (1995) demonstrated that a greater effect of low CP diet on PWD and growth performance is observed likely under commercial conditions.

4. Influence of low protein diets on fat deposition

4.1 Impact of low protein diet on lipid metabolism

Numerous previous study showed relation dietary protein level with fat deposition in the animal body. Several studies demonstrated that reduction of dietary protein level resulted in increase of fat deposition (Cromwell et al., 1978, Karlsson et al., 1993; ; Chiba et al., 2002). According to Teye et al. (2006), low CP diets having unbalanced amino acids with net energy (NE) have been used to promote fat deposition in pigs and especially to increase IMF for the benefit of eating quality. However, other researchers still suggested that a tendency for much higher fat deposition with low protein diets even when the pigs are provided with balanced amino acids (Figueroa et al., 2002;Gomez et al., 2002). According to Wood et al. (2013), IMF accumulation was increased fed low protein diet and also highest fed low protein diet with unbalance of amino acids. In this study, however, there was no significant difference between control and low protein diet in subcutaneous or intermuscular fat deposition.

There have been many studies on the causes of fat deposition when low protein diets are fed. The fat deposition is decided by the difference in the rates of lipogenesis and lipolysis. These reactions are regulated by metabolic enzymes and controlled by functional genes in the growth and development process of muscle tissue (Wang et al. 2012). Jurie et al., (2007) also mentioned that IMF deposition was decided by not only the rates of lipogenesis and lipolysis but fatty acid transport in muscle tissue.

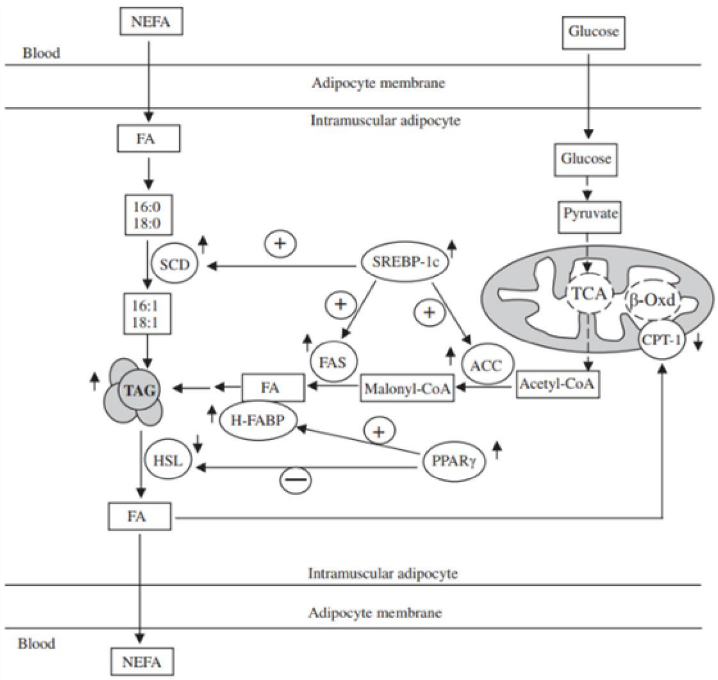

Figure 3. The impact of low dietary protein on lipid metabolism in porcine muscle tissue (Wang et al., 2012) ↑: Up-regulation of gene expression or increased concentration of metabolite. ↓: Down-regulation of gene expression or decreased concentration of metabolite. +: Enhanced metabolic pathway; - : Inhibited metabolic pathway. TCA: tricarboxylic acid cycle; β-Oxd: β-oxidation.

There is evidence that a positive connection between IMF deposition and expression level of SREBP-1 mRNA in muscle tissue of pigs exists (Chen et al., 2008). Some studies indicated a positive relationship between SCD protein expression and amount of total fatty acids in muscle of pigs supplied a low protein diet (Doran,2006). According to report of Wang et al. (2012), there is evidence that the low CP diet increased the mRNA and protein expression of SREBP-1c, ACC, FAS, and SCD. Additionally, mRNA and protein expression level of lipolytic genes including HSL and CPT-1 were decreased in the LP diet group. Moreover, Guo et al. (2011) showed a positive correlation between an elevated IMF content in pigs fed the low protein diet and activation of PPARg and H-FABP mRNA expression. Zhao et al. (2010) demonstrated that subcutaneous fat deposition was increased in pigs with low protein diet mainly by up-regulation of lipogenic genes at 60 and 100 kg and by down-regulation of lipolytic genes at 60 kg and up-regulation at 100 kg.

Dietary protein level have effect on fatty acid composition in a muscle. According to Wang et al. (2012), the concentration of C18:2, C18:3 and polyunsaturated fatty acid (PUFA) were higher in pigs fed low protein diet than those fed high protein diet. The variance of SCD may result in the difference of fatty acid composition between LP and HP diet. Cohen and Jeffrey (2004) demonstrated that SCD is responsible for the generation of mono-unsaturated fatty acids, which catalyzes its substrates palmitic (16:0) and stearic acid (18:0) to generate the products palmitoleic (16:1) and oleic acid (18:1). Wang et al. (2012) showed that the mRNA and protein expressions of SCD in pigs fed LP diet were higher than those fed HP diet. Futhermore, Wood et al. (2013) explained that oleic acid is the main product of de novo fat synthesis in the pig and it is logical that its concentration increases as the pig gets fatter.

On the other hand, Teye et al. (2006) and Alonso et al. (2010) suggested that pigs fed LP diet showed markedly lower content of

PUFA and higher IMF content. According to Lambe et al. (2013), although the evidence of differences in fat metabolism between pigs fed HP diet and those fed LP diet, indicated by differences in fatty acid composition, there was no significant differences in total fat deposition through the computed tomographic (CT) scans on the pigs during growth.

4.2 Impact of low protein diet on pork quality

Numerous previous studies showed that the IMF deposition was elevated by low protein diet (Teye et al., 2006;Alonso et al., 2010;Wood et al., 2013). Frenandez et al. (1999) indicated that the elevated IMF content in muscle may improve the sensory meat quality such as tenderness, flavor, juiciness and the nutritional value of meat. Like this, other reports also showed the relation between higher tenderness and juiciness and a high IMF content of meat fed low protein diet (Cisneros, Ellis, Baker, Easter, & McKeith, 1996; Teye et al., 2006). Moreover, according to study of Font-i-Furnols et al. (2012), high IMF content improved acceptability of pork perceived by consumer. Dikeman (1987) explained that IMF activated the saliva secretion and improved the juiciness by coating on the tongue, teeth and other parts of the mouth. So the effort have been made to achieve enough IMF to ensure a pleasant eating experience, but a low enough level to mitigate the health concern about high-fat pork (Fortin et al., 2005). High consumption of saturated fatty acids (SFA) may result in elevated plasma cholesterol contributing to cardiovascular disease (Zhang et al., 2007).

Suárez-Belloch et al. (2016) and Teye et al. (2006) showed that Hunter L* value increased in pork fed low protein diet and also moderate elevation of Hunter L* value can improve some visual attributes providing higher lightness. And also, the Hunter b* value has been related to marbling (Suárez-Belloch et al. 2016). According to the study of Goerl et al. (1995), low protein diets increased the Hunter b* values of pork.

Glycolytic potential means that the capacity of all substrates available in a muscle for the generation of lactate after slaughter (Monin and Sellier, 1985). It is of interest because muscle glycogen content at slaughter affects both the rate and the extent of post mortem pH drop (Henckel et al., 2000). Glycogen stored in the muscle, resulted in the production of lactic acid through glycolysis, which caused a drop in pH (Huff-Lonergan and Lonergan, 2005). Ruusunen et al., (2007) showed that glycolytic potential was higher in the low-protein group than in the high-protein group. This is in accordance with a study by Katsumata et al. (2003), who also showed that glycogen content is higher in pigs fed a low-lysine diet than in those fed a high-lysine diet.

5. Environmental impacts of low protein in diets

Nitrogen source including ammonium (NH_4^+) and volatile organic compounds (VOC) are major pollutant of pig manure contributing to environmental pollution (Zahn et al.,1997). According to Jackson et al. (1986) manure NH_4^+ is generated by hindgut oxidative deamination of surplus AA through removal of α-amino-N. and also bacterial urease present in feces could convert urinary urea into NH_4^+ when urine comes in contact with fecal matter. Ammonia is also generated by enzymatic and bacterial degradation of other nitrogenous source present in urine. Kay and Lee (1997) conducted practical feeding studies that showed ammonia emission was reduced in pigs fed low protein diet. This observation was accordance with report of Richert and Sutton (2000) that indicated a 33% reduction of NH_3 emission when dietary CP was reduced from 14 to 10%. Furthermore Otto et al. (2002) reported that decreasing 3% of CP level resulted in a 20% reduction in total nitrogen excretion and also reduction of 9% CP level decreased 40% of total nitrogen excretion. Like this, Canh et al. (1998) demonstrated that reducing dietary CP content in diet have effect on reduction in the amount of nitrogen excretion. On the other hand, Gatel and Grosjean (1992) indicated that reduction of nitrogen excretion was observed only in urinary nitrogen but not in faecal nitrogen excretion when lowering dietary CP level in diet. Sutton et al. (1999) and Li et al. (2015) suggested that feeding the reduced CP diets resulted in the reduction of manure NH_4^+ content but not of stored manure N.

Ⅲ. Effect of Low Protein Levels with L-Valine Supplemented in Weaning Diet on Growth Performance, Fecal Score, Blood Profiles, Nutrients Digestibility, Carcass Characteristics and Economic Analysis in Weaning to Finishing Pigs

ABSTRACT: This study was conducted to evaluate optimal crude protein levels with L-valine supplementation in weaning pig diet considering subsequent growth performance, fecal score, blood profiles, nutrient digestibility, carcass characteristics and economic analysis from weaning to finishing pigs. A total of 160 weaning pigs ([Yorkshire×Landrace]×Duroc), with an average body weight of 7.86±1.05kg, were used for 22 weeks feeding trial. Pigs were allotted into one of five treatments by body weight and sex in 4 replicates with 8 pigs per pen in a randomized complete block (RCB) design. The treatments were included 1) Corn-SBM based diet with L-valine supplementation + protein content suggested by NRC (1998) (HP), 2) Basal diet + protein content suggested by NRC (1998) - 1% (MHP), 3) Basal diet + protein content suggested by NRC (1998) - 1.5%, 4) Basal diet + protein content suggested by NRC (2012) and 5) Corn-SBM based diet without L-valine supplementation + protein content suggested by NRC (2012). Reducing CP level had negative effect on body weight (BW) ($P<0.01$) and average daily gain (ADG) ($P<0.01$) during early growing phase. However, there was no significant

effect of reducing CP level on BW and ADG at the end of experiment. Also, average daily feed intake (ADFI) decreased as dietary protein level decreased in 7-10 week (linear, $P<0.05$). On the other hand, L-valine supplementation in weaning diet improved BW in 22 week, ADG in 7-14 week and ADFI in 11-14 week ($P<0.01$, $P<0.01$ and $P<0.05$, respectively) compared LP group and LPV- group. There was no significant impact of reducing CP level and L-valine supplementation in weaning diet on fecal score, but fecal consistency tended to decrease as dietary protein level decreased (linear, $P<0.10$). In blood analysis, there was a positive effect of reducing CP level and L-valine supplementation in weaning diet on blood urea nitrogen (BUN) concentration in both weaning and growing-finishing period ($P<0.01$; linear, $P<0.05$). Nutrient digestibility and nitrogen balance was not affected by dietary treatments. In carcass characteristics, pH and water holding capacity (WHC) were decreased linearly as dietary CP level decreased (linear, $P<0.05$). However, crude fat, Hunter L* and b* value showed increasing linear response as dietary protein level decreased (linear, $P<0.05$). The fatty acid composition of *longissimus muscle* was changed by CP level leading to increased MUFA concentration (linear, $P<0.05$). When pigs were fed low CP diet, feed cost per weight gain, days to market weight and total feed cost were diminished compared to higher CP treatment groups ($P<0.05$). Moreover, L-valine supplementation resulted in improving days to market weight. Consequently, lowering dietary CP level did not show any detrimental impact on growth performance and increase amino acids availability,

crude fat content and MUFA concentration in muscle. Moreover, decreased dietary CP level reduce BUN concentration, feed cost per weight gain, total feed cost, pH and WHC in muscle. On the other hand, supplementation of L-valine in weaning diet resulted in improved growth performance, BUN concentration and numerically decreased days to market weight during growing and finishing period. Although much lower CP level diet was provided during weaning period compared to NRC (2012), there was no detrimental effect on the whole growth performance of pigs. When pigs were fed lowered dietary CP treatment diet, it is desirable to consider supplementing L-valine in weaning pigs' diet.

Key words : Protein level, Nitrogen excretion, Carcass characteristics, Growth performance, Weaning to finishing pig

Introduction

Protein is a source of nitrogen and essential amino acids in the body and is used to synthesize polypeptides in order to maintain a lot of metabolism in the body (Wu, 2010). Thus, supply of adequate protein and amino acids is a crucial role in growth of animals (Carpenter et al., 2004). However, as revised from NRC (1998) to NRC (2012), crude protein and amino acid requirements have changed significantly. NRC (2012) showed relatively low crude protein requirement and high amino acid requirement compared to NRC (1998).

The crude protein level in the weaning diet affected the intestinal microflora and diarrhea, according to Opapeju (2009), high crude protein content proliferated the intestinal proteolytic pathogen bacteria, which were associated with piglet diarrhea. In addition, it also increases potential toxic substances such as ammonia, amines, indoles and phenols in the large intestine. Studies have been reported that it can increase amino acid utilization by lowering crude protein and improving amino acid balance for rainbow trout (Green and Hardy, 2002), and that it can reduce nitrogen excretion by reducing crude protein levels in feeds (Nyachoti et al., 2006). It can also improve nitrogen balance by reducing the amount of nitrogen released into the manure that is not digested in the digestive tract (Lordelo et al., 2008). This is a crucial issue that must be considered in the practical field where environmental concern is constantly increasing (Song, 2017). The level of crude protein in the feed can also affect the pork quality, because it can influence on the deposition of IMF (Wood et al, 2013). According to

Wang et al. (2012), IMF levels can be controlled by the level of crude protein in the feed, but the mechanism has not been clarified.

Reducing the crude protein content has several advantages. In the process, however, essential amino acids are prone to become insufficient (Mavromichalis et al., 1998). An example is valine shortage. Valine is the second limiting amino acid in feeding pigs with lower crude protein content in piglets (Mavromichalis et al., 1998;Norgaard and Fernandez, 2004). It has been reported that providing valine deficiency feed to weaning piglets results in decrease of feed intake and consequently affects growth performance (Gloaguen et al., 2011). Therefore, attention should be paid to the valine deficiency when the level of crude protein in feed is reduced.

Thus the crude protein content in the feed can affect on the various physiology of the animal. However, while the NRC was revised, the Korea Livestock Specification Standard (2012) did not propose the crude protein requirement for each stage of growing. So it was concluded that the process of verifying whether changes in the protein requirements suggested by the NRC is indeed appropriate for domestic situation is insufficient. Therefore, this study was conducted to evaluate optimal crude protein levels with L-valine supplementation in weaning pig diet considering growth performance, fecal score, blood profiles, nutrient digestibility, carcass characteristics and economic analysis of weaning to finishing pigs.

Materials and Methods

Experimental animals and management

A total of 160 weaning pigs ([Yorkshire × Landrace] × Duroc) with an average body weight of 7.86 ± 1.05 kg were used for 22 weeks feeding trial at experimental farm of Seoul National University. All pigs were housed in an environmentally controlled building with plastic-slotted floors facility (1.95 x 1.42m) during weaning periods and half-slotted concrete floors facility (2.60 x 2.84m) during growing to finishing periods. Each pen was equipped with a feeder and a nipple drinker to provide *ad-libitum* access.

Experimental design and diets

Experimental pigs were allotted to one of five treatments by BW and sex in 4 replications with 8 pigs per pen in a randomized complete block (RCB) design. Dietary treatments were: 1) HP : corn-SBM based diet with protein requirement of NRC (1998), 2) MHP : corn-SBM based diet with protein requirement of NRC (1998) - 1%, 3) MLP : corn-SBM based diet with protein requirement of NRC (1998) - 1.5%, 4) LP : corn-SBM based diet with protein requirement of NRC (2012), 5) LPV- : LP treatment diet without L-valine supplementation. After weaning period, LPV- was fed same experimental diet with LP. All nutrients except for protein were met or exceeded the requirement of NRC (2012). Lysine, methionine, threonine, tryptophan and valine were considered to meet or exceed the requirement of NRC (2012). Experimental diets formula and chemical compositions were presented in Tables 1, 2, 3, 4, 5 and 6.

Growth performance

Body weight (BW) and feed intake were recorded at 0, 2, 6, 10, 14, 18 and 22 week to calculate the average daily gain (ADG), average daily feed intake (ADFI) and gain-to-feed ratio (G:F ratio).

Fecal score

Fecal score was measured every 8:00 am for 42 days during weaning phase. Data were recorded by each pen and divided into 2 phases to assess the general pattern (Phase 1 and Phase 2). Fecal consistency scoring was based on the following index used by Sherman et al. (1983): 0, normal (feces firm and well formed); 1, soft consistency (feces soft and formed); 2, mild diarrhea (fluid feces, usually yellowish); and 3, severe diarrhea (feces watery and projectile). After recording data, evidence of watery diarrhea was cleaned away everytime to avoid infection from previous day.

Blood sampling and analysis

Blood samples were taken from the jugular vein of randomly selected 4 pigs in each treatment for measuring blood urea nitrogen (BUN), glucose, triglyceride, free fatty acids and creatinine when the body weights were recorded. Collected blood samples were quickly centrifuged for 15 min by 3,000 rpm at 4℃. Then, the serum samples were transferred to 1.5 ml plastic tubes by pipette and stored at –20℃

until later analysis. The blood urea nitrogen (BUN), glucose, triglyceride, free fatty acids and creatinine concentration was analyzed using blood analyzer (Cobas 8000, Roche, Germany).

Digestibility trial

A total of 12 crossbred barrows, averaging 32.08 ± 1.773 kg body weight, were allotted to individual metabolic crate () in completely randomized design (CRD) with 3 replicates to evaluate the nutrient digestibility and nitrogen retention. Experimental diets of growing phase (HP: 18% crude protein, MHP: 17% crude protein, MLP: 16.5% crude protein, LP: 15.68% crude protein) were provided to each treatment animals. Total collection method was used for the apparent nutrient digestibility. After a 5 days adaptation period, 5 days of collection period was followed. To determine the first and last day of collection days, 5% of ferric oxide and chromium oxide were added in the first and last experimental diet as selection marker, respectively. During the experimental period, water was provided *ad libitum* and all pigs were fed a daily level of 1.6 times the estimated maintenance requirement for energy (i.e. 106 kcal of ME per kg of $BW^{0.75}$; NRC, 1998). Total urine was collected daily in a plastic container containing 50 ml of 4 N H_2SO_4 to avoid nitrogen evaporation and frozen during the 5 days of collection period for nitrogen retention analysis. Collected feces and urine samples were stored –20 ℃ until analysis.

Pork quality and carcass characteristics

At the end of experiment, 4 pigs from each treatment group were slaughtered for the carcass analysis. *Longissimus muscles* were collected from nearby 10th rib on right side of carcass. Because of chilling procedure, 30 minutes after slaughter was regarded as initial time. The pH and meat color were measured at 0, 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 determined by CIE color L*, a* and b* value using a CR300 (Minolta Camera Co., Japan). Proximate of pork samples were analyzed by the method of AOAC (2005).

Centrifuge method was used for measuring water holding capacity of pork (Abdullah and Najdawi, 2005). *Longissimus muscle* samples were grounded and sampled in filter tube, and heated in water bath at 80℃ for 20 min and centrifuged for 10 min at 2,000 rpm and 10℃ (Eppendorf centrifuge 5810R, Germany). Then after that, to calculate the cooking loss, *longissimus muscles* were packed with polyethylene bag and heated in water bath until core temperature reached 72℃ and weighed before and after cooking. After heated, samples were cored (0.5 inch in diameter) parallel to muscle fiber and the cores were used to measure the shear force using as alter (Warner Bratzler Shear, USA). Cooking loss, shear force, and water holding capacity of pork were analyzed by animal origin food science, Seoul National University.

Fatty acid composition

Lipids in pork samples were extracted from duplicate 10 g samples with chloroform : methanol (2.1, v/v) (Folch et al., 1957) and shaking incubator (25℃, 120 rpm) for 24 hours. Extracted lipids 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 N2 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 then repeated heating process one more time. After then, 2 mL of iso-octane and 1 mL saturated NaCl was added, centrifuged at 2500 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. Collected excreta were pooled and dried in an air-forced drying oven at 60°C for 72 h, and ground into 1 mm particles in a Wiley mill for chemical analysis. Experimental diet and excreta samples were analyzed for contents of dry matter (procedure 930.15; AOAC, 1995), ash (procedure 942.05; AOAC, 1995), ether extract (procedure 920.39; AOAC, 1995), N by using the Kjeldahl procedure with Kjeltec (KjeltecTM 2200, Foss Tecator, Sweden). Experimental diet and excreta samples were analyzed for contents of CP content (nitrogen × 6.25; procedure 988.05; AOAC, 1995).

Economic analysis

As the experimental pigs were reared in the same environmental condition, economic analysis was calculated using only the feed cost without considering other factors. The total feed cost (Won) per body weight gain (kg) was calculated using 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 22 weeks.

Statistical analysis

The experimental data was analyzed as a randomized complete block design using the general linear model (GLM) procedure of SAS.

For data on growth performance, fecal score and economic analysis a pen was considered as an experimental unit, while individual pig was used as an unit for data on blood profile, nutrient digestibility and pork quality. Linear and quadratic effects for equally spaced treatments were assessed by measurement of orthogonal polynomial contrast. The differences were declared significant at $P<0.05$ or highly significant at $P<0.01$.

Results and Discussion

Growth performance

The effect of low crude protein (CP) and L-valine supplementation in weaning diet on growth performance was presented in Table 7. Reducing CP level showed effect on body weight (BW), average daily gain (ADG), average daily feed intake (ADFI) and gain/feed ratio (G/F ratio) especially during growing period. The body weight tended to decrease linearly with decreasing levels of CP in diet (linear, $P=0.06$), while BW decreased linearly in the late growing period (linear, $P<0.05$). However, there was no significant difference at final BW. ADG showed quadratic response in the growing period (quadratic, $P<0.05$), but there was no significant effect on ADG in the whole experimental period. ADFI decreased as the crude protein level decreased during the early growing period (linear, $P<0.05$) and tended to decrease linearly in the growing period (7-14 week; linear, $P=0.06$). G/F ratio showed the highest in MLP treatment ($P<0.05$) and increased with linear response in late finishing period (linear, $P<0.05$). In many of previous studies, there was no negative effect on growth performance, even when the amount of CP was reduced (Wahlstrom and Libal, 1983; Tjong et al., 1972; Carpenter et al., 2004). In addition, some researchers reported that the low CP diet with balanced amino acid may boost feed intake (Le Bellego and Noblet, 2002; Fabian et al., 2002). However, in present study, there was a negative effect on BW, ADG and ADFI in the growing period. According to Teye et al. (2006) and Ruusunen et al. (2007), it has been reported that reduction of CP had a negative effect on growth rate. We observed that the negative effect of low CP was not found in the finishing period. It was the result of the compensatory growth. Fabian et al. (2004) reported that growth retardation by low CP could be recovered by compensatory growth. The restriction period was the growing period because of decreased feed intake. As the feed intake recovered in finishing period, there was no difference in the final weight because the compensatory growth was achieved in the finishing period. Therefore, the results of present study suggested that the reduction of CP up to the level of NRC (2012) did not show a detrimental effect from weaning to finishing period.

The effect of L-valine supplementation in weaning diet did not occur in the weaning period but the ADG was increased in the growing period ($P<0.05$) and the final BW was increased ($P<0.05$). Feed intake of LPV- group was significantly decreased in the late growing period ($P<0.05$), but the G/F ratio did not show a significant difference. According to the Gloaguen et al. (2011), pigs fed valine deficient diet was showed decreased feed intake. In addition, some researchers reported that consumption of feed with poor amino acid balance was reduced (Maurin et al., 2005; Hao et al., 2005). However, in the present study, no significant difference was observed in weaning period but there was a negative effect on the growth performance in the growing period supplied by identical feed. LPV- treatment also should have undergone compensatory growth due to increased feed intake and fulfillment of the Val requirement from the finishing period, but the compensatory growth was incomplete. The incomplete compensatory growth pattern was obtained from many other researchers (Gilster and Wahlstrom, 1973; Zimmerman and Khajarern, 1973; Campbell and Biden, 1978; Hogberg and Zimmerman, 1978; Wahlstrom and Libal, 1983). Therefore, the supplementation of L-valine can prevent incomplete compensatory growth caused by valine deficiency.

Consequently, when CP level was reduced in weaning diet, L-valine supplementation in the diet showed improved the growth performance of weaning to finishing pigs by satisfying the ideal amino acid profiles.

Fecal score

The effect of low CP and L-valine supplementation in weaning diet on fecal score was presented in Table 8. Reducing CP level in weaning diet did not show significant differences in fecal consistency. In addition, L-valine supplementation into low CP diet did not effect on fecal consistency. However, fecal consistency tended to decrease linearly as CP level was reduced (linear, $P<0.10$). Heo et al. (2014) reported that reducing CP level in weaning diet decreased fecal consistency because protein fermentation by proteolytic bacteria in the hindgut decreased. Opapeju et al. (2009) demonstrated that the number of ETEC K88 in the small and large intestine digesta was reduced in low CP diet. However, present study did not show significant effect of low CP diet on fecal score. Although weaning piglets recovered from post-weaning syndrome and developed intestinal function normally in late weaning phase (van Beers-Schreurs et al., 1992), fecal score in present study was not recovered until late weaning phase because of heat stress. Lambert (2008) and Pearce et al. (2013) mentioned that heat stress reduced intestinal barrier integrity and increased intestinal permeability. So, it could cause endotoxemia and diarrhea.

In conclusion, reducing CP level and L-valine supplementation in weaning diet has no effect on fecal consistency compared with high protein diet and low protein diet without L-valine supplementation respectively.

Blood profiles

The effect of low CP and L-valine supplementation in weaning diet on blood profiles such as blood urea nitrogen (BUN), creatinine, glucose, free fatty acid (FFA) and triglyceride (TG) were shown in Table 9 (weaning phase) and Table 10 (growing-finishing phase). The BUN concentration was usually used as and indicator of excessive amino acids which are inefficiently metabolized and released into the blood (Jeong et al., 2010). The BUN concentration not only showed significant differences among treatments during 2 week, 6 week and 18 week but also linearly decreased as dietary CP decreased during weaning to finishing period except for 14 week (linear, $P<0.05$). These results was in agreement with other authors (Yang et al., 2000; Mejia-Guadarrama et al., 2002). It suggested that high CP diet had excessive amino acids content for pigs and low CP diet was used more efficiently than high CP diet. However, LPV- group showed higher BUN concentration than LP group. LPV- group had unbalanced amino acid content due to valine deficiency and disproportion among amino acids increased BUN concentration (Fernandez-Figares et al., 2007). It restricted availability of amino acids for protein synthesis and caused more generation of urea nitrogen due to degradation of surplus amino acids. Namely, low CP diet with L-valine supplementation in weaning diet showed higher availability of amino acids for protein synthesis.

Blood creatinine is mainly used as an index for presuming body muscle content because it is released into blood in amounts proportional to muscle content (Rassin and Bhatia, 1992). Namely, Blood creatinine has positive correlation with content of total muscle (Baxmann, 2008) and striated muscle (Schultte, 1981). However, any difference among treatments was not detected in this study, so we can conclude that both CP level and L-valine supplementation in weaning diet did not affect on muscle production during weaning to finishing pigs.

Metabolites such as free fatty acids (FFA), glucose and triglyceride (TG) were not influenced by dietary CP level. Guo et al., (2011) suggested that low CP diet stimulated synthesis of TG in muscle using FFA and glycerol. However, blood FFA and TG concentration showed not significant difference among treatments and large fluctuations regardless of dietary CP level. TG concentration was in accordance with some researchers who reported poor correlations between plasma triglyceride concentration and tissue lipid content (Mersmann and MacNeil, 1985; Lukefahr et al., 1989). So it implicated that dietary CP level did not influence on blood concentration of FFA, glucose and TG. Like the dietary CP levels, L-valine supplementation also did not showed any difference. So it is concluded that low CP diet with L-valine supplementation in weaning diet did not affect on blood FFA, glucose and TG concentration.

In conclusion, reducing CP level and L-valine supplementation in weaning diet has positive effect increasing availability of amino acids in both weaning and growing-finishing period.

Nutrient digestibility

The effect of low CP and L-valine supplementation in weaning diet on nutrient digestibility and nitrogen retention were shown in Table 11. There was no significant difference among treatments in nutrient digestibility. Moreover, nitrogen retention also did not show significant difference among treatment. O'Connell et al. (2006) showed that nutrient digestibility of dry matter, crude protein and energy were not significantly different between high CP and low CP group. However, Numerous previous study showed that low CP diet had higher nitrogen retention or lower nitrogen excretion value than high CP diet (Kay and Lee, 1997; Richert and Sutton, 2000; Otto et al., 2002). On the other hand, Gatel and Grosjean (1992) indicated that when lowering dietary CP level in diet the reduction of nitrogen excretion was observed only in urinary. In present study, it was thought that the nitrogen emission was decreased as the CP level decreased, but the results showed no significant difference nitrogen balance. Although BUN concentration showed significant difference among treatment suggesting the availability of amino acids was improved, but urinary nitrogen resulted from urea showed no significant difference. However, the experimental feed used in digestibility trial was stored for about 6 month. It might cause a decay of experimental feed and affect on nutrient digestibility and nitrogen excretion. Consequently, lowering dietary CP level down to

NRC (2012) requirement with L-valine supplementation had no detrimental effect on nutrient digestibility and nitrogen excretion.

Carcass characteristics

The effect of low crude protein and L-valine supplementation in weaning diet on carcass characteristics was presented in Table 12. From the results of proximate analysis, no significant difference was found in moisture, crude protein and crude ash of pork. However, crude fat content increased linearly with increasing crude protein content in the diet (linear, $P<0.05$). Deng et al. (2007) and Friesen et al. (1994) reported that compensatory growth was caused by variations in decreasing the rate of protein synthesis and increasing the ratio of energy stored as fat. In addition, Kamalakar et al. (2009) reported that compensatory growth was related with fatness, IMF content and tenderness in pork. Meanwhile, many of preceding research have shown that fat accumulation was increased when the crude protein level of feed was reduced (Kerr et al., 1995; Tuitoek et al., 1997; Adeola and Young, 1989; Bereskin et al., 1990; Karlsson et al., 1993; Chiba et al., 2002). It is believed that the surplus energy not used for protein accumulation due to limitation of protein or amino acids was stored as a fat (Teye et al., 2006). In addition, when the crude protein content in feed decreased, the expression of genes such as H-FABP and PPARr involved in TAG synthesis is increased (Guo et al., 2011) and lipogenic enzymes were more easily expressed in muscle (Doran et al., 2006). Similar to these results, present study showed that the fat content of pork increased as the crude protein content in the diets decreased. Consequently, low protein diet could increase fat accumulation in muscle.

Physicochemical analysis of pork showed no significant difference in cooking loss and shear force. Some researchers insisted that the elevated fat content of pork not only increased the juiciness and tenderness but also improved the meat quality (Ruiz et al., 2002). Fat content increased with linear response (linear, $P<0.05$), but there was no significant difference in shear force. It is considered that the difference in crude fat content was insignificant, so did not contribute to tenderness. However, WHC decreased linearly as the crude protein content of feed decreased (linear, $P<0.05$). WHC is affected by pH, ionic strength and protein oxidation (Huff-Lonergan and Lonergan, 2005). As shown in Table 13, pH decreased with decreasing crude protein content of feed (linear, $P<0.05$). Therefore, in present study, WHC was linearly decreased due to reduced pH.

Glycogen stored in the muscle, resulted in the production of lactic acid through glycolysis, which caused a drop in pH (Huff-Lonergan and Lonergan, 2005). M. Ruusunen et al., (2007) and Katsumata et al. (2003) found that the pH of pork fed low lysine diet decreased due to increased glycolytic potential. Similarly there was a linear decrease in pH as crude protein level decreased (linear, $P<0.05$). This decrease in pH seems to have a direct impact on WHC reduction.

The effect of low crude protein and L-valine supplementation on weaning diet on meat color (CIE value) was presented in Table 14. As the crude protein content of feed decreased, the Hunter L* value of pork increased linearly with significant difference ($P<0.05$). The current result was in agreement with the report of Suárez-Belloch et al. (2016) and Teye et al. (2006) which showed that Hunter L* value increased with decreasing crude protein content in the feed. Therefore, reduction of pH decreased WHC and then it caused water exudation from pork. Finally Hunter L* value increased by the increased reflection of light due to exudation of water. Suárez-Belloch et al. (2016) also mentioned that moderate elevation of Hunter L* value can improve some visual attributes providing higher lightness.

Low protein diets increased the Hunter b* values of muscle (Goerl et al., 1995), which is coincidence of the result of this study. The Hunter b* value has been related to marbling (Suárez-Belloch et al. 2016). Similarly, elevated crude fat of pork was contributed to increasing Hunter b* value. However, some researchers have found no significant difference of low protein or lysine diets on meat color (Cisneros et al., 1996; Witte et al., 2000).

As a result, reducing the CP content in the feed increased fat content, meat color (Hunter L* and b* value) and also decreased pH and WHC in *longissimus muscle*, but did not result in degradation of the pork quality.

Fatty acid composition

The effect of low crude protein and L-valine supplementation on weaning diet on fatty acid composition in *longissimus muscle* was presented in Table 15. The concentration of C16:0 was linearly increased as crude protein levels was decreased (linear, $P<0.04$). According to report of Wang et al. (2012), lipogenesis genes such as

SREBP-1c, ACC and FAS were up-regulated in pigs fed low CP diet. Wood et al. (1998) mentioned that low protein diet could restrict protein deposition and the energy which would have been used for protein synthesis is stored as a fat. Thus, low CP diet may increased lipogenesis and palmitic acids (C16:0) a product of fatty acid synthesis. The concentration of C16:1 showed a significant difference among treatments and was highest in MLP. Moreover, the concentration of C18:1 also showed a significant difference among treatments and was increased linearly as crude protein level was reduced. It maybe caused by elevated expression of SCD gene related with conversion from C16:0 and C18:0 into C16:1 and C18:1 respectively. Doran et al. (2006) and Wang et al. (2012) showed positive correlation concentration of C18:1 with expression level of SCD gene. Additionally, it contributed to linearly increased concentration of MUFA (linear, $P<0.05$). Zhang et al. (2007) demonstrated that PUFA and MUFA increased hepatic low-density lipoprotein (LDL) receptor activity, thereby reducing circulating LDL-cholesterol contributing cardiovascular risk.

Consequently, reducing crude protein level in pigs diet lead to more lipogenesis and linearly increased concentration MUFA such as C16:1, C18:1 and C20:1. However, total fatty acids did not show significant difference among treatments.

Economic analysis

The effect of low crude protein and L-valine supplementation on weaning diet on feed cost, days to reaching 110kg body weight were presented in Table 16. There was significant difference in feed cost per weight gain during 7-10 week, 15-18 week, 0-22 week according to effect of dietary crude protein levels ($P<0.05$, $P<0.01$, $P<0.05$, respectively). Also, as crude protein level decreased, feed cost per weight gain was linearly reduced during 15-18 week, 19-22 week and 0-22 week (linear, $P<0.01$). The saving cost effect of feed cost per weight gain was especially prominent in the finishing period. It is interpreted that the nutrient supply is sufficient even with low protein diet during the finishing period. The total feed cost per pig was reduced linearly during 7-10 week as crude protein levels was decreased (linear, $P<0.05$). In addition, total feed cost for market weight showed significant difference ($P<0.05$), and linearly decreased as the crude protein content decreased (linear, $P<0.05$). This reduction in feed costs is due to lower surplus protein sources such as SBM. The total feed cost for market weight of LP treatment was lower about 7,043 won than that of HP treatment. On the other hand, there was no significant difference in days to market weight.

The effect of L-valine supplementation on weaning diet on economic analysis was less than that of dietary protein levels. Rather, supplementing L-valine resulted in numerically higher feed cost per weight gain and total feed cost per pig. However, the addition of L-valine resulted in numerical shortening of the days to market weight by 8 days. It is more economical to supplement L-valine because the extra feed costs caused by adding L-valine are lower than the costs incurred due to delayed days to market weight.

As a result, lowering CP level in the diet showed reduce of the feed cost per weight gain and total feed cost. The addition of L-valine increased feed costs, but shortened days to market weight with economical effect. Therefore, reducing crude protein levels in the feed up to level of NRC (2012) with L-valine supplementation was the most economical feed strategy in this study.

Conclusion

Dietary CP level had negative impact on growth performance during growing period. but this negative effect was compensated completely during finishing periods. On the other hand, L-valine supplementation had positive effect on growth performance. Crystalline valine-free diet underwent incomplete compensatory growth. There was no significant difference in fecal score among treatments. Reducing CP level and L-valine supplementation in weaning diet showed positive effect on BUN concentration in both weaning and growing-finishing period. Nutrient digestibility and nitrogen balance showed no significant difference. Low CP group had lower pH, WHC and higher crude fat content, MFUA concentration and Hunter L*, b* value than high CP group in *longissimus muscle*. Additionally, low CP with L-valine supplementation improve economical profits due to reduced total feed cost and days to market weight. Consequently, lowering dietary CP level down to NRC (2012) had no negative effect on growth performance, fecal consistency, blood profile, nutrient digestibility, carcass characteristics and economic analysis in weaning to finishing pigs. Moreover, when lowering the dietary CP level, it is desirable to consider supplementing L-valine.

Table 1. Formula and chemical compositions of the experimental diets in phase I (1 to 2 weeks)

	Treatments[1]				
	HP	MHP	MLP	LP	LPV-
Ingredient, %					
Ground corn	29.95	32.18	33.45	37.32	36.96
SBM, 45%	38.58	35.35	33.78	28.58	28.92
Soypeptide	4.00	4.00	4.00	4.00	4.00
Wheat	11.80	12.34	12.45	13.07	13.20
Whey powder	4.00	4.00	4.00	4.00	4.00
Lactose	8.00	8.00	8.00	8.00	8.00
Soy oil	0.50	0.47	0.45	0.40	0.49
MDCP	1.26	1.32	1.34	1.44	1.43
Limestone	1.09	1.09	1.09	1.08	1.08
DL-methionine, 80%	0.10	0.12	0.12	0.15	0.15
Vit. Mix[2]	0.10	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30
L-threonine, 99%	0.01	0.07	0.09	0.17	0.17
L-lysine-HCl, 78%	0.21	0.32	0.37	0.54	0.53
Tryptophan	0.00	0.18	0.27	0.57	0.57
Valine	0.00	0.06	0.09	0.18	0.00
Sum	100.00	100.00	100.00	100.00	100.00
Chemical composition					
ME, kcal/kg[4]	3,265.02	3,265.03	3,265.00	3,265.05	3,265.04
Crude protein, %[4]	23.70	22.70	22.20	20.56	20.56
Crude protein, %[5]	22.14	21.47	21.08	21.42	21.48
Crude fat[5]	1.04	1.05	1.28	1.36	1.42
Crude ash[5]	6.18	7.13	6.30	7.28	6.20
Lysine, %[4]	1.53	1.53	1.53	1.53	1.53
Methionine, %[4]	0.44	0.44	0.44	0.44	0.44
Ca, %[4]	0.80	0.80	0.80	0.80	0.80
P, %[4]	0.65	0.65	0.65	0.65	0.65

[1] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement, LPV-: LP without valine supplementation

[2] Provided the following quantities of vitamins per kg of complete diet : vitamin A, 8,000 IU; vitamin D3, 1,800IU; vitamin E, 60IU; thiamine, 2mg; riboflavin, 7mg; calcium pantothenic acid, 25mg; niacin, 27mg; pyridoxine, 3mg; biotin, 0.2mg; folic acid, 1mg; vitamin B12, 0.03mg

[3] Provided the following quantities of minerals per kg of complete diet : Se, 0.3mg; I, 1mg; Mn, 51.6mg; CuSO4, 105mg; Fe, 150mg; Zn, 72mg; Co, 0.5mg

[4] Calculated value

[5] Analyzed value

Table 2. Formula and chemical compositions of the experimental diets in phase II (4 to 6 weeks)

	Treatments[1]				
	HP	MHP	MLP	LP	LPV-
Ingredient, %					
Ground corn	42.97	45.58	46.76	48.13	48.00
SBM, 45%	30.11	26.93	25.33	23.70	23.94
Soypeptide	4.00	4.00	4.00	4.00	4.00
Wheat	13.40	13.54	13.76	13.80	13.77
Whey powder	2.00	2.00	2.00	2.00	2.00
Lactose	4.00	4.00	4.00	4.00	4.00
Soy oil	0.44	0.40	0.38	0.36	0.42
MDCP	1.13	1.19	1.21	1.25	1.24
Limestone	0.97	0.97	0.97	0.96	0.97
DL-methionine, 80%	0.09	0.11	0.11	0.12	0.12
Vit. Mix[2]	0.10	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30	0.30
L-threonine, 99%	0.06	0.11	0.13	0.16	0.16
L-lysine-HCl, 78%	0.33	0.44	0.50	0.55	0.54
Tryptophan	0.00	0.17	0.26	0.35	0.34
Valine	0.00	0.06	0.09	0.12	0.00
Sum	100.00	100.00	100.00	100.00	100.00
Chemical composition					
ME, kcal/kg[4]	3,265.03	3,265.04	3,265.00	3,265.00	3,265.00
Crude protein, %[4]	20.90	19.90	19.40	18.88	18.88
Crude protein, %[5]	24.34	20.92	20.98	20.96	18.76
Crude fat[5]	1.55	1.49	2.20	1.26	1.77
Crude ash[5]	5.84	5.75	4.45	5.55	4.41
Lysine, %[4]	1.40	1.40	1.40	1.40	1.40
Methionine, %[4]	0.40	0.40	0.40	0.40	0.40
Ca, %[4]	0.70	0.70	0.70	0.70	0.70
P, %[4]	0.60	0.60	0.60	0.60	0.60

[1] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement, LPV-: LP without valine supplementation

[2] Provided the following quantities of vitamins per kg of complete diet : vitamin A, 8,000 IU; vitamin D3, 1,800IU; vitamin E, 60IU; thiamine, 2mg; riboflavin, 7mg; calcium pantothenic acid, 25mg; niacin, 27mg; pyridoxine, 3mg; biotin, 0.2mg; folic acid, 1mg; vitamin B12, 0.03mg

[3] Provided the following quantities of minerals per kg of complete diet : Se, 0.3mg; I, 1mg; Mn, 51.6mg; CuSO4, 105mg; Fe, 150mg; Zn, 72mg; Co, 0.5mg

[4] Calculated value

[5] Analyzed value

Table 3. Formula and chemical compositions of the experimental diets in phase III (7 to 10 weeks)

	Treatments[1]			
	HP	MHP	MLP	LP
Ingredient, %				
Ground corn	53.96	56.72	58.05	60.23
SBM, 45%	27.25	24.24	22.72	20.21
Wheat	10.03	10.02	9.99	9.98
Palm kernel meal	4.04	4.03	4.04	4.07
Tallow	1.83	1.80	1.80	1.79
MDCP	1.04	1.08	1.12	1.16
Limestone	0.96	0.96	0.96	0.96
DL-methionine, 80%	0.04	0.05	0.06	0.08
Vit. Mix[2]	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
L-threonine, 99%	0.02	0.07	0.09	0.13
L-lysine-HCl, 78%	0.23	0.33	0.39	0.47
Tryptophan	0.00	0.10	0.18	0.32
β-mannanase	0.10	0.10	0.10	0.10
Sum	100.00	100.00	100.00	100.00
Chemical composition				
ME, kcal/kg[4]	3,265.04	3,265.05	3,265.01	3,265.02
Crude protein, %[4]	18.00	17.00	16.50	15.68
Crude protein, %[5]	18.11	16.13	16.60	15.27
Crude fat[5]	3.21	3.65	4.23	3.63
Crude ash[5]	6.18	7.13	7.28	6.30
Lysine, %[4]	1.12	1.12	1.12	1.12
Methionine, %[4]	0.32	0.32	0.32	0.32
Ca, %[4]	0.66	0.66	0.66	0.66
P, %[4]	0.56	0.56	0.56	0.56

[1] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement, LPV-: LP without valine supplementation

[2] Provided the following quantities of vitamins per kg of complete diet : vitamin A, 8,000 IU; vitamin D3, 1,800 IU; vitamin E, 80 IU; thiamine, 2 mg; riboflavin, 7 mg; calcium pantothenic acid, 30 mg; niacin, 30 mg; pyridoxine, 3 mg; biotin, 0.2 mg; folic acid, 1 mg; vitamin B12, 0.10 mg

[3] Provided the following quantities of minerals per kg of complete diet : Se, 0.15 mg; I, 0.5 mg; Mn, 25.80 mg; CuSO4, 52.50 mg; Fe, 75 mg; Zn, 36 mg; Co, 0.25mg

[4] Calculated value

[5] Analyzed value

Table 4. Formula and chemical compositions of the experimental diets in phase IV (11 to 14 weeks)

	Treatments[1]			
	HP	MHP	MLP	LP
Ingredient, %				
Ground corn	58.95	61.51	62.86	65.63
SBM, 45%	22.85	19.80	18.28	15.09
Wheat	10.00	10.00	10.00	10.00
Palm kernel meal	3.96	4.11	4.08	4.11
Tallow	1.64	1.64	1.63	1.62
MDCP	0.92	0.96	1.00	1.05
Limestone	0.87	0.87	0.86	0.86
DL-met, 80%	0.02	0.03	0.04	0.05
Vit. Mix[2]	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
L-threonine, 99%	0.00	0.05	0.08	0.13
L-lysine-HCl, 78%	0.19	0.29	0.34	0.45
Tryptophan	0.00	0.14	0.23	0.41
β-mannanase	0.10	0.10	0.10	0.10
Sum	100.00	100.00	100.00	100.00
Chemical composition				
ME, kcal/kg[4]	3,265.02	3,265.06	3,265.05	3,265.06
Crude protein, %[4]	16.30	15.30	14.80	13.75
Crude protein, %[5]	15.82	15.02	14.64	14.27
Crude fat[5]	4.29	5.20	4.59	5.50
Crude ash[5]	6.20	5.84	5.75	5.55
Lysine, %[4]	0.97	0.97	0.97	0.97
Methionine, %[4]	0.28	0.28	0.28	0.28
Ca, %[4]	0.59	0.59	0.59	0.59
P, %[4]	0.52	0.52	0.52	0.52

[1] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement, LPV-: LP without valine supplementation

[2] Provided the following quantities of vitamins per kg of complete diet : vitamin A, 8,000 IU; vitamin D3, 1,800 IU; vitamin E, 80 IU; thiamine, 2 mg; riboflavin, 7 mg; calcium pantothenic acid, 30 mg; niacin, 30 mg; pyridoxine, 3 mg; biotin, 0.2 mg; folic acid, 1 mg; vitamin B12, 0.10 mg

[3] Provided the following quantities of minerals per kg of complete diet : Se, 0.15 mg; I, 0.5 mg; Mn, 25.80 mg; $CuSO_4$, 52.50 mg; Fe, 75 mg; Zn, 36 mg; Co, 0.25mg

[4] Calculated value

[5] Analyzed value

Table 5. Formula and chemical compositions of the experimental diets in phase V (15 to 18 weeks)

	Treatments[1]			
	HP	MHP	MLP	LP
Ingredient, %				
Ground corn	58.95	61.51	62.86	65.63
SBM, 45%	22.85	19.80	18.28	15.09
Wheat	10.00	10.00	10.00	10.00
Palm kernel meal	3.96	4.11	4.08	4.11
Tallow	1.64	1.64	1.63	1.62
MDCP	0.92	0.96	1.00	1.05
Limestone	0.87	0.87	0.86	0.86
DL-methionine, 80%	0.02	0.03	0.04	0.05
Vit. Mix[2]	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
L-threonine, 99%	0.00	0.05	0.08	0.13
L-lysine-HCl, 78%	0.19	0.29	0.34	0.45
Tryptophan	0.00	0.14	0.23	0.41
β-mannanase	0.10	0.10	0.10	0.10
Sum	100.00	100.00	100.00	100.00
Chemical composition				
ME, kcal/kg[4]	3,265.03	3,265.05	3,265.01	3,265.01
Crude protein, %[4]	15.50	14.50	14.00	12.13
Crude protein, %[5]	15.69	15.78	15.01	12.83
Crude fat[5]	3.50	4.62	4.58	4.61
Crude ash[5]	4.45	4.41	4.88	4.04
Lysine, %[4]	0.84	0.84	0.84	0.84
Methionine, %[4]	0.26	0.26	0.26	0.26
Ca, %[4]	0.52	0.52	0.52	0.52
P, %[4]	0.47	0.47	0.47	0.47

[1] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement, LPV-: LP without valine supplementation

[2] Provided the following quantities of vitamins per kg of complete diet : vitamin A, 8,000 IU; vitamin D3, 1,800 IU; vitamin E, 80 IU; thiamine, 2 mg; riboflavin, 7 mg; calcium pantothenic acid, 30 mg; niacin, 30 mg; pyridoxine, 3 mg; biotin, 0.2 mg; folic acid, 1 mg; vitamin B12, 0.10 mg

[3] Provided the following quantities of minerals per kg of complete diet : Se, 0.15 mg; I, 0.5 mg; Mn, 25.80 mg; $CuSO_4$, 52.50 mg; Fe, 75 mg; Zn, 36 mg; Co, 0.25mg

[4] Calculated value

[5] Analyzed value

Table 6. Formula and chemical compositions of the experimental diets in phase VI (19 to 22 weeks)

	Treatments[1]			
	HP	MHP	MLP	LP
Ingredient, %				
Ground corn	67.90	70.59	71.86	75.21
SBM, 45%	14.66	11.64	10.11	6.23
Wheat	10.00	9.97	9.97	9.96
Palm kernel meal	4.09	4.09	4.16	4.20
Tallow	1.28	1.27	1.27	1.26
MDCP	0.62	0.67	0.70	0.77
Limestone	0.72	0.73	0.72	0.72
DL-methionine, 80%	0.00	0.01	0.02	0.04
Vit. Mix[2]	0.10	0.10	0.10	0.10
Min. Mix[3]	0.10	0.10	0.10	0.10
Salt	0.30	0.30	0.30	0.30
L-threonine, 99%	0.00	0.05	0.07	0.14
L-lysine-HCl, 78%	0.13	0.23	0.28	0.41
Tryptophan	0.00	0.15	0.24	0.46
β-mannanase	0.10	0.10	0.10	0.10
Sum	100.00	100.00	100.00	100.00
Chemical composition				
ME, kcal/kg[4]	3,265.04	3,265.01	3,265.01	3,265.00
Crude protein, %[4]	13.20	12.20	11.70	10.43
Crude protein, %[5]	14.49	13.60	12.62	11.10
Crude fat[5]	4.77	5.25	5.08	5.42
Crude ash[5]	3.82	3.76	4.97	3.96
Lysine, %[4]	0.71	0.71	0.71	0.71
Methionine, %[4]	0.23	0.23	0.23	0.23
Ca, %[4]	0.46	0.46	0.46	0.46
P, %[4]	0.43	0.43	0.43	0.43

[1] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement, LPV-: LP without valine supplementation

[2] Provided the following quantities of vitamins per kg of complete diet : vitamin A, 8,000 IU; vitamin D3, 1,800 IU; vitamin E, 80 IU; thiamine, 2 mg; riboflavin, 7 mg; calcium pantothenic acid, 30 mg; niacin, 30 mg; pyridoxine, 3 mg; biotin, 0.2 mg; folic acid, 1 mg; vitamin B12, 0.10 mg

[3] Provided the following quantities of minerals per kg of complete diet : Se, 0.15 mg; I, 0.5 mg; Mn, 25.80 mg; $CuSO_4$, 52.50 mg; Fe, 75 mg; Zn, 36 mg; Co, 0.25mg

[4] Calculated value

[5] Analyzed value

Table 7. Influences of low crude protein and valine supplementation in weaning diet on growth performance of weaning to finishing pigs

Criteria	Treatments					SEM[1]	P-value[2]	
	HP	MHP	MLP	LP	LPV-		Lin.	Quad.
Body weight, kg								
Initial	7.86	7.86	7.86	7.86	7.86	0.231	-	-
2 wk	9.57	9.61	9.76	9.76	10.33	0.317	0.44	0.81
6 wk	19.46	19.26	19.11	18.49	18.85	0.550	0.34	0.66
10 wk	37.44^{a}	37.23^{ab}	37.94^{a}	34.32^{b}	34.19^{b}	0.887	0.06	0.08
14 wk	57.85^{A}	57.90^{A}	57.63^{A}	53.97^{AB}	49.52^{B}	1.201	0.04	0.17
18 wk	78.63	78.66	79.62	76.89	72.75	1.369	0.45	0.48
22 wk	102.49^{A}	103.88^{A}	105.10^{A}	102.38^{A}	96.02^{B}	1.322	0.97	0.21
Average daily gain, g								
0-2 wk	123	125	136	136	177	8.6	0.46	0.82
3-6 wk	354	345	334	312	304	11.0	0.22	0.62
0-6 wk	276	272	268	253	262	8.9	0.30	0.76
7-10 wk	642^{A}	642^{A}	673^{A}	565^{B}	548^{B}	15.9	0.05	0.02
11-14 wk	729	638	703	702	547	23.2	0.51	0.90
7-14 wk	686^{A}	690^{A}	688^{A}	633^{A}	548^{B}	16.4	0.12	0.18
15-18 wk	770	769	814	849	861	23.5	0.14	0.92
19-22 wk	823	870	879	879	802	13.2	0.06	0.17
15-22 wk	797	821	848	865	831	11.5	0.10	0.41
0-22 wk	614^{a}	624^{a}	632^{a}	614^{a}	573^{b}	7.9	0.99	0.20
Average daily feed intake, g								
0-2 wk	320	286	306	295	338	12.5	0.51	0.54
3-6 wk	737	769	723	710	696	22.8	0.60	0.47
0-6 wk	598	608	584	572	577	17.8	0.46	0.72
7-10 wk	1,292	1,263	1,194	1,113	1,109	32.9	0.02	0.48
11-14 wk	1,882^{a}	1,835^{a}	1,757^{a}	1,735^{a}	1,478^{b}	45.2	0.15	0.85
7-14 wk	1,587^{a}	1,549^{ab}	1,475^{ab}	1,424^{bc}	1,294^{c}	35.2	0.06	0.87
15-18 wk	2,325	2,180	2,242	2,294	2,015	48.2	0.98	0.33
19-22 wk	2,823	2,780	2,856	2,775	2,732	36.1	0.78	0.82
15-22 wk	2,583	2,490	2,560	2,543	2,448	34.4	0.85	0.66
0-22 wk	1,679	1,635	1,627	1,598	1,493	24.9	0.23	0.82
G:F ratio								
0-2 wk	0.382	0.438	0.428	0.453	0.499	0.0084	0.10	0.43
3-6 wk	0.482	0.450	0.460	0.440	0.445	0.0110	0.33	0.87
0-6 wk	0.464	0.447	0.456	0.443	0.463	0.0108	0.58	0.94
7-10 wk	0.497^{b}	0.508^{b}	0.566^{a}	0.510^{b}	0.497^{b}	0.0084	0.22	0.07
11-14 wk	0.386	0.405	0.402	0.405	0.373	0.0105	0.58	0.75
7-14 wk	0.431	0.447	0.469	0.446	0.424	0.0072	0.39	0.26
15-18 wk	0.332	0.352	0.364	0.370	0.428	0.0110	0.09	0.39
19-22 wk	0.294	0.314	0.308	0.317	0.296	0.0070	0.25	0.64
15-22 wk	0.310	0.331	0.331	0.340	0.341	0.0060	0.04	0.35
0-22 wk	0.366	0.382	0.389	0.384	0.383	0.0028	0.06	0.09

[1] Standard error of means.
[2] LPV- was excluded in orthogonal polynomial analysis.
[a,b,c] Means with different superscripts in the same row significantly differ($P<0.05$).
[A,B] Means with different superscripts in the same row significantly differ($P<0.01$).

Table 8. Influences of low crude protein and valine supplementation in weaning diet on fecal consistency of weaning pigs

Criteria	Treatments[1]					SEM[2]	*P*-value[3]	
	HP	MHP	MLP	LP	LPV-		Lin.	Quad.
Fecal consistency[4]								
0-2 wk	1.27	1.29	1.21	1.13	1.07	0.097	0.08	0.41
3-6 wk	1.98	1.35	1.36	1.33	1.20	0.114	0.07	0.34
0-6 wk	1.71	1.33	1.30	1.14	1.04	0.096	0.07	0.57

[1] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement, LPV-: LP without valine supplementation

[2] Standard error of means.

[3] LPV- was excluded in orthogonal polynomial analysis.

[4] fecal consistency scoring index : 0, normal (feces firm and well formed); 1, soft consistency (feces soft and formed); 2, mild diarrhea (fluid feces, usually yellowish); and 3, severe diarrhea (feces watery and projectile).

Table 9. Influence of low crude protein and valine supplementation in weaning diet on blood profiles of weaning pigs[1]

Criteria	Treatment[2]					SEM[3]	*P*-value[4]	
	HP	MHP	MLP	LP	LPV-		Lin.	Quad.
Blood urea nitrogen, mg/dL								
2 week	19.55[A]	16.20[B]	14.80[B]	11.38[C]	13.78[BC]	0.739	<0.01	0.49
6 week	18.83[A]	16.43[AB]	16.40[AB]	11.38[C]	14.33[B]	0.762	<0.01	0.11
Creatinine, mg/dL								
2 week	0.72	0.76	0.67	0.65	0.76	0.027	0.36	0.82
6 week	0.77	0.79	0.77	0.66	0.70	0.023	0.27	0.20
Free fatty acid, μEq/L								
2 week	74.00	87.75	49.50	63.0	102.67	17.136	0.60	0.86
6 week	80.25	87.00	79.00	63.50	63.0	17.034	0.68	0.61
Glucose, mg/dL								
2 week	93.00	85.25	93.75	92.25	91.00	2.416	0.87	0.65
6 week	94.75	84.75	87.25	91.50	91.50	2.400	0.55	0.17
Triglyceride mg/mL								
2 week	40.23	30.75	29.50	35.50	42.25	2.995	0.54	0.12
6 week	42.50	31.25	32.25	35.75	42.05	2.983	0.42	0.34

[1] Least squares means for 4 pigs per treatment.
[2] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement, LPV-: LP without valine supplementation.
[3] Standard error of mean
[4] LPV- was excluded in orthogonal polynomial analysis.
[ABC] Means in a same row with different superscript letters significantly differ (P<0.01).

Table 10. Influence of low crude protein and valine supplementation in weaning diet on blood profiles of growing-finishing pigs[1]

Criteria	Treatment[2]				SEM[3]	*P*-value[4]	
	HP	MHP	MLP	LP		Lin.	Quad.
Blood urea nitrogen, mg/dL							
10 week	12.75	14.08	9.08	8.15	0.963	0.03	0.36
14 week	11.20	9.15	9.95	7.78	0.571	0.07	0.97
18 week	17.15[A]	10.65[B]	10.35[BC]	6.25[C]	1.157	<0.01	0.11
22 week	9.65	8.35	8.05	4.60	0.747	0.03	0.56
Creatinine, mg/dL							
10 week	0.86	1.04	0.98	0.87	0.038	0.95	0.07
14 week	1.20	1.20	1.32	1.19	0.033	0.90	0.35
18 week	1.18	1.23	1.30	1.27	0.030	0.34	0.41
22 week	1.37	1.34	1.29	1.18	0.037	0.09	0.68
Free fatty acid, µEq/L							
10 week	92.50	88.67	88.50	70.00	6.806	0.42	0.68
14 week	167.75	84.75	64.75	114.00	12.230	0.67	0.25
18 week	85.00	155.50	92.25	90.00	11.146	0.65	0.18
22 week	121.00	195.75	64.00	134.75	11.920	0.70	0.09
Glucose, mg/dL							
10 week	92.75	90.50	87.75	99.25	2.342	0.43	0.15
14 week	84.25	91.75	92.75	85.25	1.492	0.80	0.20
18 week	88.00	82.75	91.75	90.00	1.901	0.55	0.89
22 week	89.50	92.25	93.50	87.75	2.007	0.77	0.36
Triglyceride mg/mL							
10 week	58.50	63.00	60.50	66.25	4.675	0.63	0.94
14 week	60.50	83.00	66.00	61.75	5.509	0.89	0.27
18 week	75.25	61.25	61.75	62.75	5.803	0.59	0.52
22 week	57.00	55.25	69.25	81.00	7.456	0.23	0.73

[1] Least squares means for 4 pigs per treatment.
[2] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement.
[3] Standard error of mean
[4] LPV- was excluded in orthogonal polynomial analysis.
[ABC] Means in a same row with different superscript letters significantly differ (P<0.01).

Table 11. Influence of low crude protein and valine supplementation in weaning diet on nutrient digestibility in growing pigs[1]

Criteria	Treatment[2]				SEM[3]	*P*-value	
	HP	MHP	MLP	LP		Lin.	Quad.
Nutrient digestibility, %							
Dry matter	87.92	90.73	83.33	86.34	1.079	0.31	0.93
Crude protein	84.63	87.35	77.40	81.29	1.493	0.21	0.80
Crude ash	68.89	72.43	50.02	58.70	3.516	0.15	0.66
Crude fat	81.20	81.64	69.25	77.55	2.195	0.33	0.34
Nitrogen retention, g/d							
N intake	79.96	76.48	75.33	74.19	0.652	-	-
Fecal N	12.29	9.67	17.03	13.89	1.104	0.34	0.87
Urinary N	16.42	13.12	16.63	13.75	0.759	0.41	0.90
Total N excretion	28.70	22.79	33.66	27.63	1.672	0.82	0.96
N retention[4]	51.26	53.70	41.67	46.56	1.836	0.17	0.68
N retention, %[5]	64.10	70.21	55.32	62.75	2.234	0.50	0.85

[1] Least squares means for 3 pigs per treatment. Initial BW : 32.08kg
[2] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement.
[3] Standard error of mean.
[4] N retention=N intake − Fecal N − Urinary N.
[5] N retention (%) = N retention / N intake × 100

Table 12. Influence of low crude protein and valine supplementation in weaning diet on carcass characteristics of *longissimus muscle*[1]

Criteria	Treatment[2]				SEM[3]	*P*-value	
	HP	MHP	MLP	LP		Lin.	Quad.
Proximate analysis, %							
Moisture	72.16	71.85	72.28	72.70	0.270	0.41	0.64
Crude protein	23.95	24.19	23.65	23.91	0.120	0.55	0.96
Crude fat	2.17	2.81	3.63	3.59	0.211	0.03	0.20
Crude ash	1.49	1.37	1.44	1.44	0.027	0.31	0.25
Physiochemical property							
Cooking loss, %	29.12	29.65	31.81	30.06	0.525	0.42	0.27
Shear force, kg/0.5 inch^2	52.46	60.01	62.89	57.34	2.701	0.61	0.34
WHC[4], %	73.39	73.58	72.08	69.50	0.701	0.04	0.32

[1] Least squares means for 4 pigs per treatment.
\[2] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement.
[3] Standard error of mean.
[4] Water holding capacity.

Table 13. Influences of low crude protein and valine supplementation in weaning diet on pH of *longissimus muscle* after slaughter[1]

Criteria	Treatments[2]				SEM[3]	*P*-value	
	HP	MHP	MLP	LP		Lin.	Quad.
Time after slaughter							
0 hour	6.07	5.97	5.91	5.75	0.069	0.09	0.97
3 hour	5.78	5.70	5.62	5.58	0.049	0.12	0.80
6 hour	5.59	5.55	5.56	5.43	0.034	0.07	0.73
12 hour	5.63	5.51	5.61	5.50	0.035	0.03	0.74
24 hour	5.69	5.58	5.60	5.50	0.032	0.03	0.60

[1] Least squares means for 4 pigs per treatment.
[2] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement.
[3] Standard error of means.

Table 14. Influences of low crude protein and valine supplementation in weaning diet on meat color of *longissimus muscle* after slaughter[1]

Criteria	Treatments[2]				SEM[3]	*P*-value	
	HP	MHP	MLP	LP		Lin.	Quad.
Hunter value, L[4]							
0 hour	37.69	39.70	40.87	43.16	0.814	0.03	0.97
3 hour	38.45[b]	41.80[ab]	42.73[ab]	45.99[a]	0.921	<0.01	0.85
6 hour	40.48	42.76	43.70	46.76	0.833	0.01	0.91
12 hour	42.58	44.73	45.67	48.10	0.723	0.01	0.97
24 hour	43.37[b]	46.45[ab]	45.76[b]	49.22[a]	0.777	<0.01	0.97
Hunter value, a*[5]							
0 hour	9.22	8.85	9.36	9.18	0.329	0.96	0.91
3 hour	10.18	9.55	11.05	10.51	0.352	0.59	0.99
6 hour	10.62	10.16	11.16	10.86	0.351	0.73	0.96
12 hour	12.06	11.66	12.03	12.04	0.376	0.96	0.83
24 hour	11.06	11.17	11.42	11.39	0.355	0.88	0.76
Hunter value, b*[6]							
0 hour	4.70	4.84	4.97	5.49	0.146	0.09	0.60
3 hour	4.99[b]	5.33[b]	5.69[ab]	6.25[a]	0.162	<0.01	0.83
6 hour	5.32	5.65	5.88	6.39	0.170	0.04	0.87
12 hour	5.69	5.87	6.02	6.44	0.146	0.11	0.76
24 hour	6.06	5.95	5.93	6.42	0.137	0.24	0.21

[1] Least squares means for 4 pigs per treatment.
[2] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement.
[3] Standard error of means.
[4] L - luminance or brightness (vary form black to white).
[5] a* - red·green component (+a=red, -a=green).
[6] b* - yellow·blue component (+b=yellow, -b=blue).
[a,b] Means with different superscripts in the same row significantly differ(P<0.05).

Table 15. Influences of low crude protein and valine supplementation in weaning diet on fatty acid composition of *longissimus muscle*[1]

Criteria	Treatments[2]				SEM[3]	*P*-value	
	HP	MHP	MLP	LP		Lin.	Quad.
Fatty acid composition, %							
C14:0	1.29[b]	1.30[b]	2.17[a]	1.59[b]	0.120	0.13	0.10
C16:0	36.99	36.64	50.13	47.51	2.253	0.04	0.63
C16:1	3.43[b]	3.26[b]	5.98[a]	4.08[b]	0.348	0.18	0.09
C17:0	1.40	1.01	1.35	1.74	0.091	0.08	0.04
C18:0	22.40	21.88	27.15	26.97	1.343	0.19	0.96
C18:1 n-9	45.20[bc]	41.62[c]	70.28[a]	58.65[ab]	3.712	0.03	0.32
C18:2 n-6	45.68	45.41	44.64	51.51	2.682	0.50	0.57
C18:3 n-6	0.56	0.54	0.56	0.72	0.037	0.11	0.25
C18:3 n-3	0.80	0.71	0.77	0.79	0.051	0.99	0.69
C20:1	0.71[bc]	0.59[c]	1.08[a]	0.91[ab]	0.062	0.04	0.57
C20:2	2.00	1.74	1.82	2.49	0.135	0.18	0.11
C21:0	2.77	2.74	2.62	3.45	0.175	0.19	0.25
C20:4 n-6	20.11	17.78	17.04	21.39	1.324	0.75	0.28
C20:5 n-3	0.70	0.56	0.55	0.76	0.046	0.60	0.10
C22:6 n-3	0.51	0.46	0.44	0.59	0.047	0.58	0.36
SFA[4]	64.85	63.56	83.43	81.25	3.786	0.07	0.83
UFA[5]	119.69	112.66	143.14	141.88	6.382	0.15	0.92
MUFA[6]	49.34[bc]	45.47[c]	77.35[a]	63.64[ab]	4.085	0.04	0.29
PUFA[7]	70.35	67.19	65.80	78.24	4.203	0.55	0.43
UFA/SFA ratio	1.84	1.76	1.72	1.75	0.020	0.12	0.18

[1]Least squares means for 4 pigs per treatment.

[2]HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement.

[3]Standard error of means

[a,b,c] Means with different superscripts in the same row significantly differ(P<0.05).

[4]SFA = saturated fatty acids

[5]UFA = unsturated fatty acids

[6]MUFA = monounsaturated fatty acids

[7]PUFA = polyunsturated fatty acids

Table 16. Influences of low crude protein and valine supplementation in weaning diet on economic benefits of weaning to finishing pigs

Criteria	Treatment[1]					SEM[2]	P-value[3]	
	HP	MHP	MLP	LP	LPV-		Lin.	Quad.
Feed cost per weight gain, won/kg								
0-2 wk	1,434	1,248	1,331	1,220	1,092	48.4	0.15	0.57
3-6 wk	965	1,033	1,024	1,052	1,041	25.2	0.33	0.82
7-10 wk	723[a]	698[a]	625[b]	687[a]	704[a]	11.1	0.08	0.07
11-14 wk	946	838	844	820	912	26.9	0.18	0.48
15-18 wk	1,066[A]	934[B]	899[B]	865[BC]	763[C]	27.7	<0.01	0.06
19-22 wk	1,193	990	995	955	1,030	28.1	<0.01	0.04
0-22 wk	1,054[a]	956[b]	953[b]	933[b]	924[b]	14.6	<0.01	0.04
Total feed cost per pig, won/head								
0-2 wk	2,437	2,179	2,329	2,253	2,649	88.6	0.53	0.55
3-6 wk	9,520	9,958	9,360	9,198	8,839	296.0	0.62	0.46
7-10 wk	12,998	12,527	11,778	10,879	10,846	340.3	<0.01	0.52
11-14 wk	18,047[A]	17,359[A]	16,537[A]	16,118[A]	13,731[B]	451.2	0.06	0.82
15-18 wk	20,851	19,304	19,726	19,744	17,339	445.8	0.49	0.32
19-22 wk	25,551	24,808	25,326	24,220	23,846	342.8	0.29	0.85
0-22 wk	89,404[a]	86,134[a]	85,056[a]	82,412[ab]	77,249[b]	1501.9	0.06	0.82
Total feed cost per pig, won/head (reached 110kg)								
	91,749[a]	88,017[ab]	86,554[abc]	84,706[bc]	81,457[c]	1208.7	0.03	0.55
Days to market weight (reached 110kg)								
	166	164	160	161	169	2.1	0.95	0.55

[1] HP: corn-SBM diet with NRC (1998) protein requirement, MHP: basal diet with NRC (1998) protein requirement − 1%, MLP: basal diet with NRC (1998) protein requirement − 1.5%, LP: basal diet with NRC (2012) protein requirement, LPV-: LP without valine supplementation

[2] Standard error of means.

[3] LPV- was excluded in orthogonal polynomial analysis.

[a,b,c] Means with different superscripts in the same row significantly differ(P<0.05).

[A,B,C] Means with different superscripts in the same row significantly differ(P<0.01).

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Ⅴ. Summary in Korean

본 연구는 돼지의 성장단계별 최적의 조단백질 수준과 이유자돈시기에 L-valine의 첨가가 자돈 및 육성·비육기의 성장성적, 분변지수, 혈액성상, 영양소 소화율, 도체특성 및 경제성 분석에 미치는 영향을 검증하고자 수행되었다. 평균 체중 7.86 ± 1.05 kg의 3원 교잡종 ([Yorkshire × Landrace] × Duroc) 이유자돈 160두를 공시하였으며, 22 주 동안 사양실험이 진행되었다. 전체 5처리 4반복, 반복당 8두씩 성별과 체중에 따라 난괴법 (RCBD; Randomized Complete Block Design)으로 배치하였다. 실험의 처리구는 1)HP: 옥수수-대두박을 기초로 한 사료 + NRC (1998)에서 제시된 단백질 요구량 + L-valine 2)MHP: 기초사료 + NRC (1998)에서 제시된 단백질 요구량 - 1 % + L-valine, 3)MLP: 기초사료 + NRC (1998)에서 제시된 단백질 요구량 - 1.5 % + L-valine, 4)LP: 기초사료 + NRC (2012)에 의해 제시된 단백질 요구량 + L-valine, 5)LPV-: 기초사료 + NRC (2012)에 의해 제시된 단백질 요구량. 사양 실험에서, 육성기에서 체중과 일당증체량에 유의적인 차이가 있었다. 또한 일당사료섭취량은 사료 내 조단백질 수치가 감소함에 따라 7-10주에 감소했다. 반면에, 자돈기의 L-valine 보충은 22주차 체중, 7-14주차 일당증체량 및 11-14주차 일당사료섭취량을 개선시켰다. 분변 지수는 처리구간 유의적인 차이가 없었으나, 사료 내 조단백질 수준이 감소함에 따라 분변 지수는 감소하는 경향이 있었다. 마찬가지로 자돈시기에 L-valine의 보충은 분변 지수에 유의적인 영향을 미치지 않았다. 혈액 분석 결과, 사료 내 조단백질 수준이 감소함에 따라 이유자돈기에서 BUN 농도가 유의적인 차이를 보이며 감소하였으며 육성비육기에서 선형적으로 감소하였다. 또한 자돈기의 L-valine의 첨가는 BUN 농도

를 감소시킴으로써 아미노산 이용율을 증대시키는 것으로 사료된다. 영양소 소화율 및 질소축적에서는 처리구간 유의적인 차이가 나타나지 않았다. 도체 특성에서 사료 내 단백질 수준이 감소함에 따라 pH와 보수력은 선형적으로 감소했다. 그러나 사료 내 단백질 수치가 감소함에 따라 조지방, Hunter L * 및 b * 값은 선형적으로 증가하는 반응을 보였다. 돼지가 낮은 조단백질을 섭취했을 때, 증체당 사료 비용 및 총 사료 비용은 높은 조단백질 처리구에 비해 낮았다. 또한, L-valine의 보충은 시판 일수를 개선하였다. 따라서, 사료 내 조단박질 수준을 낮추는 것은 성장 성적에 해로운 영향을 미치지 않으며 아미노산 이용률을 증대시키며, 근육의 조지방 함량 및 MUFA 농도를 증가시킨다. 또한, 사료 내 조단백질 수준 감소는 BUN 농도, 체중 증가 당 사료 비용, 총 사료 비용, 근육 내 pH 및 보수력을 감소시켰다. 한편, 자돈사료에 L-valine을 보충하면 성장률이 향상되며, BUN 농도가 낮아지며, 출하일령이 감소하였다. 그러므로 사료 내 조단백질 수준을 NRC (2012)에서 제시하는 수준 까지 낮추는 것은 어떠한 부정적인 영향이 나타나지 않았으며 사료 내 조단백질 수준을 낮출 때 L-valine을 보충하는 것이 바람직할 것으로 사료된다.

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