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Effect of Split-sex Feeding with Different Protein Levels on Growth Performance, Blood Profile, Pork Quality and Economic Analysis in Growing to Finishing Pigs

암, 수 분리사육시 사료 내 단백질 함량이 육성 - 비육돈에 성장성적, 혈액성상, 돈육 품질 그리고 경제성분석에 미치는 영향

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Summary

A number of domestic farmers have been utilizing feeding and management system of foreign country such as Denmark and the Netherlands without any modifications. In many cases, this can be problematic or not working effectively rather than improving animal industry in Korea. This failure is due to different conditions such as climate, environment and condition of swine farm compared to other countries. For example, split-sex feeding system has been broadly utilized in foreign countries however, it has not worked well for animal industry in Korea. The split-sex feeding means that gilts and barrows are separated and fed their diet with different feeding program. This is based on the finding that gilts and barrows have different growth rates, feed efficiencies and nutrient requirements. So far, the most of feeding study for pigs has designed in the absence of separation of barrows and gilts. Thus, the role of sex in experimental diet impacts on efficiency of feed utilization has not been assessed. A study was conducted to evaluate the effects of split-sex feeding with different protein contents in diet on growth performance, blood profiles, pork quality and economic analysis in pigs from growing to finishing. A total of 160 growing pigs ([Yorkshire × Landrace] × Duroc), averaging 30.55 ± 5.925 kg body weight, were assigned into one of five treatments. Each treatment diet is provided as followed by treatment 1) control (CON): barrows and gilts were penned together with protein requirement of NRC (2012), 2) Gilt: gilts were separately penned with protein requirement of NRC (2012) 3) Barrow : barrows separately penned with protein requirement of NRC (2012) 4) Gilt –1% : gilts were separately penned with 1 % lower protein requirement of NRC (2012) 5) Barrow – 1%

: barrows were separately penned with 1 % lower protein requirement of NRC (2012). In feeding trials, the split-sex feeding by NRC requirement had no significant differences on BW, ADG and G:F ratio compared with those of CON treatment (mixed treatment). However, split-sex feeding fed low protein diet had detrimental effects on growth performance. The blood creatinine in gilts was higher than that of barrows at 6 week. The BUN (blood urea nitrogen) concentration was decreased as dietary protein level decreased at 3 and 6 weeks and gilts showed lower BUN concentration than barrows at 9 week. The backfat thickness of barrows showed significantly higher than that of gilts regardless of dietary treatments. Pork color, cooking loss, shear force and proximate analysis of longissimus muscle were not affected by dietary protein, however, barrows showed higher WHC (water holding capacity) than that of gilts. The greatest economical profit was obtained in condition of sex split feeding without lowering CP in the diet. In conclusion, split-sex feeding had no detrimental effects on growth performance and pork quality but economical profit was decreased when pigs were fed low protein diet.

Key words: Split-sex feeding, Protein, Growing·finishing pig, Growth performance, Pork quality

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List of Abbreviation

AA	Amino acid
ADFI	Average daily feed intake
ADG	Average daily gain
AOAC	Association of official analytical chemists
BUN	Blood urea nitrogen
BW	Body weight
CP	Crude protein
DM	Dry matter
EU	European union
FMD	Foot-and-mouth disease
FTA	Free trade agreement
LSY	Litters per sow per year
MSY	Marketted-pigs per sow per year
NRC	National research council
PD	Protein deposition
PED	Porcine epidemic diarrhea
PRRS	Porcine reproductive and respiratory syndrome
PSY	Piglet per sow per year
RCB	Randomized complete block
SAS	Statistical analysis system

I. Introduction

Korea swine industry has been struggled by several reasons, not only FTA (free trade agreement) but also incidence of various diseases such as FMD (foot and mouth disease), PED (porcine epidemic diarrhea) and PRRS (porcine reproductive and respiratory syndrome). Furthermore, when compared to the average total production cost, swine industry of Korea takes approximately 40% higher costs than European countries. One of the reasons is that many domestic farmers have utilized feeding and management of foreign country such as Denmark and the Netherlands without any modifications despite different environmental conditions should be considered for application of new feeding system. The split-sex feeding (feeding gilts and barrows, separately) was suggested because growth performance was differed by gender. Although, there was a clear benefit of split-sex feeding, lots of swine researches were conducted with housing barrows and gilts in the same pens. Therefore, gender effect in swine researches is hardly figured out in nutritional experiments. Consequently, the first objective of this research is to observe the responses of barrows and gilts to various levels of dietary protein in order to determine the optimal levels of nutrients for maximizing growth rate and carcass leanness of pigs when barrows and gilts were penned separately. The second objective of this research is to evaluate the economic analysis by sex split feeding compared to mixed feeding. Therefore, the current study was conducted to evaluate the effect of split-sex feeding with different level of protein on growth performance, blood profile, backfat thickness, pork quality and economic profit in growing-finishing pigs.

II. Literature Review

1. Introduction

1.1 Recent situation of swine industry in Korea

In the last decade, agricultural production in Korea has increased steadily. The 43% of the total production is in the livestock area (Table 1). This index means the livestock production in Korea is the highest among them. The livestock industry plays a central role in the agriculture of Korea. Also production amount of rice unchanged from the first was reversed by pig production.

Despite the fact that it occupies a big part in Korea, there is no international competitiveness. Currently, Korea has the FTA with 52 countries around the world, including Europe and the US. According to the FTA, the opening of agricultural products is accelerating. As a result, the agriculture industry is experiencing a lot of suffering. In order for Korean pig farming to develop into a sustainable industry, it is very important to continuously improve the productivity of farms and secure international competitiveness. Especially productivity improvement of domestic pig industry is essential. However, there is a big difference in the productivity of domestic pig farms compared to the average results of the farms in Denmark and the Netherlands, which have achieved the best farm performance in the world (Table 2). In 2016, the average PSY of denmark pig farms has already exceeded 30 pigs. However, the average PSY of domestic pig farms is 20.8. Therefore, in domestic pig farms, innovative management and continuous efforts to improve productivity are essential to reduce the gap between farming performance in developed countries.

Table 1. Changes in production output by year

Year	Gross agricultural output (A)	Gross livestock industry output (B)	B/A %
2005	350,889	117,672	33.5
2006	352,324	116,763	33.1
2007	346,850	112,773	32.5
2008	384,698	135,929	34.3
2009	413,643	164,840	39.8
2010	416,774	174,714	41.9
2011	413,582	149,909	63.2
2012	443,003	160,225	36.2
2013	446,088	162,328	36.4
2014	449,168	187,819	41.8
2015	445,188	191,257	42.9

(MAFRA, 2016)

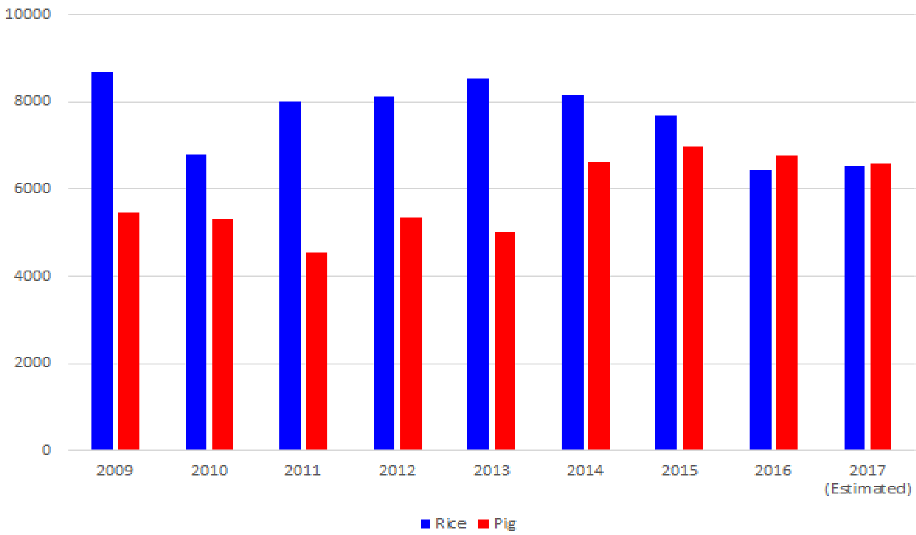

Figure1. Comparison of production amount of rice and pig (KREI, 2017)

Table 2 The productivity of pig selected countries

	PSY	MSY	LSY	Mortality of pig (%)[1)]
Korea	20.8	17.9	2.18	9.4
England	24.1	22.7	2.27	3.2
USA	24.6	22.2	2.37	4.9
Spain	25.8	24.2	2.34	3.5
France	27.4	26.1	2.32	2.5
belgium	27.8	26.0	2.32	3.1
Netherlands	29.2	27.8	2.37	2.3
Denmark	30.5	28.5	2.26	3.7

(HANDON FARMS, 2016 and INTERPIG Report, 2014)

1) Mortality of pig : Korea is mortality after weaning but selected countries is mortality after 11 weeks.

1.2 Non-systemic swine management in domestic swine farm

The management of animal production has changed significantly across the European Union (EU) over the last half of the 20th century (Tawse, 2010). Over this time, pork production has intensified, which means that total number of pigs increased, but the total number of farms that breed them decreased (Blokhuis et al., 2003). The management of animal production has been changed and applied according to the actual situation of each country.

Unfortunately, A number of domestic farmers have been utilizing feeding and management system of foreign country such as Denmark and the Netherlands without any modifications. In many cases, this can be problematic or not working effectively rather than improving animal industry in Korea. This failure is due to different conditions such as climate and environment (Figure 2, 3). For example, split-sex feeding system has been broadly utilized in foreign countries however, it has not work well for animal industry in Korea.

Figure 2. July 2017 weather in Denmark (google, 2017)

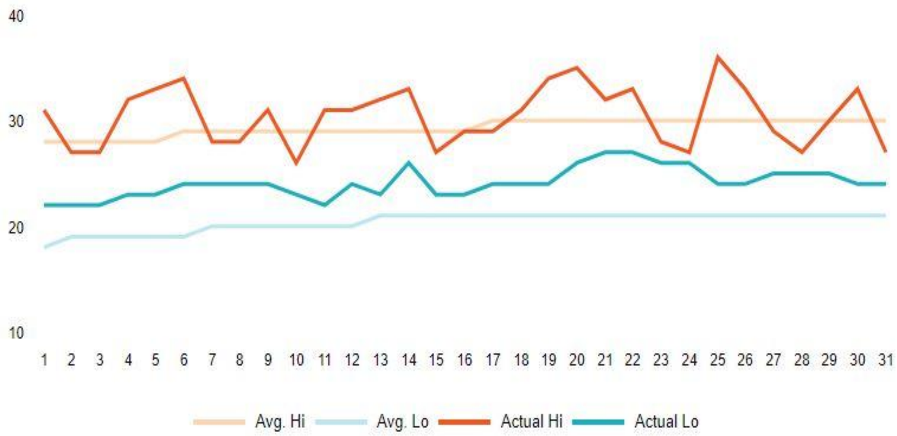

Figure 3. July 2017 weather in Korea (google, 2017)

2. split-sex feeding

2.1 Growth pattern by sex

There are confirmed differences in growth performance between boars, gilts and barrows (Whittemore et al. 1988; Campbell et al. 1990a; Dunshea et al. 1993a, 1998a; King et al. 2000). Also, Some researchers have reported that energy intake and protein deposition is higher for boars than for gilts or barrows (Campbell et al. 1985b; King et al. 1997; Dunshea et al. 1998a). Also, Campbell et al. (1985b) reported that in finisher pigs (>55 kg liveweight) a plateau in protein deposition was achieved in all sex classes of pigs at an intake of around 35 MJ DE/d but studies (Rao and McKracken, 1992; King et al. 1997; Dunshea et al. 1998a) conducted with genetically improved pigs suggest that the plateau occurs at higher feed intakes or zero in the case of elite boars. The meaning from those research is that improved boars and some gilts may be fed ad libitum to maximize protein deposition without excessive fat deposition. Black et al. (2001) reported that this is particularly so when it is realized that feed intake is generally lower under commercial conditions than it is in the individually housed pigs that have been used for many of these studies. The situation is not so clear with finisher barrows since they have a similar maximal rate of protein deposition as gilts but a higher voluntary feed intake (Dunshea et al. 1993a). At live weights below about 50kg liveweight, improved boars and barrows have a similar potential to deposit lean tissue (Suster et al. 2001a) but barrows are still fatter because of their greater feed intake. Also, Comparisons between gilt and barrow show that gilt have excellent feed efficiency and barrow is relatively poor because barrow have higher fat accumulation than gilt (Peinado et al., 2008). One of the studies of productivity reduction regarding castration of male has been reported to inhibit the natural assimilation of androgens that increase meat production, and as a result, it has been reported that efficiency and meat production are actually reduced (Jensen et al., 1995).

In summary, Barrows consume more feed and gain BW more rapidly than do gilts (Ekstrom, 1991). Conversely, gilts are more efficient in converting feed to BW gain and deposit a higher percentage of muscle and a lower percentage of fat tissue in their carcasses than do barrows (Ekstrom, 1991). Because gilts have a greater accretion rate of lean tissue and a lower feed intake than barrows, their amino acid requirements should be higher. Also gilt have excellent feed efficiency and barrow is relatively poor.

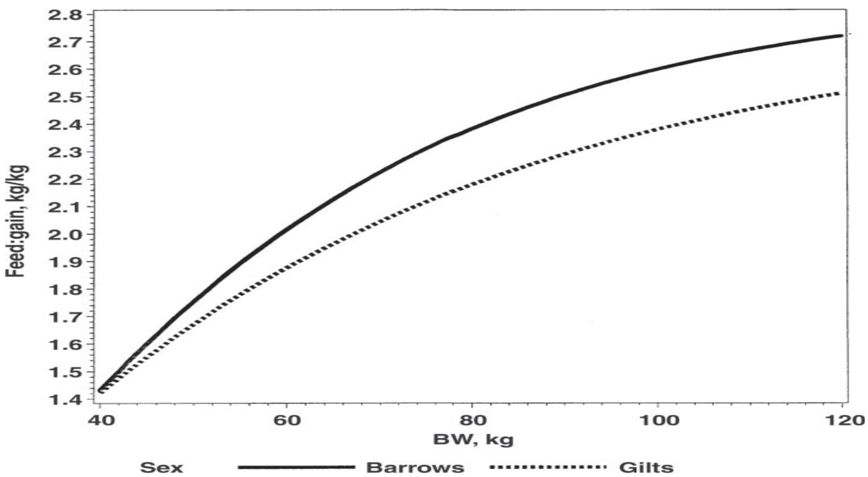

Figure 4. Relationship of feed:gain to BW for the barrows and gilts (Schinckel et al., 2009)

2.2 Protein deposition by sex

The protein deposition curves are shown in figure 5 for the two sex. The biological maximum of the muscle tissue growth was estimated to 75.79 kg and 75.74 kg for barrows and gilts, respectively (Dargutin Vincek et al, 2012). Up to 100 days of age, barrows have higher protein deposition than gilts. However, since 100 days of age, it is time for gilts to deposit more protein than barrows (Dargutin Vincek et al, 2012). In other words, it can be said that the protein requirement of gilts is higher than that of barrows. The reason why protein deposition varies according to sex is PDmax. PDmax is highest in entire males, intermediate in gilts, and lowest in barrow (Swine nutrition, 2nd edition). During the growing-finishing phase, the difference in PDmax between gilts and barrows is approximately 5% but varies between 2 and 15% (Moughan and Verstegen, 1988; Stranks et al., 1988; Thompson et al., 1996). The decline in PDmax with increasing live body weight tends to start at lower live body weight in barrows than in gilts (Thompson et al., 1996). Lean percentage for barrows was at its maximum at a mean BW of 60 kg and for gilts at 119kg (Mohrmann et al., 2006). Similary, the highest percentages of lean tissue occurred at 55 kg live weight for barrows and at 72 kg for gilts. Both studies confirmed higher lean percentages for gilts (Kastelic, 1997).

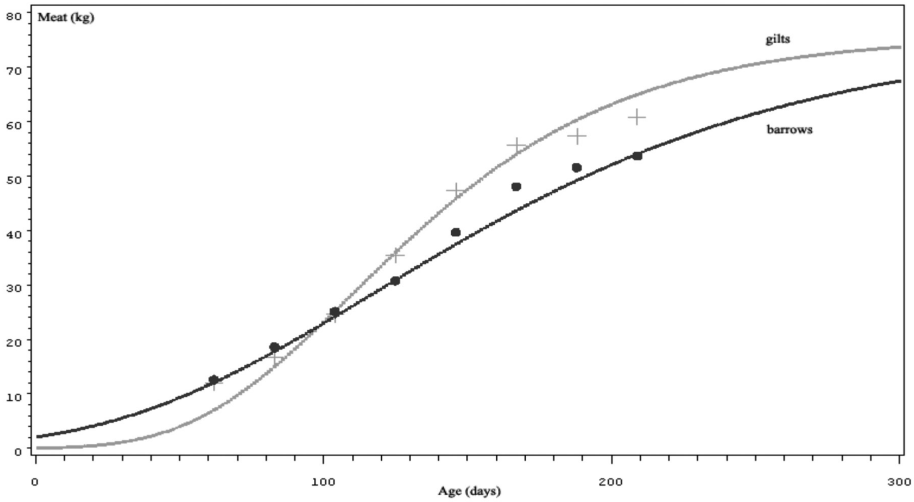

Figure 5. The curve of muscle tissue of gilts and barrows (Dargutin Vincek, 2012)

2.3 Lipid deposition by sex

The rate of lipid deposition in adipose tissue is determined by genotype, sex as well as degree of maturity (VSP pig nutrition, 2015). When protein deposition rate decreases, lipid deposition becomes the major component of the weight gain (Figure 7, Whittemore, 1993). In a pig consuming a high carbohydrate diet, the major source of energy for both oxidation and storage as fat is glucose. The partitioning of glucose between oxidation and lipogenesis is influenced by a number of factors including sex, age, liveweight, ambient temperature and genetic background (Dunshea and D'Souza, 2003). The fat tissue growth was seen that the growth of fat tissue accelerates in the later stages (Kouba et al., 1999). The subcutaneous adipose tissue (backfat) is the mos prominent fat depot in the pig at all stages of growth including the newborn (Mittchell et al., 2001). In general, barrows have higher backfat thickness than gilts (Ekstrom, 1991). These differences are related to the absence of sexual hormones in barrows. Since testosterone is an anabolic hormone, it is responsible for decreasing protein breakdown and promoting muscle protein deposition (Guyton and Hall, 2008).

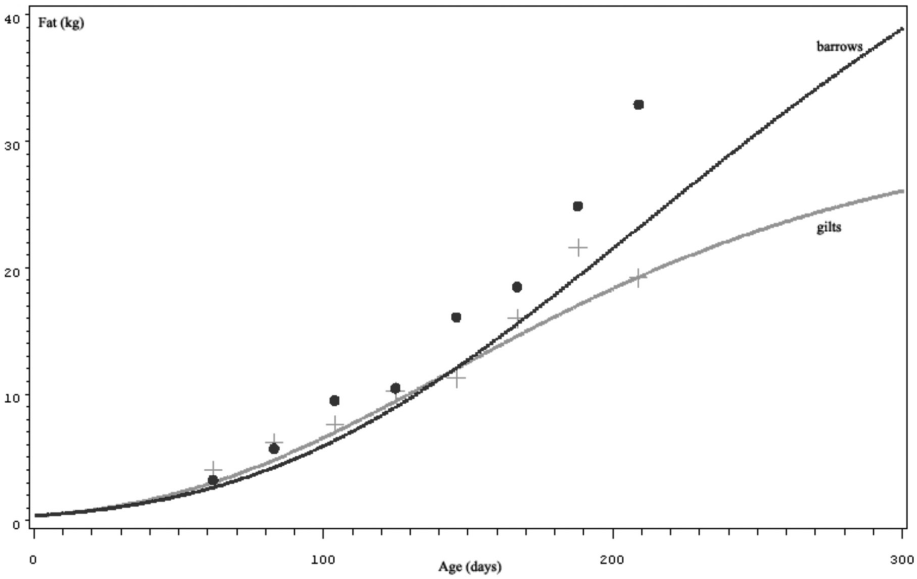

Figure 6. The curve of fat tissue of gilts and barrows (Dargutin Vincek, 2012)

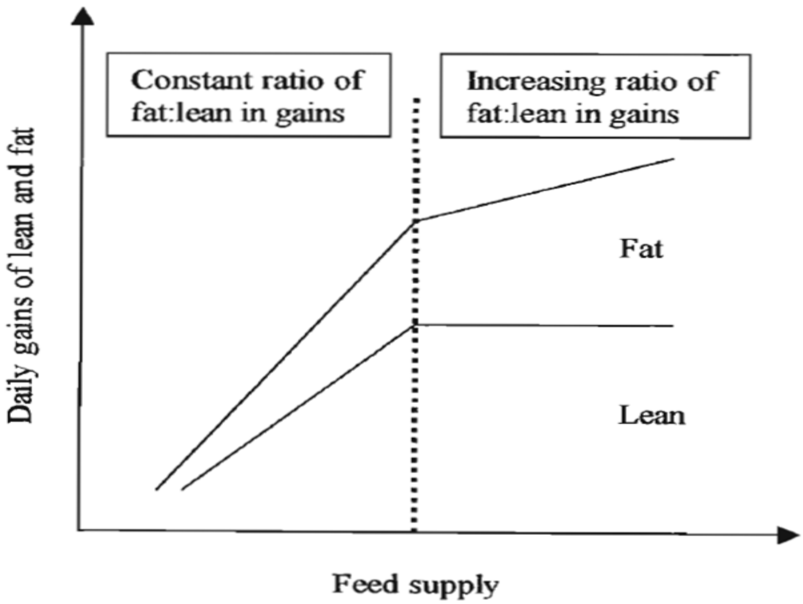

Figure 7. The ratio of lean to fat in gain will tend to be constant until maximum potential lean growth rate is achieved (Whittemore, 1993).

2.4 Nutrient requirements by sex

Gilts have a greater accretion rate of lean tissue and a lower feed intake than barrows. So their amino acid requirements should be higher. Several studies have been carried out to determine differences in protein or lysine requirements of barrows and gilts (Baker et al., 1967; Hale and Southwell, 1967; Lucas et al., 1971; Wahlstrom et al., 1971; Bereskin et al., 1976; Watkins et al., 1977; Christian et al., 1980; Yen et al., 1986a,b; Cromwell et al., 1990). In these experiments, protein and lysine levels were too wide to measure protein and lysine requirements between the two sexes. Also, in some of the studies, the numbers of pigs per treatment were relatively small.

In 1979, the NRC estimated that the lysine requirement of pigs (sex undefined) from 60 to 100 kg BW was 0.57%. In 1988, the NRC estimated that the lysine requirement of pigs (sex undefined) from 50 to 110 kg BW fed corn-soybean meal diets was 0.60%. Additionally, in the 1988 publication, the NRC estimated a lysine requirement of 0.70% for developing gilts from 50 to 110 kg. The ARC (1981) of Great Britain, SCA of Australia (1987) and JRC of Japan (1993) did not differentiate between barrows and gilts in their estimates of the protein and amino acid requirements of finishing pigs. The Australian Committee estimated similar lysine requirements for boars and gilts, but they did not estimate a requirement for barrows. But the NRC (2012) differentiate between barrows and gilts in their estimates of the protein and amino acid requirements of growing - finishing pigs. The difference between barrows and gilts in the protein requirements is presented in Table 5..

Table 3. Protein requirements for growing·finishing pigs.

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

1)Calculated from total nitrogen × 6.25.

Table 4. Lysine requirements for growing·finishing pigs.

Item	Body weight (kg)			
NRC, 1998	**20 – 50**	**50 – 80**	**80 – 120**	
Lysine[1], %	0.95	0.75	0.60	
NRC, 2012	**25 – 50**	**50 – 75**	**75 – 100**	**100 – 135**
Lysine[1], %	1.12	0.97	0.84	0.71
ARC, 1981	**15 – 50**		**50 – 90**	
Lysine[1], %	1.10		0.78	
SCA, 1987	**20 – 50**		**50 – 90**	
Lysine[1], %	0.83		0.60	
JRC, 1993	**30 – 70**		**70 – 110**	
Lysine[1], %	0.75		0.56	

1) Lysine requirement for total basis (%).

Table 5. Protein and lysine requirements for growing·finishing pigs.

Item	Body weight (kg)					
NRC, 2012	**50-75**		**75 – 100**		**100 – 135**	
Sex	Barrow	Gilt	Barrow	Gilt	Barrow	Gilt
CP[1], %	13.3	14.1	11.6	12.7	10.0	10.9
Lys[2], %	0.93	0.99	0.80	0.89	0.67	0.74

1) Calculated from total nitrogen × 6.25.

2) Lysine requirement for total basis (%).

3. Dietary protein in growing-finishing pigs

3.1. Dietary protein level and protein deposition

Protein deposition is the positive balance between protein synthesis and degradation. Reeds and Davis (1992) reported that together protein synthesis and degradation are included in the general concept of protein turnover. On a daily basis, protein turnover may involve as much as five times the requirement for dietary protein, but fortunately around 80% of the amino acids from protein breakdown are reutilized (Reeds and Davis, 1992). Fractional protein synthesis rates in skeletal muscles at birth have been estimated as 12-14% per day, but decrease exponentially to around 6% per day at 25 kg and further to 4% per day at 80 kg live weight (Mittchell et al., 2001).

An upper limit to daily protein deposition (PDmax), which is determined by the genetics of the pigs, is a central parameter because the pig's potential for depositing protein largely determines the pig's requirement for amino acids. Moreover, high calorie studies have shown that increasing feed intake (of a balanced diet) beyond ad libitum intake does lead to increased growth rate, but not to increased body protein deposition (McCracken et al., 1994). PDmax is dependent on the stage of growth as the maximum rate of protein deposition changes during the course of growth (Noblet et al., 2000). The protein deposition is controlled by PDmax that limits certain protein deposition level. PDmax is largely constant up to approximately 80 to 90 kg live body weight (Moughan and

Verstegan, 1988; Moughan, 1995; Quiniou et al., 1995) and that mathematical equations such as the Gompertz function can be used to represent the decline in PDmax as pigs become mature. Consequently, protein intake above PDmax requirement is essential for maximum growth of pigs.

3.2. Effect of dietary protein level on growth performance

The protein requirements of the pig have been widely studied (Whittemore et al., 2001) in terms of the growth and feeding efficiency of both the improved (Campbell et al., 1984; Hansen and Lewis, 1993). On the other hand, Feed conversion efficiency and growth rate of pigs fed to appetite are not significantly affected by dietary protein or non essential nitrogen content when the levels of essential amino acids are maintained adequate to meet the requirements (Wahlstrom and Libal, 1974;Bereskin et al., 1976; Sharda et al., 1976;Easter and Baker, 1980; Noblet et al., 1980; Stahly et al., 1981; Asche et al., 1985). Also, There are many experiments that excess CP intake has been shown to increase energy expenditure (Buttery and Boorman, 1976) and impact organ size and energy metabolism (Yen, 1997; Nyachoti et al., 2000). Noblet et al. (1987) observed that pigs fed diets containing 37.5 g protein/Mcal DE had lower heat production (HP) compared with pigs fed a diet containing 45 g protein/Mcal DE. Kerr et al. (2003) reported that pigs fed a 12% CP, AA supplemented diet had a lower HP than pigs fed a 16% CP diet. In addition, reduced plasma urea N observed in pigs fed the low-CP, AA-supplemented diet (Lopez et al., 1994; Kerr and Easter, 1995) is another indication of a reduced energy need for deaminating excess AA.

3.3 Effect of dietary protein level on Pork quality

Several researches suggested that dietary protein level that was matched to requirement of pig improved carcass characteristics (Wagner et al., 1963; Cromwell et al., 1978, Kerr et al., 1995, Hansen and Lewis, 1993). Also, the pattern of fat deposition in finishing pigs is important for carcass and meat quality (Kouba, Bonneau, & Noblet, 1999; Kouba & Sellier,2011; Wood, 1984). Moreover, for improved pigs slaughtered at a weight of ~100 kg, Critser et al. (1995), Tuitoek et al.(1997) and Dannenberger et al. (2012) found no significant effect on carcass traits of dietary protein levels ranging from 11.0% to 14.2%, 13.1% to 18.4%, or 15% to 19.6% respectively. Only by using a wider range of dietary protein content (from 13% to 25%, and from 11% to 23%, respectively) Chen et al. (1999) observed a linear effect on backfat thickness, and Hansen and Lewis (1993) a quadratic effect on percentage of lean of the carcass.

Recently, low protein diet has been used to increase the intramuscular fat. the intramuscular fat (IMF) has potential sensory benefits, so deposition of fat within the muscle could enhance product quality (Teye et al., 2006) Ellis and McKeith (1999) suggested that the simplest means to increase intramuscular fat levels of pork is via feeding protein-deficient diets. On the contrary, the reduction of dietary protein generally increased the IMF content (Doran et al., 2006; Alonso et al.,2010) but the effect seems to be determined more to lysine than protein restriction (Madeira et al., 2013). The reduction of non-essential nitrogen level in the diet is also associated with a decreased nitrogen loss in urine (Sharda et al., 1976; Russell et al., 1983) and a subsequent lower contribution of deaminated protein to ME supply. In addition, the efficiency of utilization of digestible nutrients for maintenance or fat deposition is lower for deaminated protein than for carbohydrate or fat (Hoffmann and Schieman, 1971; Schulz, 1975; Just, 1982). A decrease in the dietary protein level and the subsequent enrichment in carbohydates or fat for the same level of limiting essential amino acid would allow an improved efficiency of ME utilization, resulting in a tendency for increased carcass fatness.

3.4. split-sex feeding by dietary protein levels

Barrows consume more feed and gain BW more rapidly than do gilts (Ekstrom, 1991). Conversely, gilts are more efficient in converting feed to BW gain and deposit a higher percentage of muscle and a lower percentage of fat tissue in their carcasses than do barrows (Ekstrom, 1991). Because gilts have a greater accretion rate of lean tissue and a lower feed intake than barrows, their amino acid requirements should be higher. In 2012, the NRC differentiate between barrows and gilts in their estimates of the protein requirements of growing-finishing pigs.

Split-sex feeding of swine can further improve feed efficiency. It is well established that gilts consume less feed on a ad libitum basis and require greater diet nutrient density than barrows (Cromwell et al., 1993). By penning and feeding gilts and barrows separately, producers can more precisely formulate diets for specific sexes and avoid over fortification and excessive excretion of nutrients. furthermore, increased fat deposition and decreased rate of lean deposition occur at an earlier growth stage in barrows than in gilts; therefore, dietary protein and amino acid levels can be more precisely changed at different growth stages for each sex.

Ⅲ. Effect of Split-sex Feeding with Different Protein Levels on Growth Performance, Blood Profile, Pork Quality and Economic Analysis in Growing to Finishing Pigs

Abstract: Split-sex feeding system has been broadly utilized in foreign countries however, it has not worked well for animal industry in Korea. The split-sex feeding means that gilts and barrows are separated and fed their diet with different feeding program. This is based on the finding that gilts and barrows have different growth rates, feed efficiencies and nutrient requirements. So far, the most of feeding study for pigs has designed in the absence of separation of barrows and gilts. Thus, the role of sex in experimental diet impacts on efficiency of feed utilization has not been assessed. A study was conducted to evaluate the effects of split-sex feeding with different protein contents in diet on growth performance, blood profiles, pork quality and economic analysis in pigs from growing to finishing. A total of 160 growing pigs ([Yorkshire × Landrace] × Duroc), averaging 30.55 ± 5.925 kg body weight, were assigned into one of five treatments. Each treatment diet is provided as followed by treatment 1) control (CON): barrows and gilts were penned together with protein requirement of NRC (2012), 2) Gilt: gilts were separately penned with protein requirement of NRC (2012) 3) Barrow : barrows separately penned with protein requirement of NRC (2012) 4) Gilt –1% : gilts were separately penned with 1 % lower protein requirement of NRC (2012) 5) Barrow – 1% : barrows were separately penned with 1 % lower protein requirement of NRC (2012). In feeding trials, the split-sex feeding by NRC requirement had no significant differences on BW, ADG and G:F ratio compared with those of CON treatment (mixed treatment). However, split-sex feeding fed low protein diet had detrimental effects on growth performance. The blood creatinine in gilts was higher than that of barrows at 6 week. The BUN (blood urea nitrogen) concentration was decreased as dietary protein level decreased at 3 and 6 weeks and gilts showed lower BUN concentration than barrows at 9 week. The backfat thickness of barrows showed significantly higher than that of gilts regardless of dietary treatments. Pork color, cooking loss, shear force and proximate analysis of longissimus muscle were not affected by dietary protein, however, barrows showed higher WHC (water holding capacity) than that of gilts. The greatest economical profit was obtained in condition of sex split feeding without lowering CP in the diet. In conclusion, split-sex feeding had no detrimental effects on growth performance and pork quality but economical profit was decreased when pigs were fed low protein diet.

Key words: Split-sex feeding, Protein, Growing·finishing pig, Growth performance, Pork quality

Introduction

In Korea, many swine management techniques are already utilized to improve productivity but split-sex feeding is not easy to utilize in Korea. The split-sex feeding means that gilt and barrow are separated and applied to other feed program (Cline et al., 1995). The beginning of split-sex feeding is that gilts and barrows have different growth pattern (Cline et al., 1995). In general, barrows consume more feed and gain BW more rapidly than do gilts (Ekstrom, 1991). Conversely, gilts are more efficient in converting feed to BW gain and deposit a higher percentage of muscle and a lower percentage of fat tissue in their carcasses than do barrows (Ekstrom, 1991). For that reasons, when gilts and barrows were penned together with feeding same diet, barrows consume only the feed and produces a lot of fat, resulting in lowering the quality of the pork quality and wasting the feed (Ekstrom, 1991). In order to increase the pork quality and feed efficiency, it is necessary to utilize the split-sex feeding.

Split-sex feeding is based on the finding that gilts and barrows have different growth rates, feed efficiencies and nutrient requirements. So far, the most of feeding study for pigs has designed in the absence of separation of barrows and gilts (Cromwell et al., 1993). Thus, the role of sex in experimental diet impacts on efficiency of feed utilization hasn’t been assessed. Therefore, the current study was conducted to evaluate the effect of split-sex feeding with different level of protein on growth performance, blood profile, back-fat depth, pork quality and economic profits in growing-finishing pigs.

Materials and Methods

Experimental animals and management

A total of 160 weaning pigs ([Yorkshire × Landrace] × Duroc) with an average body weight of 30.55 ± 5.925 kg were used for 11 weeks feeding trial at experimental farm of Seoul National University. Pigs were alloted into each treatments by body weight and sex in 4 replicated with 8 pigs per pen in a randomized completed block (RCB) design. All pigs were housed in an environmentally controlled building fully-concrete floors facility (2.60 × 2.84m) during growing to finishing periods. Feed and water were provided *ad libitum* during the whole experimental period by a 4 hole stainless feeder and a nipple installed in each pen.

Experimental design and diet

Treatments were: 1) Control (CON) : barrows and gilts were penned together and fed formulated diet by protein requirement of NRC (2012), 2) Gilt : gilts were separately penned and fed formulated diet based on protein requirement of NRC (2012) 3) Barrow : barrows were separately penned and fed formulated diet based on protein requirement of NRC (2012) 4) Gilt − 1% : gilts were separately penned and fed formulated diet based on protein requirement of NRC (2012) -1.0% 5) Barrow − 1% : barrows were separately penned and fed formulated diet based on protein requirement of NRC (2012) -1.0%. The dietary protein level is determined to nutrient requirement from NRC (2012).

Experimental diets were formulated for 4 phases, including growing phase1 (0-3 week), growing phase2 (4-6 week), finishing phase1 (7-9 week), finishing phase2 (10-11 week). All nutrients of experimental diets except CP were met or exceeded the nutrient requirement of NRC (2012). Formula and chemical composition of experimental diet were presented in Table 1, 2, 3 and 4.

Growth performance

Body weight and feed intake were monitored at 0, 3, 6, 9 and 11 weeks to analyze average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G/F ratio).

Blood sampling and analysis

Blood samples were collected from the jugular vein of randomly selected six pigs (Except for CON treatment – three gilts and three barrow) in each treatments for measuring levels Insulin-like growth factor-1 (IGF-1), blood creatinine and blood urea nitrogen (BUN) when the body weights were recorded. Collected blood samples were centrifuged for 15 min at 3,000 rpm on 4 ℃ (Eppendorf centrifuge 5810R, Germany). The sera were carefully transferred to 1.5 ml plastic tubes and stored at –20 ℃ until later analysis. IGF-1 concentration in blood was measured by using hormone analyzer (Immulite 2000, DPC, SUA). Creatinine was measured by kinetic colorimetry assay using a blood analyzer (Modular analytics, PE, Roche, Germany). Total BUN concentration was analyzed using a blood analyzer (Ciba-Corning model, Express Plus, Ciba Corning diagnostics Co.).

Backfat thickness

Backfat thickness was measured at the P_2 (mean value from both sides of the last rib and 65 mm away from the backbone) using Ultra-sound (Lean-meter, Renco Corp., Minneapolis, MN, USA). Backfat thickness were recorded at 6, 9 and 11 weeks and pigs were selected from two to three replication (16 pigs).

Pork quality and carcass traits

In CON treatment, 3 gilts and 3 barrows slaughtered for the carcass analysis. In the other treatments, 6 pigs were slaughtered for the carcass analysis. Longissimus muscles were used from nearby 10^{th} rib on right side of carcass. Because of chilling procedure, 30 minutes after slaughter was regarded as initial time. The time to measure pork color were in 0, 3, 6, 12 and 24 hour. The pork color was determined by CIE color L*, a* and b* value using a CR300 (Minolta Camera Co., Japan). Proximate of pork samples were a analyzed by the method of AOAC (1995).

Centrifuge method was used for 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 paked 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.

Chemical Analyses

Diets were ground by a Cyclotec 1093 Sample Mill (Foss Tecator, Hillerod, Denmark) and ground diets were analyzed. All analyses were performed in duplicate samples and analyses were repeated if results from duplicate samples varied more than 5% from the mean. Experimental diet was analyzed for contents of dry matter (procedure 930.15; AOAC, 1995), 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 was analyzed for contents of CP content (nitrogen × 6.25; procedure 988.05; AOAC,1995),

Economical analysis

As the experimental pigs were reared in the same environmental condition, economical efficiency was calculated using only the feed cost without considering other factors. The total feed cost and feed cost (won) per body weight gain (kg) was calculated using amount of the total feed intake and feed price. Calculation of estimated feed cost was done as follows;

Estimated feed cost (won) =

$$\text{Total feed cost from 30 to 99kg BW} + \frac{\text{feed cost from 99 to 110kg BW}}{\text{weight gain from 99 to 110kg BW}} \times (\text{110kg}-\text{final BW})$$

The days to market weight (110 kg) was estimated from the body weight at the end of feeding trial at 11 weeks from beginning of experiment. The rate of payment (Table 12) was converted according to 1+, 1 grade (%).

Net income of swine farm = Carcass price (5,000 won/carcass kg) - total feed cost (won/head) - production cost (129,229 won)

Statistical analysis

All data were analyzed using PROC MIXED procedures of SAS. Each pen was regarded as an experimental unit in feeding trial, and individual pig was used as an experimental unit in blood profiles and carcass analysis. The statistical model included two main effects, sex and dietary protein level. Significance for treatment effects was reported at $P<0.05$, with a trend between $0.05 \leq P<0.1$.

Results and Discussion

Growth performance

The effect of split-sex feeding with different protein diet on growth performance was presented in Table 6. During late growing period (4-6 week), barrow showed higher ADFI than that of gilt (SEX, P=0.03). During early finishing period (7-9 week), barrow showed higher ADG and ADFI than gilt (SEX, P<0.01, P=0.01). In finishing period (7-11 week), barrow showed higher ADG and ADFI than those of gilt (SEX, P=0.04, P=0.03). During the whole experimental period (0-11 week), barrow showed higher ADG and ADFI than those of gilt (SEX, P=0.03, P=0.02).

The differences in ADG and ADFI between gilt and barrow are well known (Augspurger et al., 2002; Latorre et al., 2004). The result of current study was in agreement with previous researches which observed barrows are higher in ADG than gilt in ADG (Ekstrom, 1991). Also, voluntary feed intake of barrows is higher than that of gilts (Schinckel, 1994). Similar to this previous report, barrows showed higher ADG and ADFI than that of gilts.

During early finishing period (7-9 week), when pigs fed low protein diet had lower ADG (CP, P=0.04). In finishing period (7-11 week), when pigs fed low protein diet had lower ADG (CP, P<0.01). During the whole experimental period (0-11 week), when pigs fed low protein diet had lower ADG (CP, P=0.04).

Dietary protein and amino acids are required for muscle development, and lack of protein and amino acid intake has a negative impact on pig growth and muscle development (Schinckel and de Lange, 1996). ADG decreased significantly as feed protein decreased (Edmonds and Baker, 2003). Pigs fed high crude protein showed significantly increased ADG as the level of protein in the feed was increased (Kerr et al., 2003). The result of current study was in agreement with previous researches which observed decrease of ADG by lower crude protein diet.

During late finishing period (10-11 week), there was a interaction in G:F ratio (CP*SEX, P=0.04). Gilt by NRC requirement had higher G:F than Barrow by NRC requirement.

Comparisons between gilt and barrow showed that gilt have excellent feed efficiency and barrow is relatively poor because barrow have higher fat accumulation than gilt (Peinado et al., 2008). There are two reasons for that. First, castration blocks the synthesis of androgen that increases muscle. As a result, the feed efficiency is reduced by 12% and the muscle is reduced by 6.5% (Jensen et al., 1995). Second, protein deposition is highest in entire males, intermediate in gilts, and lowest in castrates (swine nutrtion, 2^{nd} edition). The difference in PDmax between gilts and barrows is approximately 5% but varies between 2 and 15% (Moughan and Verstegen 1988; Stranks et al., 1988; Thompson et al., 1996). Collectively, gilts require higher levels of dietary protein to maximize rate and efficiency of gain and carcass muscle than do barrow (Cromwell et al., 1993). Similar to this observation, the protein diet by NRC requirement had a much more positive effect on gilts than on barrows in G:F ratio.

During the whole experimental period, CON and split-sex feeding were no significant difference in BW and ADG by NRC requirement. But split-sex feeding with low protein diet had negative effect on BW, ADG and ADFI.

Consequently, the current study demonstrated split-sex feeding with low protein diet had negative effect on BW, ADG and ADFI. Also, split-sex feeding by NRC requirement had no significant difference on BW, ADG and G:F ratio compared with those of CON treatment.

Blood profiles

The effect of split-sex feeding with different protein diet on IGF-1, blood creatinine concentration and BUN were shown in Table 7.

During whole experimental period, there was no significant difference in IGF-1 ($P>0.05$). IGF-1 is secreted from the liver and stimulated by GH (Growth Hormone) to promote ossification and growth of cartilage (Suzuki et al., 2004). There was also a positive correlation between the growth rate of pigs and feed efficiency (Owens et al., 1999). But Sier and Swiger (1971) reported that there was a significant difference in GH secretion only in the age and body weight, and there was no significant difference by sex. In line with these observation, we also observed no significant difference by sex.

As a result of blood creatinine, gilt showed significantly higher creatinine concentration than barrow at 6 week (SEX, $P=0.03$). Blood creatinine has been used as an index to estimate the degree of muscle accumulation (Patel et al, 2012). Blood creatinine level is positively correlated with the degree of total muscle (Baxmann, 2008). Dargutin et al. (2012) reported that gilts accumulate more lean meat compared to barrow from 100 days of age. conversely, barrows have carcass fatness than gilts (Ekstrom, 1991). These differences are related to the absence of sexual hormones in barrows. The result of current study was in agreement with previous researches which observed gilts showed significantly higher creatinine concentration than barrows. But there was no significant difference in blood creatinine through dietary protein levels (CP, $P>0.05$).

At 3 week and 6 week, reduction of BUN was observed when pigs were fed low protein diet (CP, $P<0.01$). BUN is a representative index of the amino acid utilization efficiency of pigs and has been used as a response index to determine protein requirement (Hatori et al., 1994; Cai et al., 1996; Coma et al. 1995). In general, excessive levels of crude protein may reduce protein availability (Jeong et al., 2010). Thus, an increase in BUN implies an inefficient metabolism of excessive amino acids (Jeong et al., 2010). In previous study when the CP is decreased, the BUN decreases (Chen et al., 1995, 1996; Gomez et al., 1998; Yen et al., 2000; Jeong et al., 2010). In current study, lower BUN concentrations was detected when CP was decreased (CP, $P<0.01$). At 9 week, Gilt showed lower BUN concentrations than Barrow (SEX, $P<0.01$). Gilts also produce more muscle than barrow and require more protein than barrow (Cromwell et al., 1993). For that reasons, gilt had lower BUN than barrow in current study (SEX, $P<0.01$).

In blood profile, only sex and dietary protein level affect blood profiles, however there was no significant difference between sex split feeding and CON.

Backfat thickness

The effect of split-sex feeding with different protein diet on backfat thickness were shown in Table 8. On the 6 week, the backfat thickness were thicker in pigs were fed low protein diet (CP, P=0.09). Many different treatments reported that there was tendency for increased body fatness with low protein diets (Goerl et al., 1995; Kerr et al., 1995). A decrease in the dietary protein level and the subsequent enrichment in carbohydates or fat for the same level of limiting essential amino acid would allow an improved efficiency of ME utilization, resulting in a tendency for increased carcass fatness. The result of current study was in agreement with previous researches which observed the backfat thickness becomes thicker when pigs were fed low protein diet.

On the 11 week, barrow showed higher backfat thickness than gilts (SEX, P<0.01). This result is in agreement with those reported in the literature, in which gilts have generally a lower average backfat thickness than barrows (Borosky et al., 2011). These differences are related to the absence of sexual hormones in barrows. Since testosterone is an anabolic hormone, it is responsible for decreasing protein breakdown and promoting muscle protein deposition (Guyton and Hall, 2008). The result of current study was in agreement with previous researches which observed gilt showed thinner backfat thickness than barrow.

In order to get 1+,1 grade on current grading criteria, backfat thickness of 15 ~ 27mm is necessary for better grading. In conclusion, in order to meet the 1+ requirement (backfat thickness: more than 17 mm and less than 25 mm) barrow needs earlier days to market weight than gilt.

Pork quality

The effect of split-sex feeding with different protein diet on pork quality of longissimus muscle (LM) were shown in Table 9. In the present study, there were no differences in proximate analysis of the pork after slaughter among treatments. In physiochemical property, we cannot fined any significant difference in cooking loss and shear force. However, barrow showed higher WHC than gilt (SEX, P=0.02).

The influence of sex on meat quality was varied and sometimes not completely clear (Piao et al., 2004). The conflicting reports in the literature might partly be explained by the differences in genotype, pre- and post-slaughter handling and measuring methods (Piao et al., 2004). No significant difference between gilts and barrows was found in proximate analysis (p>0.10). However, Uttaro (1993), Unruh (1996), Larzul (1997) and Piao et al. (2004) reported that crude protein was lower in the LM of barrows compared with gilts, while fat content were higher in the LM of barrows compared with gilts. That’s because the average carcass weight of gilts and barrows were different from each other. It is considered that the weight effect was the main factor, so the gender effect did not appear.

Cooking loss and shear force for LM of barrows were no different from those of gilts. Similarly, it was reported that there was no significant difference in cooking loss and shear force between gilts and barrows (Suzuki et al., 2003; Beattie et al. 1999). In WHC, barrow showed higher WHC than gilt (SEX, P=0.02). The water holding capacity (WHC) of meat products is a very important quality attribute which has an influence on product yield, which in turn has economic implications, but is also important in terms of eating quality (Cheng et al., 2008). Nold et al. (1999), Armero et al. (1999), Latorre et al. (2003), Lampe et al. (2006) found differences that barrows had higher intramuscular fat than gilts. High intramuscular fat content tended to yiled higher WHC than on of low fat content (Joseph et al., 2010). The reasons are unknown but possibly the fat loosens the microstructure allowing water to be retained.

The effect of sex split feeding with different protein diet on meat color (CIE value) of growing-finishing pigs were shown in Table 10. Consumer consider meat color as an important parameter for freshness. Thus, meat color has the greatest impacts on consumer's decision tin the market. Larzul et al. (1997) reported that sex did not affect the L* values of pork and Choi et al. (2000) found Hunter L*, a* and b* value had no relation with sex of pigs. The result of current study was in agreement with previous researches which there is a no significant differences in meat color.

Economic analysis

The effect of split-sex feeding with different protein diet on feed cost per weight gain, total feed cost per pig (reached 110kg body weight), days to market weight (Reached 110kg body weight), 1+, 1 grade and net income of swine farm was presented in Table 11.

There was no significant difference in feed cost per weight gain. But numerical decrease of feed cost per weight gain was observed when split-sex feeding was applied without lowering CP. In total feed cost per pig, barrow tended to had higher total feed cost than gilt. This is because gilt had higher G:F ratio than barrow in growth performance. In days to market weight, gilt fed low protein diet showed the lowest days to market weight ($P<0.05$). This result is attribute to the lowest ADG. In 1+,1 grade, the highest score was shown when split-sex feeding was applied without lowering CP. For that reasons, gilt and barrow treatments which received high rates of payment showed the highest net income.

In conclusion, split-sex feeding without lowering CP showed the greatest economical benefit to swine producers.

Conclusion

The split-sex feeding by NRC requirement had no significant difference on BW, ADG and G:F ratio compared with those of CON treatment (mixed treatment). However, split-sex feeding fed low protein diet had detrimental effects on growth performance of growing pigs. The backfat thickness of barrow showed significantly higher than those of gilts. When gilts and barrows were reared separately, net profit was the higher than that of mixed rearing.

Consequently, this experiment demonstrated that split-sex feeding gave much higher net profit to swine producers when pigs were fed diet formulated by NRC (2012) requirement. In conclusion, split-sex feeding had no detrimental effects on growth performance and pork quality but net profit was decreased when pigs were fed low protein diet.

Table 1. Formula and chemical composition of growing phase1 (0-3 week).

	Treatment[1]				
	CON	CP		CP - 1%	
		Gilt	Barrow	Gilt	Barrow
Ingredients, %					
Ground corn	59.90	59.09	61.17	61.76	63.85
SBM, 45%	20.32	21.24	19.12	18.22	16.10
Wheat	10.00	10.00	10.00	10.00	10.00
Palm kernel meal	3.98	3.98	3.98	3.98	3.98
Tallow	2.21	2.22	2.21	2.20	2.19
SBM, 45%	1.12	1.10	1.14	1.16	1.19
Wheat	0.98	0.98	0.98	0.98	0.98
Palm kernel meal	0.07	0.07	0.08	0.08	0.09
Vit. Mix[2]	0.03	0.30	0.30	0.30	0.30
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%	0.12	0.11	0.10	0.16	0.15
L-Lysine-HCl, 78%	0.46	0.43	0.42	0.53	0.52
Trypthophan, 10%	0.30	0.25	0.27	0.40	0.42
β-mannanase	0.10	0.10	0.10	0.10	0.10
Chemical composition					
ME, kcal/kg[4]	3300.02	3300.02	3300.03	3300.01	3300.03
Crude protein, %[4]	15.69	16.00	15.19	15.00	14.19
Crude protein, %[5]	15.12	15.53	14.98	14.78	14.07
Crude fat[5]	4.67	5.16	5.13	5.56	5.68
Crude ash[5]	9.43	9.84	9.12	9.33	9.12
Lysine, %[4]	1.12	1.12	1.12	1.12	1.12
Methionine, %[4]	0.32	0.32	0.32	0.32	0.32
Ca, %[4]	0.66	0.66	0.66	0.66	0.66
Total P, %[4]	0.56	0.56	0.56	0.56	0.56

[1] Control: Gilt + Barrow, Gilt (CP) : only gilt by NRC requirement; Barrow (CP) : only barrow by NRC requirement; Gilt (CP-1%) : only gilt by low CP requirement; Barrow (CP-1%) : only Barrow by low CP requirement;

[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 composition of growing phase2 (4-6 week).

	Treatment[1]				
	CON	CP		CP - 1%	
		Gilt	Barrow	Gilt	Barrow
Ingredients, %					
Ground corn	65.41	64.64	66.73	67.37	69.46
SBM, 45%	15.16	15.98	13.90	13.00	10.89
Wheat	10.00	10.00	10.00	10.00	10.00
Palm kermel meal	3.98	3.98	3.98	3.98	3.98
Tallow	2.02	2.01	2.01	1.98	1.98
SBM, 45%	1.00	0.99	1.02	1.03	1.07
Wheat	0.89	0.89	0.89	0.89	0.89
Palm kernel meal	0.05	0.06	0.05	0.07	0.06
Vit. Mix[2]	0.03	0.03	0.03	0.03	0.03
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%	0.12	0.12	0.11	0.17	0.16
L-Lysine-HCl, 78%	0.44	0.44	0.43	0.53	0.53
Trypthophan, 10%	0.40	0.35	0.35	0.45	0.45
β-mannanase	0.10	0.10	0.10	0.10	0.10
Chemical composition					
ME, kcal/kg[4]	3300.01	3300.02	3300.00	3300.03	3300.01
Crude protein, %[4]	13.75	14.06	13.25	13.07	12.25
Crude protein, %[5]	13.42	13.88	13.12	13.01	12.12
Crude fat[5]	4.80	5.29	5.18	5.37	5.43
Crude ash[5]	4.78	4.36	3.83	4.02	4.24
Lysine, %[4]	0.97	0.99	0.93	0.99	0.93
Methionine, %[4]	0.28	0.29	0.27	0.29	0.27
Ca, %[4]	0.59	0.59	0.59	0.59	0.59
Total P, %[4]	0.52	0.52	0.52	0.52	0.52

[1] Control: Gilt + Barrow, Gilt (CP) : only gilt by NRC requirement; Barrow (CP) : only barrow by NRC requirement; Gilt (CP-1%) : only gilt by low CP requirement; Barrow (CP-1%) : only Barrow by low CP requirement;

[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 composition of finishing phase1 (7-9 week).

	Treatment[1]				
	CON	CP		CP - 1%	
		Gilt	Barrow	Gilt	Barrow
Ingredients, %					
Ground corn	70.24	68.82	71.55	71.55	74.23
SBM, 45%	10.91	12.31	9.64	9.31	6.57
Wheat	10.00	10.00	10.00	10.00	10.00
Palm kermel meal	3.98	3.98	3.98	3.98	3.98
Tallow	1.79	1.80	1.79	1.76	1.76
SBM, 45%	0.82	0.81	0.85	0.86	0.90
Wheat	0.82	0.81	0.81	0.81	0.81
Palm kernel meal	0.04	0.04	0.02	0.06	0.04
Vit. Mix[2]	0.03	0.03	0.03	0.03	0.03
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%	0.11	0.12	0.11	0.16	0.16
L-Lysine-HCl, 78%	0.41	0.43	0.40	0.53	0.51
Trypthophan, 10%	0.35	0.35	0.32	0.45	0.50
β-mannanase	0.10	0.10	0.10	0.10	0.10
Chemical composition					
ME, kcal/kg[4]	3300.02	3300.05	3300.03	3300.00	3300.04
Crude protein, %[4]	12.13	12.69	11.63	11.69	10.63
Crude protein, %[5]	12.01	12.42	11.22	11.25	10.33
Crude fat[5]	6.73	5.68	4.99	5.32	5.01
Crude ash[5]	4.43	4.33	3.80	3.74	3.84
Lysine, %[4]	0.84	0.89	0.80	0.89	0.80
Methionine, %[4]	0.25	0.26	0.23	0.26	0.23
Ca, %[4]	0.52	0.52	0.52	0.52	0.52
Total P, %[4]	0.47	0.47	0.47	0.47	0.47

[1] Control: Gilt + Barrow, Gilt (CP) : only gilt by NRC requirement; Barrow (CP) : only barrow by NRC requirement; Gilt (CP-1%) : only gilt by low CP requirement; Barrow (CP-1%) : only Barrow by low CP requirement;

[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 4. Formula and chemical composition of finishing phase2 (10-11 week).

	Treatment[1]				
	CON	CP		CP - 1%	
		Gilt	Barrow	Gilt	Barrow
Ingredients, %					
Ground corn	75.09	73.96	76.17	76.65	78.85
SBM, 45%	6.38	7.60	5.33	4.55	2.31
Wheat	10.00	10.00	10.00	10.00	10.00
Palm kermel meal	3.98	3.98	3.98	3.98	3.98
Tallow	1.62	1.62	1.62	1.59	1.60
SBM, 45%	0.71	0.70	0.73	0.75	0.79
Wheat	0.75	0.74	0.75	0.74	0.74
Palm kernel meal	0.02	0.02	0.01	0.03	0.02
Vit. Mix[2]	0.03	0.03	0.03	0.03	0.03
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%	0.11	0.11	0.10	0.16	0.15
L-Lysine-HCl, 78%	0.40	0.39	0.38	0.50	0.48
Trypthophan, 10%	0.41	0.35	0.40	0.51	0.55
β-mannanase	0.10	0.10	0.10	0.10	0.10
Chemical composition					
ME, kcal/kg[4]	3300.05	3300.04	3300.00	3300.02	3300.03
Crude protein, %[4]	10.43	10.88	10.00	9.88	9.00
Crude protein, %[5]	10.22	10.65	9.87	9.55	8.87
Crude fat[5]	4.03	4.46	3.99	4.01	4.56
Crude ash[5]	4.42	3.85	3.23	3.21	3.51
Lysine, %[4]	0.71	0.74	0.67	0.74	0.67
Methionine, %[4]	0.21	0.22	0.20	0.22	0.20
Ca, %[4]	0.46	0.46	0.46	0.46	0.46
Total P, %[4]	0.43	0.43	0.43	0.43	0.43

[1] Control: Gilt + Barrow, Gilt (CP) : only gilt by NRC requirement; Barrow (CP) : only barrow by NRC requirement; Gilt (CP-1%) : only gilt by low CP requirement; Barrow (CP-1%) : only Barrow by low CP requirement;

[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; $CuSO_4$, 105mg; Fe, 150mg; Zn, 72mg; Co, 0.5mg

[4] Calculated value

[5] Analyzed value

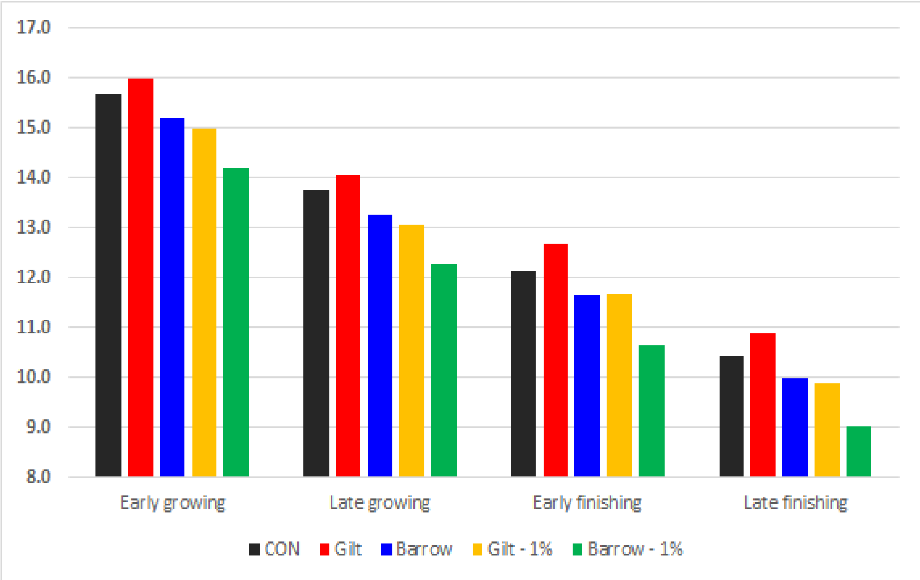

Figure 1. CP requirement of each treatment in the whole period

Table 5. Experimental design of subdivision of growing-finishing period by protein levels.

Treatment	Early growing (0-3 week)	Last growing (3-6 week)	Early finishing (6-9 week)	Late finishing (9-11 week)
CON	15.7%	13.8%	12.1%	10.4%
Gilt	16.0%	14.1%	12.7%	10.9%
Barrow	15.2%	13.3%	11.6%	10.0%
Gilt−1%	15.0%	13.1%	11.7%	9.9%
Barrow-1%	14.2%	12.3%	10.6%	9.0%

Table 6 . Effect of split-sex feeding with different protein diet on growth performance in growing-finishing pigs[1]

Criteria	Treatment					SEM[2]	P-value		
	CON	CP		CP - 1%			CP	SEX	CP*SEX
		Gilt	Barrow	Gilt	Barrow				
Body weight[3], kg									
Initial	30.55	30.55	30.55	30.55	30.55	0.560	-	-	-
3 week	47.32^{a}	44.62^{b}	46.88^{a}	44.23^{b}	44.83^{b}	1.480	0.75	0.71	0.82
6 week	64.73	60.25	64.85	57.54	61.90	1.891	0.54	0.34	0.98
9 week	87.65^{AB}	81.43^{CD}	88.87^{A}	77.26^{D}	83.32^{BC}	2.166	0.33	0.16	0.89
11 week	102.86^{A}	98.20^{A}	104.20^{A}	91.09^{B}	98.40^{A}	2.320	0.23	0.22	0.90
ADG, g									
0-3 week	799^{A}	670^{B}	778^{A}	651^{B}	680^{B}	19.6	0.16	0.10	0.33
4-6 week	828	744	855	633	812	33.4	0.31	0.07	0.65
0-6 week	813	707	816	642	746	24.6	0.22	0.06	0.96
7-9 week	1,011^{AB}	917^{BC}	1,057^{A}	849^{C}	940^{BC}	23.3	0.04	<0.01	0.57
10-11 week	1,074	1,190	1,077	994	1,070	31.6	0.15	0.78	0.18
7-11 week	1,038^{a}	1,023^{a}	1,064^{a}	905^{b}	992^{ab}	19.0	<0.01	0.04	0.40
0-11 week	927^{A}	867^{A}	943^{A}	776^{B}	869^{A}	19.2	0.04	0.03	0.80
ADFI, g									
0-3 week	1,775	1,778	1,863	1,688	1,789	56.1	0.56	0.51	0.95
4-6 week	2,613	2,259	2,581	2,001	2,610	90.1	0.55	0.03	0.45
0-6 week	2,194	2,019	2,222	1,844	2,200	67.6	0.53	0.09	0.62
7-9 week	3,279^{ab}	2,809^{bc}	3,343^{a}	2,438^{c}	3,075^{b}	99.3	0.41	0.01	0.80
10-11 week	3,523	3,069	3,523	3,172	3,172	80.1	0.47	0.20	0.20
7-11 week	3,401^{a}	2,939^{b}	3,433^{a}	2,805^{b}	3,123^{ab}	86.0	0.20	0.03	0.60
0-11 week	3,012^{a}	2,634^{bc}	3,048^{a}	2,441^{c}	2,838^{ab}	80.9	0.22	0.02	0.96
G:F ratio									
0-3 week	0.450^{a}	0.377^{b}	0.417^{ab}	0.386^{b}	0.380^{b}	0.0119	0.52	0.46	0.40
4-6 week	0.317	0.329	0.332	0.317	0.311	0.0074	0.30	0.87	0.96
0-6 week	0.371	0.350	0.368	0.348	0.339	0.0072	0.36	0.76	0.57
7-9 week	0.308	0.327	0.316	0.348	0.305	0.0095	0.86	0.26	0.55
10-11 week	0.304^{b}	0.390^{a}	0.309^{b}	0.315^{b}	0.336^{ab}	0.0112	0.30	0.20	0.04
7-11 week	0.304	0.352	0.313	0.323	0.318	0.0123	0.47	0.19	0.30
0-11 week	0.308	0.332	0.311	0.318	0.306	0.0115	0.46	0.23	0.74

[1] A total 160 cossbred pigs was fed from average initial body 30.55 ± 5.925 kg and the average final body weight was 98.95 kg.

[2] Standard error of the means.

[3] Values are means for four pens of eight pigs per pen.

A,B Means in a same row with different superscript letters significantly differ (P<0.01).

a,b Means in a same row with different superscript letters significantly differ (P<0.05).

Table 7. Effect of split-sex feeding with different protein diet on blood profiles in growing-finishing pigs[1]

Criteria	CON	CP Gilt	CP Barrow	CP - 1% Gilt	CP - 1% Barrow	SEM[2]	P-value CP	P-value SEX	P-value CP*SEX
IGF-1, ng/Ml									
Initial		----------------- 217.4 -----------------				-	-	-	-
3 week	256.1	227.1	241.7	190.7	240.9	8.80	0.29	0.08	0.31
6 week	262.2	172.6	255.0	235.4	222.9	14.10	0.64	0.30	0.16
9 week	234.3	246.2	224.2	275.7	206.6	10.39	0.81	0.07	0.34
11 week	274.9	244.6	227.8	259.0	222.8	8.67	0.82	0.21	0.64
Creatinine, mg/dL									
Initial		----------------- 0.77 -----------------				-	-	-	-
3 week	0.83	1.06	0.81	1.05	0.85	0.037	0.86	0.03	0.80
6 week	0.87	0.81	1.04	1.13	1.00	0.045	0.24	0.70	0.15
9 week	0.89	1.27	1.18	1.18	1.14	0.049	0.22	0.23	0.62
11 week	1.40	1.27	1.40	1.16	1.36	0.043	0.47	0.14	0.75
Blood urea nitrogen, mg/dL									
Initial		----------------- 8.2 -----------------							
3 week	9.3	10.5	8.8	6.5	6.9	0.43	<0.01	0.30	0.13
6 week	7.3	9.5	7.4	4.8	6.9	0.42	<0.01	0.93	<0.01
9 week	8.2	8.0	9.5	6.5	10.0	0.42	0.54	<0.01	0.28
11 week	10.7	9.8	9.3	8.4	11.2	0.43	0.30	0.92	0.25

[1] Least squares means of 5 observations per treatment.

[2] Standard error of the means.

Table 8. Effect of split-sex feeding with different protein diet on backfat thickness in growing-finishing pigs[1]

Criteria	Treatment					SEM[2]	P-value		
	CON	CP		CP - 1%			CP	SEX	CP*SEX
		Gilt	Barrow	Gilt	Barrow				
Backfat thickness, mm									
6 week	10.2	10.9	10.8	11.2	12.0	0.219	0.23	0.18	0.71
9 week	12.9	12.5	13.2	13.6	15.5	0.475	0.09	0.40	0.22
11 week	16.5	17.5	20.3	17.8	22.2	0.464	0.17	<0.01	0.64

[1] Least squares means of 10 observations per treatment.

[2] Standard error of the means.

Table 9. Effect of split-sex feeding with different protein diet on pork quality of longissimus muscle[1]

Criteria	Treatment[2]					SEM[3]	P-value		
	CON	CP		CP - 1%			CP	SEX	CP*SEX
		Gilt	Barrow	Gilt	Barrow				
Proximate analysis, %									
Moisture	73.04	73.46	74.96	70.15	73.28	0.74	0.53	0.72	0.35
Crude protein	21.27	22.27	21.11	23.42	21.27	0.24	0.48	0.58	0.87
Crude fat	2.17	2.27	2.34	2.38	2.75	0.96	0.84	0.52	0.27
Crude ash	1.44	1.43	1.26	1.13	1.27	0.07	0.52	0.88	0.48
Physiochemical property									
Cooking loss, %	25.47	25.54	26.26	26.83	26.12	0.35	0.54	1.00	0.45
Shear force, kg/0.5 $inch^2$	64.55	65.70	71.37	67.00	66.18	3.69	0.85	0.81	0.75
WHC[4], %	79.17	73.92	78.05	70.56	77.67	0.96	0.41	0.02	0.51
Backfat thickness, %									
P_2 mm	25.13	24.00	24.75	22.75	25.00	0.812	0.79	0.44	0.69

[1] Least squares means for 4 pigs per treatment.
[2] Control: Gilt + Barrow, Gilt (CP) : only gilt by NRC requirement; Barrow (CP) : only barrow by NRC requirement; Gilt (CP-1%) : only gilt fed low protein diet; Barrow (CP-1%) : only Barrow fed low protein diet;
[3] Standard error of mean
[4] Water holding capacity. .

Table 10. Effect of split-sex feeding with different protein diet on pork color after slaughter[1]

Criteria	Treatment[2]					SEM[3]	P-value		
	CON	CP		CP - 1%			CP	SEX	CP*SEX
		Gilt	Barrow	Gilt	Barrow				
CIE value, L[4]									
0 hour	42.12	41.87	42.81	42.31	40.12	0.425	0.52	0.48	0.69
24 hour	45.23	46.11	46.25	46.01	45.31	0.382	0.41	0.38	0.49
CIE value, a[5]									
0 hour	2.31	2.87	2.42	3.10	2.91	0.252	0.38	0.29	0.31
24 hour	4.30	4.24	4.11	4.81	4.43	0.187	0.41	0.45	0.36
CIE value, b[6]									
0 hour	4.58	4.78	5.12	4.80	5.11	0.245	0.37	0.47	0.32
24 hour	6.32	6.48	6.72	7.02	7.12	0.182	0.42	0.50	0.38

[1] Least squares means for 4 pigs per treatment.
[2] Control: Gilt + Barrow, Gilt (CP) : only gilt by NRC requirement; Barrow (CP) : only barrow by NRC requirement; Gilt (CP-1%) : only gilt fed low protein diet; Barrow (CP-1%) : only Barrow fed low protein diet;
[3] Standard error of means.
[4] L - luminance or brightness (vary from black to white).
[5] a - red·green component (+a=red, -a=green).
[6] b - yellow·blue component (+b=yellow, -b=blue).

Table 11. Change in the rate of payment according to the rate of 1+,1 grade (%)

1+,1 ratio	~40%	40~50%	50~60%	60~70%	70~80%	80~90%	90%~
Rate of Payment	72.5%	73.5%	74.5%	75.0%	75.5%	76.0%	77.0%

Table 12. Effect of split-sex feeding with different protein diet on economic benefits[1]

Criteria	Treatment[2]					SEM[3]	P-value		
	CON	CP		CP - 1%			CP	SEX	CP*SEX
		Gilt	Barrow	Gilt	Barrow				
Feed cost per weight gain, won/kg									
0-3 week	754	904	802	881	877	24.2	0.61	0.31	0.34
4-6 week	1,034	991	969	1,066	1,023	26.1	0.33	0.62	0.87
7-9 week	995	955	952	903	988	25.6	0.90	0.56	0.53
10-11 week	974	762	954	958	863	31.4	0.44	0.47	0.05
Growing period	894	948	885	973	950	20.7	0.39	0.41	0.71
Finishing period	984	858	953	931	925	19.2	0.63	0.35	0.30
Overall	939	903	919	952	938	13.9	0.38	0.97	0.69
Total feed cost per pig, won/head (reached 110kg)									
	$68,393^{ab}$	$63,648^{ab}$	$68,536^{a}$	$60,902^{b}$	$66,507^{ab}$	1210.0	0.38	0.07	0.89
Days to market weight (reached 110kg)									
	156^{b}	158^{b}	153^{b}	167^{a}	160^{ab}	2.4	0.15	0.32	0.88
1+, 1 grade, %									
	62.5	100	75	50	50	9.8	0.14	0.61	0.61
Net income of swine farm, won/pigs[4]									
	229,409	246,600	231,830	225,144	236,444	2421.0	0.44	0.87	0.24

[1] CON : Least squares means for 8 pigs per treatment.
Gilt, barrow Gilt-1%, Barrow −1% : Least squares means for 4 pigs per treatment.

[2] Control: Gilt + Barrow, Gilt (CP) : only gilt by NRC requirement; Barrow (CP) : only barrow by NRC requirement; Gilt (CP-1%) : only gilt fed low protein diet; Barrow (CP-1%) : only Barrow fed low protein diet;

[3] Standard error of means.

[4] Carcass price (5,000 won/carcass kg) - total feed cost (won/head) - production cost (129,229S won/head)

[a,b] Means in a same row with different superscript letters significantly differ ($P<0.05$).

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Ⅴ. Summary in Korean

본 연구는 암, 수 분리사육시 사료 내 단백질 함량이 육성 – 비육돈에 성장성적, 혈액성상, 돈육 품질 그리고 경제성분석에 미치는 영향에 대하여 알아보고, 이를 바탕으로 양돈농가에 암, 수 분리사육 사양 관리를 제시하기 위하여 수행되었다. 평균 체중 30.55 ± 5.925 kg의 3원 교잡종 ([Yorkshire × Landrace]) × Duroc) 육성돈 160두를 공시하였으며, 전체 5처리 4반복, 반복 당 8두씩 성별과 체중에 따라 난괴법 (RCBD; Randomized Complete Block Design)으로 배치하였다. 실험의 처리구는 다음과 같다. 1) control(CON) : 암컷과 거세돈을 함께 사육하는 처리구 (NRC (2012) CP 요구량) 2) Gilt : 암컷만 사육하는 처리구 (NRC (2012) 암컷 CP 요구량) 3) Barrow : 거세돈만 사육하는 처리구 (NRC (2012) 거세돈 CP 요구량) 4) Gilt - 1% : 암컷만 사육하는 처리구 (NRC (2012) 암컷 CP 요구량 - 1.0%) 5) Barrow -1 % : 거세돈만 사육하는 처리구 (NRC (2012) 거세돈 CP 요구량 - 1.0%)로 처리구를 구성하였다. 사양실험 결과, 암, 수 분리사육시 사료 내 단백질 함량이 육성, 비육돈에 미치는 영향은 사료 내 단백질 함량을 감소시키지 않고 암수 분리 사육하였을 때 CON treatment과 유의적인 차이를 보이지 않았다. 반면 사료 내 단백질 함량을 감소시켰을 때 성장성적에 부정적인 영향을 보였다. 혈액성상을 분석한 결과, 6주차 암컷이 거세돈에 비해 높은 혈중 Creatinine 농도를 보였다 (P=0.03). 이는 암컷이 거세돈에 비해 근육생성량이 상대적으로 많아진 것에서 기인하는 것으로 사료된다. 또한 사료 내 단백질 함량을 감소시켰을 때 육성전기와 육성후기의 BUN 농도가 낮아지는 결과가 나타났으며 (P<0.01), 이를 통해 단백질 함량이 낮아짐에 따라 그 이용률은 증가되는 것을 알 수 있었다. 등지방(P_2) 두께를 측정한 결과, 6주차에 사료 내 단백질 함량을 감소시켰을 때 등지방이 두꺼워지는 경향을 보였으며 (P=0.09), 11주차에는 거세돈이 암컷에 비해 두꺼운 등지방을 보였다 (P<0.01). 도축 후 채취한 등심근을 대상으로 한 일반성분 분석 결과 수분, 조단백질, 조지방 및 조회분 함량

에서 처리구간의 유의적인 차이가 발견되지 않았으며, 육색에서도 유의적인 차이가 나타나지 않았다. 또한 돈육 품질을 분석한 결과 가열감량과 전단력에서는 유의적인 차이를 보이지 않았으나, 보수력에서 거세돈이 암컷에 비해 높은 보수력을 보였다 (P=0.02). 경제성 분석을 한 결과, 사료 내 단백질 함량을 감소시키지 않고 암수 분리 사육을 하였을 때 농가의 경제성에 가장 긍정적인 영향을 미쳤다. 결론적으로 사료 내 단백질 함량을 감소시키지 않고 암, 수 분리사육 하는 것이 성장성적과 돈육 특성에서는 CON treatment과 유의적인 차이가 나타나지 않았으며, 1등급 비율의 향상으로 지육가격이 상승되고 사료비용은 절감되어서 경제적인 이득을 얻을 수 있을 것으로 사료된다.