A Dissertation
for the Degree of Doctor of Philosophy

Evaluation of Creep Feeding Duration and Creep Feed Quality for Suckling Piglets to Improve Growth Performance during Pre- and Post-weaning

이유 후 자돈의 사료적응성 향상을 위한 입붙이 사료의 급여기간과 품질의 조절방안

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이 논문을 농학박사 학위논문으로 제출함

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허 필 승

허필승의 농학박사 학위논문을 인준함

2013 년 8 월

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Overall Summary

Evaluation of Creep Feeding Duration and Creep Feed Quality for Suckling Piglets to Improve Growth Performance during Pre- and Post-weaning

These experiments were conducted to evaluate the 1) Effects of early feeding of highly digestible creep feed on pre-weaning growth performance and gut development of suckling piglet and lactation performance of sow, 2) Effects of feeding different creep feeds on pre- and post-weaning performance and gut development in pigs and 3) Effects of supplementation of SBM during suckling period on pre- and post-weaning hematological property and immune parameter.

Experiment I. Effects of early feeding of highly digestible creep feed on pre-weaning piglet growth, gut development and lactation performance of sow

This experiment was conducted to evaluate the effect of creep feeding duration on growth performance, feed consumption and intestinal development of suckling piglets and lactating sow performance. A total of 40 multiparous sows and their litters were allotted to one of four treatments according to creep feeding duration in a completely randomized design (CRD). Eight litters per treatment were allowed to access creep feed from 4, 11, 18 or 25 d postpartum, while 8 litters were not provided creep feed during entire 28 days of lactation. Sow feed and creep feed were provided *ad libitum* during the experimental period. Providing creep feed did not affect body weight and weight gain of piglets until 17 d. From 18 to 24 day, average daily gain was improved linearly as creep feeding duration increased (linear, $P<0.05$). However, from 25 to 28 days, average daily gain tended to increase then decrease as creep feeding duration increased (quadratic, $P=0.06$). Piglets consumed creep feed (eaters) did not show differences with non-eaters, but

both of piglets showed higher weight gain than piglets not provided creep feed after 18 d significantly ($P<0.05$). In each treatments, number of eaters and creep feed consumption were increased as piglets aged. The lowest creep feed intake was observed when piglets provided creep feed from 4 d postpartum ($P<0.05$). As piglets consumed creep feed from 18 d postpartum, body weight of sow was increased during lactation, and tended to shorten weaning to estrus interval ($P=0.06$). When creep feed was not provided to piglets, higher citric acid contents in milk was observed ($P<0.05$). At 28 d, 6 piglets of each treatment were slaughtered to determine intestinal morphology and intestinal microflora. Linear reductions of duodenal villus height and crypt depth were observed as creep feeding duration decreased ($P<0.1$). In microflora population, linear increase of Ct values of *Lactobacillus casei* were observed in ileum ($P<0.05$), colon ($P<0.05$) and rectum ($P<0.05$) as creep feeding duration increased. In contrast, Ct values of *Lactobacillus plantarum* were linearly decreased in cecum, colon and rectum as creep feeding duration increased ($P<0.05$). In conclusion, providing highly digestible creep feed during lactation could improve suckling piglet performance but early allowance to creep feed declines further creep feed intake during late lactation period.

Experiment II. Effects of feeding different creep feeds on pre- and post-weaning performance and gut development in pigs

This experiment was performed to determine the effects of supplementation of different creep feeds on suckling piglet performance and further adjustment to solid feed after weaning. A total of 24 multiparous sows and their litters were allotted to one of three treatments according to completely randomized design (CRD) at 14 d postpartum. Eight litters were fed highly digestible creep feed (Creep treatment), another eight litters were fed weaning pig diet (Weaner treatment) and the others consumed sow feed as creep feed until weaning (Sow treatment).

After weaning, a total of 96 piglets were selected to evaluate their post-weaning performance, and same weaner diet was provided to every treatment. In pre-weaning performance, different creep feeds did not affect a number of eaters which consumed creep feeds, but Creep treatment group tended to perceive higher creep feed intake than Sow treatment group from 14 to 21 d (P=0.12). In addition, Creep treatment group demonstrated significantly higher average daily gain than piglets fed other treatment diets from 21 to 28 d (P<0.01). However, after weaning, Weaner treatment group represented significantly higher feed intake than other treatment groups from 0 to 14 d after weaning (P<0.05), and also showed significantly higher average daily gain than Creep treatment group (P<0.05). From 14 to 35 d post-weaning, Sow treatment group tended to note higher G:F ratio than other treatment groups (P=0.06). At 4 d after weaning, 3 male and female piglets (7.67 ± 0.72 kg) were slaughters for analyzing their intestinal morphology and microflora. Creep treatment group tended to show lower duodenal villus height (P=0.07) and the lowest V:C ratio (P=0.11) than Weaner or Sow treatment group. Higher ileal crypt depth was observed in Sow treatment group (P=0.10). In intestinal microfloras, higher Ct values of *Lactobacillus plantarum* in rectum in Sow treatment group was remarked than Creep treatment group (P<0.05). Similarly, Sow treatment group tended to show higher Ct values of *Bacillus subtilis* in colon (P=0.07), and represented the highest Ct values of *Bacillus subtilis* through ileum and large intestine numerically. In conclusion, highly digestible creep feed could improve pre-weaning performance, but grain based creep feed could be recommended on the purpose of adjustment to solid feed after weaning.

Experiment III. Effects of supplementation of SBM during suckling period on pre- and post-weaning hematological property and immunological parameter

This experiment was conducted to determine the effects of supplementation of soybean meal (SBM) as creep feed during suckling period on

pre- and post- weaning immune response and growth performance. A total of 10 multiparous lactating sows and 80 piglets were used in this experiment. At 21 d, four male piglets and four female piglets were randomly selected from each litter, and one of male and female piglets were grouped and assigned to one of four treatment considering body weight and body weight gain from birth to 20 d. The treatments were 1) Control (Suckled maternal milk only), 2) Fed 50g of milk powder/day, 2) Fed 37.5g of milk powder and 12.5 g of soybean meal/day, 4) Fed 25g of milk powder and 25g of soybean meal/day. After weaning at 28 d, pigs were allotted to weaner facility with 4 pigs per each pen according to treatment and weaning weight. Feed and water were provided *ad libitum* through feeder and nipple during the whole experimental periods. In growth performance, piglets supplemented only milk powder showed the highest average daily gain, and both of piglets supplemented 12.5g and 25g/day of SBM showed numerically higher daily body weight gain than control group during suckling period. After weaning, piglets supplemented soybean meal during suckling period had higher average daily gain and G:F ratio than other treatments. However, significant differences were not observed in pre- and post-weaning performances. In haematological properties, supplementation of soybean meal during suckling period tended to increase plasma neutrophil proportion ($P=0.06$) and decrease lymphocyte proportion ($P=0.06$) at 7 d after weaning. Plasma IgA and IgG concentration was increased with age, and supplementation of soybean meal during suckling period significantly increased both of immunoglobulins at 7 d before and after weaning ($P<0.05$). Consequently, consumption of soybean meal during suckling period induces increase of immune response but immune response had little effects on piglet performance.

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List of Abbreviation

CRD	completely randomized design
G:F	gain to feed ratio
GLM	general linear model
Ig	immunoglobulin
IU	international unit
Lin	linear response
MCP	mono-calcium phosphate
ME	metabolizable energy
Quad	quadratic response
SBM	soybean meal
SEM	standard error of mean
V:C	villus height to crypt depth
WPC	whey protein concentrate

Chapter I. General Introduction

Weaning is a gradual process in nature, and piglets become independent to sow milk at 15~20 kg body weight around 70 days of age. However, in modern sow management, piglets are abruptly weaned at 3rd or 4th week of age when they still have immature digestive system, and weaning pigs often show post-weaning disorders such as low feed consumption, growth retardation and incidence of diarrhea (Varley and Wiseman, 2001). Thus, creep feed has been provided to prevent growth retardation and improve accessibility to solid feed after weaning. In addition, modern sows have been bred for larger litter size. Increase of litter size accelerated negative energy balance of lactating sows, and limited milk production of sows being considered a factor restricting growth potential of piglets during suckling period. Therefore, creep feeding has been applied to sow management to prevent body loss of sow and compensate for poor milk yield to maximize suckling piglet performance.

In Korea, feed industries produced 5,685 million tons of swine feed in 2012 (Figure 1). Among of them, creep feed production was recorded 163 thousand tons, which had a proportion of 2.86% of total swine feed production. This indicates that usage of creep feed is regarded as overproduction compared to other countries, because creep feed comprises small portion of total feed intake during life time of domestic pigs. Creep feed consumption has highly been variable between litters and within littermates, and creep feed consumption during suckling period has been recorded from 77 to 385g in the previous studies (Newby et al., 1984; Barnett et al., 1989; Fraser et al., 1994; Bruininx et al., 2002; Sulabo et al., 2010a). Generally, pigs need three times more feed than their weight gain until reaching market weight around 110kg. In this case, of actual creep feed consumption comprises of only 0.03~0.13% of feed consumption of market pigs.

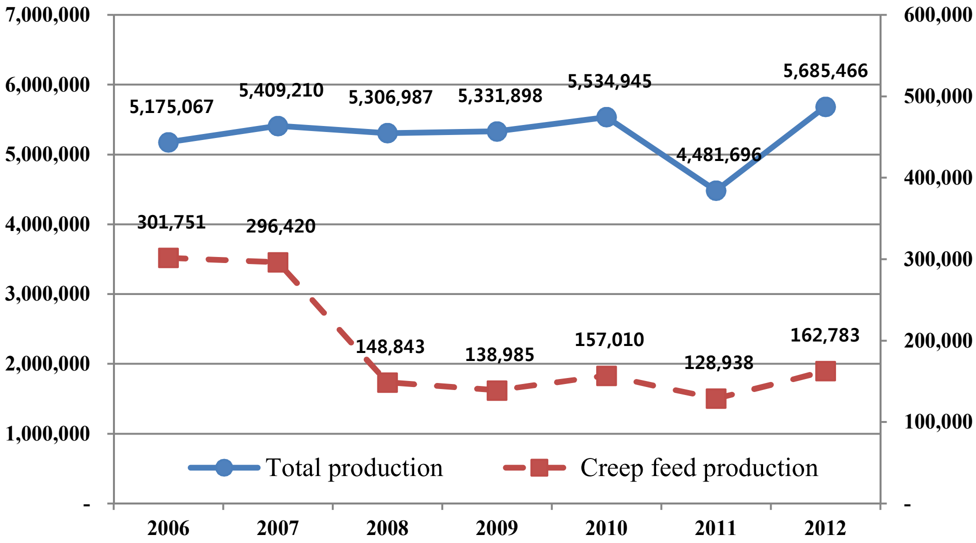

Figure 1. Recent total feed production and creep feed production in Korea (Ministry of agriculture, food and rural affairs, Korea, unit:ton)

Although, providing creep feed has been considered as a common practice in modern pig management, creep feed intake of piglets in numerous studies has been reported to be variable, and beneficial effects of creep feed are still controversial. Several studies showed some positive responses of creep feeding on pre- and post-weaning performances (English, 1980; Bruininx et al., 2002; Klindt, 2003; Kuller et al., 2004; Pluske et al., 2007), but other studies did not show any beneficial effect or observe growth promotion of piglets after weaning (Barnett et al., 1989; Sulabo et al., 2010a; Fraser et al., 1994). Reasons for conflict results of creep feeding are still uncertain, but a few researchers tried to find an answer from creep feed consumption of piglets during suckling period. Therefore, several studies were conducted to improve creep feed consumption with regard to feed ingredients (Okai et al., 1976; Fraser et al., 1994), feeder types (Sulabo et al., 2010c) and managements (Smith, 1960; Wattanakul et al., 2004; Kuller et al., 2007).

Creep feeding duration has been believed a determinant on creep feed consumption. Thus, many of the swine producers in Korea have been provided creep feed from very early days of age, expecting a higher weight gain during suckling period. However, Barnett et al. (1989) and Pajor et al. (1991) demonstrated that piglets generally started to consume creep feed from 11 or 12 day of age. Moreover, several studies reported very low consumption of creep feed until 3rd or 4th week (Okai et al., 1976; Pajor et al., 1991; Pluske et al., 2007). In addition, one of the most considerable factors in previous studies is creep feed quality. Barnett et al. (1989) used corn-SBM based diet, and also Pajor et al. (1991) used creep diet containing only 7% milk byproduct. Therefore, immunological approach with SBM as grain based creep feed may provide an answer for improving adaptability to solid feed after weaning.Positive effects of the complex digestible creep feed on piglet performance are well documented (Fraser et al., 1994; Pajor et al., 2002; Sulabo et al., 2009). Therefore, commercial creep feeds are generally formulated with palatable and digestible ingredients for young pigs, which have a premature digestive system. However, values of simple and grain based diet are relatively underestimated. On the purpose of increasing adaptation to solid feed after weaning, piglets need to consume cereal grains during suckling period. Consumption of grain diet induces maturation of digestive enzyme secretion (Owsley et al., 1986; de Passile et al., 1989), acid production (Cranwell et al., 1976) and nutrient absorption in small intestine (de Passille et al., 1989). Moreover, piglets naturally start to consume sow feed form 3rd weeks of age (Maner et al., 1959; Wallenbeck et al., 2005), which means grain based creep feed can be also utilized for young piglets during the late lactation. Therefore, creep feed quality is worth being reexamined.

Soybean meal (SBM) is one of the most abundant ingredients in swine feed and contains several anti-nutritional factors for young animals. Newby et al. (1984) mentioned that short-term access to creep feed or low creep feed intake under 100g before weaning sensitize piglets to antigens, which could induce immune response and gut damage after weaning. On the other hand, Barnett et al. (1989) also observed increase of immunological status by creep feeding, but they concluded that immune response had little effects on piglet performance. Therefore, immunological approach with supplementation of SBM as grain based creep feed may provide one of reasons for improving adaptability to solid feed after weaning.

Consequently, in this dissertation, 3 experiments were conducted to suggest proper application of creep feeding including 1) effects of creep feeding duration with highly digestible ingredients on pre-weaning piglet performances, gut development and lactation performance of sow, 2) effects of different creep feeds on pre- and post-weaning performance and gut development and 3) effects of supplementation of SBM during suckling period on pre- and post-weaning hematological property and immune parameter.

Chapter II. Literature Review

2.1 Potential Roles of Creep Feeding

2.1.1 Energy utilization of sow during lactation period

Energy requirements of sows depend on various factors such as litter size, piglet gain, lactation length and body reserves. Modern sow has been developed for larger litter size, so a loss of 10kg of body weight during lactation considered as generally acceptable. And sow could recover mobilized body reserves during lactation through the next gestation feeding program (Close and Cole, 2000).

The energy requirements of lactating sow composed with maintenance of sow and milk production. Piglets need 4g of milk for 1g weight gain, and let-down of lactating occurred at least once per 70 to 80 minute. Consequently, energy expenditure for milk production partitioned 65~80% of total energy consumption of lactating sows. Generally, feed intake of sow is related to milk yield (Noblet and Etienne, 1986), and deficient energy consumption directly affects to milk production. Sow mobilizes body reserves for cover up deficient energy for milk production for a while, but milk yield start to decrease when body reserves are depleted. O'grady et al. (1973) showed depressed milk yield and piglet growth when sows had deficient energy condition. Suck a mobilization of body reserves generally observed during the late lactation period than the early lactation period (Mullan and Williams, 1990).

Generally, sows are hard to consume sufficient feed during lactation, and they mobilize body reserves for milk production and lost their body weight. Needs of milk for piglet growth continuously increase as piglets aged, but milk production of sow increases to 2nd week of lactation and start to decline after 3rd week. Therefore, sow has negative energy balance during late lactation period and often loses their body weight more than 10kg, which can result detrimental effects on further progeny related to estrus, ovulation and embryo survival (Close and Cole, 2000).

Providing an additional energy source to suckling piglets could prevent loss of sow body reserves. Consumption of milk replacer or creep feed by piglet reduces demand for maternal milk suckling, and also reduces milk production of the sow. Therefore, providing creep feed could be applied to modern sow management purpose on prevention of body weight loss during lactation.

2.1.2 Compensation of poor milk yield during suckling period

After weaning, piglets are faced on growth retardation, which caused by several stress factors such as departed from their dam and littermates, mixed with unfamiliar penmates, changes of environment and transition to solid feed from maternal milk. Marion et al. (2003) reported that piglets had lost 9% of body weight during the first day after weaned, and they recovered lost body weight four days after weaned

And also, growth retardation of pigs after weaning affected by pre-weaning status such as weaning age, weaning weight, feed composition and development of digestibility. In the study of de Passill'e et al. (1989), they showed lighter piglets had lower pancreatic amylase level and chymotrypsin activity than heavier. This means that heavier piglets have relatively well-developed digestive system than lighter weight piglets, and weaning weight and weight gain during suckling period have been considered a major determinant of post-weaning performance (Klindt, 2003). Also, weaning weight is related to weaning age. Piglets weaned at younger age or have lighter body weight increases chance to contaminants to diseases, and easy to show lower productivity after weaning than older or heavier piglets (Cera et al., 1988; Barnett et al., 1989; Manhan and Lepine, 1991; Pluske et al., 1995). Lighter piglets have a less-developed gastrointestinal track to digest solid feed, and hard to maintain body temperature after weaned because they could not accumulate sufficient body fat during suckling period. (Sloat et al., 1985)

Generally, growth potential of piglets is hard to be attained during suckling period because of limited milk yield of their dam. Even within littermates, milk consumption of piglet depends on birth weight and teat order which affects a body weight gain during suckling period. Mahan and Lepine (1991) showed weaning weight of piglets which weaned at 21 d could be diverse from 3.5 to 9.0 kg. Furthermore, this disparity of weaning weight further effects to feed consumption, digestibility and feed conversion ratio after weaning (Efrid et al., 1982; de Passill'e et al., 1989). Therefore, pigs with lighter weaning weight need much more time to reach market weight than heavier pigs.

As mentioned before, litters in the late suckling period require an additional energy source for maximizing growth potential. In the study of Zijlstra et al. (1996), from weaning at 18^{th} day of age, pig fed milk replacer showed higher weight gain than still suckled pigs (Figure 1). This result obviously shows that sow’s milk yield is limiting factor for maximize growth performance when piglets weaned at later than 18^{th} day of age.

In several studies about creep feeding showed that creep feed could compensate poor milk yield and improve piglet performance during suckling period (Fraser, et al. 1993; Pajor et al., 2002; Sulabo et al., 2009). Because of undeveloped gastrointestinal track, suckling piglets need highly digestible creep feed for utilization. Mavromichalis (2006) showed that providing highly digestible creep feed during suckling period could improve pre-weaning body weight gain and weaning weight, and Fraser et al. (1993) also represented that complex creep diet could improve weight gain during four weeks suckling period. Moreover, Smith (1960) reported that major energy consumption of piglet depends on creep feed and only 39% of energy consumption depends on maternal milk at 6th week of age. These observations represented that creep feeding is more required when piglets weaned at later ages.

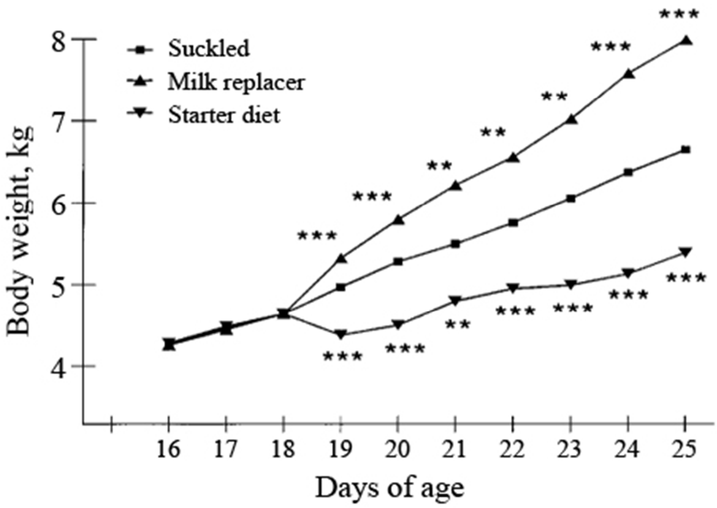

Figure 1. Mean daily body weight from 16 to 25 days of pigs, either suckled, fed milk replacer, or starter diet. Superscript means significant differ (**, P<0.1; ***, P<0.01) from suckled pigs. (Zijlstra et al. 1996)

2.1.3 Help adaptation to solid feed after weaning

Post-weaning feed intake is the most important factor to reduce growth retardation of weaning pigs (Plusky et al., 1993). In nature, weaning is a gradual process with decrease of suckling milk and increase of consumption of solid materials (Wattanakul et al., 2004). However, in modern management, piglets are weaned abruptly at 3rd or 4th week of age. Therefore, piglets have to transit to solid feed at relatively young age when their digestive systems are not developed, so piglets have trouble in digestion such as pH regulation, enzyme secretion and absorption of nutrient (Hansen et al., 1993). Because of these reasons weaning pigs often showed reduced feed intake, villus atrophy, diarrhea, lower digestibility and nutrient absorption after weaning (Cera et al., 1988).

Frequent access to solid feed during lactation could help transition from milk to solid feed after weaning. Yan et al. (2011) suggested that effects of creep feeding are much clearer at post-weaning than pre-weaning because of oral tolerance to solid feed. Providing creep feed during suckling period help sudden transition to solid feed after weaning and reduce post weaning problems (English, 1980). Several studies showed that apply to solid feed stimulates acid production and digestive enzyme activity (Cranwell et al., 1976; Owsley et al., 1986). And also, Plusky et al. (2002) demonstrated that non-digestible carbohydrate fraction induced gut development of piglets. Therefore, providing creep feed during suckling period help development of amylase and protease activities in the gut which have an advantage on degradation of solid feed and denial of feed consumption after weaned (de Passill'e et al., 1989). Therefore, providing creep feed has a role in reducing growth retardation after weaning.

2.2 Actual Application and Arguments in Creep Feeding

2.2.1 Controversial results of creep feeding

2.2.1.1 Sow and piglet performance

As presented in Chapter 2.1, providing creep feed could diminish overload of milk production and prevent body loss of the sow. However, only few reports were published about effects of creep feeding on sow performances, and also, results are controversial. Smith (1960) and Kuller et al. (2004) reported decrease of body loss by creep feeding with an intermittent sucking system. However, Sulabo et al. (2010a) reported that providing creep feed did not show any alteration of body weight and back-fat thickness of sows, and concluded that effects of creep feeding on sow performances may increase with lactating length, and creep feeding until 21st day of age does not affect to sow performances.

Theoretically, providing creep feed has a potential to compensate poor milk yield and help adaptation to solid feeding. However, benefits of creep feeding are still controversial in pre- and post-weaning performances of piglets (Barnett et al., 1989; Bruninx et al., 2002; Fraser et al., 1994; Sulabo et al., 2009). Positive results have been reported about heavier litter weight and easier transition to solid feed after weaning (English, 1980; Bruininx et al., 2002; Klindt, 2003; Kuller et al., 2004; Pluske et al., 2007). Whereas, other researches did not show any effects of creep feeding during suckling period or reported beneficial effects of creep feeding during suckling diminished after weaning (Barnett et al., 1989; Pajor et al., 1991; Fraser et al., 1994; Kuller et al., 2007; Sulabo et al., 2009).

Researchers did not report the beneficial effect of creep feeding explained their results were due to the low creep feed consumption of suckling piglets. In early study of Lodge et al. (1961), they calculated that piglets did not require additional supplements to sow's milk until 8th week of age when they were weaned at the 13kg body weight. Although, this result is hard to use in current sow management because of the increases of litter size and growth potential of piglets, English et al. (1988) also reported that piglets acquired most of energy from consumption of maternal milk, and creep feed intake took only small part of energy consumption until 4th week of age. Similarly, Okai et al. (1976) mentioned that low creep feed intake resulted from sufficient milk consumption from their dam until weaned at 21st day of age. Furthermore, Aherne et al. (1982) reported that there is little evidence that creep feeding could help adjustment to solid feed at four weeks of age. Recently, Sulabo et al. (2009) showed that providing creep feed accelerated smaller piglet's weight gain during first week after weaning, and diminished occurrence of fall back pigs during three days after weaning. However, this beneficial effect was not prolonged for five weeks, and creep feed eaters and non-eaters showed fairly consistence feed intake after weaned. Similarly, Kuller et al. (2007) also concluded that intermittent suckling did not positively or negatively affects long-term performance of pigs until slaughtered.

2.2.1.2 Development of digestive and immune system

Dietary changes, especially at birth and weaning affect intestinal environment. Piglets experience extensive changes in digestive enzyme secretion, gut morphology, and microbial population through change of diet (Varley and Wiseman, 2001).

Intestinal villus height can be considered as an indicator of nutrient absorption in pigs (Shim et al., 2005). Okai et al. (1976) mentioned that even little amount of creep feed consumption may induce piglet's digestive enzyme secretion and modify gut microbes which helpful for adjustment to solid feed after weaning. And also, Nabuurs et al. (1993) reported that shortening of intestinal villus height can be reduced by providing supplementary feed to piglets during suckling period.

However, Bruininx et al. (2004) concluded that consumption of creep feed did not affects intestinal morphology and microbial activity in colon during suckling period.

Mathew et al. (1994) reported that creep feeding from 15 to 29 day of age has a little effect on microbial population of piglet's intestine, because creep feed consumption possesses only little part milk consumption. However, Shim et al. (2005) which added oligofructose, probiotics and symbiotics in creep feed from 7 to 21 day of suckling period showed feed additives could modify intestinal microbes during suckling period. In this study, piglets consumed creep feed with additives showed higher weight gains than piglets consumed control creep feed. And they also observed increase of bifidobacteria in ileum and colon, and decrease of coliform in colon with additives.

Newby et al. (1984) mentioned that short-term access to creep feed and low creep feed intake under 100g during lactation sensitize piglets to antigens, and further exposure to solid feed after weaning could induce immune response and gut damage. Barnett et al. (1989) represented that non-eaters had the higher ovalbumin antibody titer than eaters after weaning, when they had provided creep feed contained ovalbumin during suckling period. These results indicated that piglets did not consume creep feed or consume a small amount of creep feed could show hypersensitivity to solid feed when they were weaned. However, they concluded their effects were small. Moreover, in the study of Shim et al. (2005) providing creep feed with feed additives did not affect hematological parameters such as lymphocytes, neutrophils. Increase of lymphocyte and neutrophil can be an indicator of immune response.

2.2.2 Problems associate with creep feed consumption

2.2.2.1 Variations in creep feed consumption

Amount of creep feed intake and proportion of piglet consuming creep feed are important factors to determine pre- and post-weaning performances (Sulabo et al., 2010c). Creep feed consumption has strong co-relation with pre-weaning weight gain, especially one week before weaning (Pajor et al., 1991). Therefore, pre-weaning creep feed intake stimulate post-weaning feed intake and decrease time to start consuming solid feed after weaning (Bruininx et al., 2004).

Creep feed intake of suckling piglets are highly variable, and numerous studies published variance of individual creep feed intake between litters and even within littemates (Okai et al., 1976; Barnett et al., 1989; Pajor et al., 1991; Sulabo et al., 2010a). In the study of Bruinninx et al. (2002), litters consumed creep feed from 445 to 7,840 g during 17 days before weaning at 28th day of age, and average creep feed consumption of piglet were recorded 377 g over 149 piglets during suckling period. Similarly, in the study of Fraser et al. (1994), piglets consumed an average of 385 g of highly digestible commercial creep feed during suckling period. Sulabo et al. (2009) also reported variance of creep feed consumption from 264 to 2,349 g/litter during 18 days of creep feeding until weaning at 21st day of age. In other cases, piglets often consume a very small amount of creep feed (Appleby et al., 1991; Bruininx et al., 2002). In the study of Barnett et al. (1989), piglets only consumed 77 g of creep feed, and similarly, Newby et al. (1984) reported that piglets consumed 107 g of creep feed during suckling period.

In creep feed consumption, between litter variations might be explained with genetic and environmental differences between litters and sows in their health and milk production, while variation within littermates might be induced by milk competition with littermates (Pajor et al. 1991).

2.2.2.2 Individual creep feed consumption

In relatively old studies, researchers tried to explain effects of creep feeding focused on whole litter intake, and creep feed consumption estimated by analysis of both litter means and between-litter variation. However, after their highly variable individual creep feed intakes within littermates were noticed, many of the researchers tried to study benefits of creep feeding based on individual creep feed intake of suckling piglets.

Bruininx et al. (2001) demonstrated variation of individual creep feed consumption also affects post-weaning performance of pigs. Variance of individual creep feed consumption can be explained with two opposite reasons, which are gut maturation of larger piglets and compensation of poor milk intake of smaller piglets. De Passill'e et al. (1989) revealed that digestive enzyme secretion also showed large variance within littermates, which means individual piglet's gut development maturated at a different rate within littermates. Therefore, larger or strong piglets could consume more creep feed because they have relatively developed digestive system (Pajor et al., 1991). Also, Apple by et al. (1991) reported improvement of creep feed consumption by increasing feeding space. Stronger or larger piglets also could take more space for creep feeding than weaker or smaller piglets.

Oppositely, Alger et al. (1990) showed smaller and weaker piglets consume more feed for compensating poor milk yield. Similarly, Sulabo et al. (2009) observed that creep feed eaters showed lighter pre-weaning body weight than non-eaters when creep feed provided from 18 to 21st day of age. Furthermore, they also observed piglets categorized as lighter weight showed higher number of eaters than heavier piglets, and piglets in rear or middle teat were more categorized as eaters than piglets in anterior teat. As a result, providing creep feed accelerated smaller piglet's weight gain during first week after weaning, and also diminished occurrence of fall back pigs during three days after weaned were observed in smaller pigs.

These results support the idea that creep feeding is more beneficial to smaller piglet in litter that needed additional nutrient source for compensate poor milk.

Pajer et al. (1991) explained the opposite aspects of creep feed consumption with age of piglets, which means larger piglets consume more creep feed in earlier ages by digestive maturity, but smaller piglets consume more creep feed in later ages for compensate milk.

To improve individual creep feed consumption of piglets during suckling period, researchers have tried to find a solution through feed materials (Okai et al., 1976; Fraser et al., 1994), feeder types (Sulabo et al., 2010c), managements (Smith, 1960; Wattanakul et al., 2004; Kuller et al., 2007). However, factors determine individual creep feed intake are still uncertain.

2.2.2.3 Eater versus non-eater

To estimate individual creep feed consumption, several methodologies have been introduced such as video recording, visual observation and fecal observation of marker (Plusky et al., 2007). Since researchers start to focus on individual creep feed consumption, suitable methodology for measurement of individual creep feed intake still has not been estimated (Pajot et al., 1991). To categorize piglets as eater or non-eater for estimating individual creep feed consumption, chromic oxide often added in creep diet because chrome oxide does not affect palatability of piglets (Kuller et al., 2007). Therefore, piglets could be categorized with presence of chromic oxide in feces. However, this method could make misestimating when piglets do not consume creep feed continuously or when a large amount of milk intake dilute a small amount of creep feed in the gut (Kuller et al., 2007). Similarly, Bruininx et al. (2002) reported disadvantage of chromic oxide as a qualitative indicator of categorizing eaters because they had trouble in categorizing piglets because of indistinguishable fecal color with chromic oxide. On the other hand, Pluske et al. (2007) used indigo carmine and reported that indigo carmine was a better indicator for creep feed consumption.

As described in Chapter 2.2.3.2, consumption of creep feed during suckling period showed controversial results. Carstensen et al. (2005) showed piglets had consumed larger amount of creep feed during suckling period had higher feed intake during two days after weaning than piglets had consumed small amount of creep feed. Similarly, Bruininx et al. (2004) showed good eaters had a higher daily weight gain than non-eaters, and Kuller et al. (2007) showed creep feed eaters had better net absorption in the small intestine than non-eaters. However, Sulabo et al. (2009) reported that pigs had been categorized as eaters showed lighter body weight at 21st day after weaning than non-eaters or pigs had not provided creep feed during suckling period.

In Bruininx et al. (2002), piglets categorized as eaters started to consume feed four hours after weaning, but non-eaters and non-creep providers started to consume feed from 6.7 and 6.9 hours respectively. And also, eaters consumed more amounts of feed than non-eaters and non-creep providers during 24 hours after weaning. Similarly, in the result of Pluske et al. (2007), pigs categorized as small/non eaters suffered growth retardation after weaned, but pigs categorized as good or moderate eaters grew faster than the small/non eaters. These results mean pre-weaning creep feed consumption could help adaptation to solid feeding after weaning. Furthermore, in the study of Sulabo et al. (2010b), creep feed eaters showed improved weight gains about 18% than non-eaters during three days after weaning. However, this advantage of creep feeding was disappeared at 28th day after weaning.

2.2.3 Diversity of creep feed composition and feed ingredients

Generally, creep feed has been formulated with palatable and digestible ingredients, which suckling piglets could utilize (Whitelaw et al., 1966). Moreover, Fraser et al. (1993) pointed out more than 25% of soybean meal in formulations of previous studies. Diets contain soybean meal are not easy to be digested by young animal and such diets have several anti-nutritional factors. In the early study of Whitelaw et al., (1966), they mentioned that little attention had been given to creep feed composition. However, in current days, compositions and nutrient requirement for creep feed are still not established.

Table 1 reveals several characteristics in creep feed used in previous studies. Crude protein levels in creep feed were ranged from 15.8% to 23.9%, and lysine levels were ranged from 0.98 to 1.74%. Not presented in Table 1 but Ca and available P compositions were also ranged variable from 0.79 to 0.97 and from 0.38 to 1.00%, respectively. In feed ingredients, composition of cereal grains and milk product were various in each creep feed. Moreover, many of the studies did not present chemical composition or feed formulation in papers. Effects of creep feed composition on creep feed consumption described in Chapter 2.3.3.

Table 1. Various creep feed composition and materials used in present studies

Researcher	Crude protein, %	Energy, kcal/kg	Lys, %	Characteristics
NRC, 3~5 kg (1998)	26.00	3265 ME	1.50	
Fraser et al. (1993)	Over 19.00			Commercial creep starter, no SBM, less allergenic reaction
	18.40			Corn-44%, SBM-25%, barley-15%, whey powder-7%
Bruininx et al. (2002)	16.80	2360 NE		Barley-34.88%, wheat-15%, corn-10%
Kuller et al. (2004)	21.70	3072 NE	1.46	Corn-SBM based, Milk products-34%
Carstensen et al. (2005)	19.10		1.45	Wheat-42%, corn, fish meal, whey-4.5%
Shim et al. (2005)	22.00	3570 ME	1.61	Extruded rice-30%, lactose-17.31%, Whey powder-10%, SBM-9%, corn-6%
Sulabo et al. (2009)	19.60	3502 ME	0.98	Milo-SBM 90%
	23.90	3493 ME	1.56	Whey-35%, oat-30%, plasma-6%, fish meal-6%, lactose-5%
Sulabo et al. (2010)	23.90	3495 ME	1.56 SID	Oat groats-30%, spray dried whey-25%, extruded SPC-10%, corn-6.15%, SBM-2.3%
Yan et al. (2011)	22.00	4000 DE	1.74	Whey-24.16%, corn-22.4%, fermented SBM-10%, SBM-8%
	22.00	5000 DE	1.74	Whey-21.59%, coconut oil-21.59%, fermented SBM-10%, SBM-8%

2.3 Factors Affecting Creep Feed Consumption

2.3.1 Nutritional availability

Effects of creep feeding obviously more critical when piglets received small amount of milk from sow (Whitelaw et al., 1966). In the study of Pluske et al. (2007), piglets suckled anterior teats showed the higher number of small/non eaters than piglets suckled posterior teats, and they concluded that consumption of adequate milk from the anterior teat may reduce creep feed intake. Therefore, milk yield can be a determinant of creep feed consumption. Milk yield declines with deficient energy consumption of sows (O'grady et al., 1973). Although sow can mobilize body reserves for milk production, but milk yield can be decreased when body reserves are depleted.

However, Sulabo et al. (2010b) showed that though restricted fed sows showed higher body weight loss than *ad libitum* fed sows, but restricted feeding on sows did not drive piglets to consume more creep feed during 21 days of suckling period. This result means that piglets do not consume creep feed for compensate poor milk yield until 3rd week of age, because they also reported very low creep feed consumption of suckling piglets in both of restricted fed sows and *ad libitum* fed sows. Low creep feed consumption of suckling piglets in early days of age has been reported several times by many of the other researchers (Okai et al., 1976; English, 1988; Pluske et al., 2007).

Litter size has significant co-relation with birth weight (Klindt, 2003). Barnett et al. (1989) represented that larger litters have lower birth weight, weaning weight and post-weaning average daily gain. Therefore, litter size is also an important determinant for creep feed consumption. In the research of Klindt (2003), they concluded that providing creep feed could improve birth to weaning average daily gain and weaning weight when sow lactate more than eight piglets.

Birth weight reveals growth potential of piglets, and generally larger piglets have priority to choice sow's teat. Piglets had suckled anterior teats showed higher weight gains than piglets had suckled posterior teats during suckling period, because anterior teats produce more milk. Furthermore, milk from anterior teats contains higher level of protein and DNA in milk than posterior teat (Pluske et al. 2007). Thus, birth weight is considered a major determinant affecting weaning weight. In past days when pigs weaned at 8^{th} week and market weight was 80 kg, weaning weight was considered the most important determinant for post-weaning growth because weaning weight account for 15% of market weight.

As litter increased and as weaning age decreased, importance of nutrient availability of piglets has been increased during suckling period (Klindt, 2003). Nutrient availability of piglet can be also attained by improvement of milk yield by high density sow diet or increased feed intake of sows (Sulabo et al., 2010b), but King (2000) demonstrated that piglets have growth potential to growth 450 g/day, and this requires consumption of sow milk 2 kg/day. This means sow requires 14 kg/day feed intake, which is unable to be attained. Therefore, creep feed consumption could be affected by litter size and body weight of piglets, which related to milk yield.

2.3.2 Starting age and feeding duration of creep feed

Pajor et al. (1991) mentioned that piglets started to consume creep feed by exploratory and social activity rather than nutritional demand, but consumption with nutritional demand increased with age. Longer exposure to creep feed increase opportunity to consume creep feed (Barnett et al. 1989), and when piglets initiate consuming creep feed and consume more amounts of creep feed on one day than other littermates, they consume more creep feed on the other day (Appleby et al., 1991). Therefore, pork producers have been provided creep feed from very early days of age expecting higher weight gains of suckling piglets. However, Kuller et al. (2004) showed only two days of creep feeding could improve post-weaning performance.

Sulabo et al. (2010b) hypothesized that creep feeding duration may have a role in changes of creep feed intake. However, creep feed consumption of piglets less than 3 weeks of age are very low (Okai et al., 1976). Barnett et al. (1989) showed that piglets started to consume creep feed from 11^{th} day after birth, and creep feed intake was linearly increased with age. Similarly, Pajor et al. (1991) also observed that piglets consumed creep feed from 12^{th} day of age, and piglets consumed only little amount of creep feed until 21^{st} day of age. In this research, piglets consumed only 8.3g to 53 g of creep feed until weaned at 21^{st} day of age.

In the research of Pluske et al. (2007), creep feed consumption of suckling piglets from 12 to 21^{st} day of age accounted for only 14% of total creep feed intake during suckling period, and relatively, 73% of total creep feed intake was consumed from 25 to 31^{th} day of suckling period. They calculated that creep feed contributed 1.2~17.4% of daily energy intake of suckling piglet from 21 to 35^{th} day of age. Furthermore, Smith (1960) reported that major energy consumption of piglet depends on creep feed intake and only 39% of energy consumption depends on maternal milk at 6^{th} week of suckling period. These observations represented that creep feeding is more required when piglets weaned at later ages. Sulabo et al. (2010) also concluded that individual creep feed intake more related to piglet age than age of starting creep feeding.

2.3.3 Creep feed quality

2.3.3.1 Complexity of creep feed

Generally, piglets in young age require feed with palatable and high biological value. Fraser et al. (1993) pointed out more than 25% of soybean meal in formulations of previous studies. Soybean meal contains several anti-nutritional factors, which are not digested by young animals.

Complexity of creep feed considers several factors such as digestibility, palatability and antigen properties (Sulabo et al. 2009). Therefore, creep feed complexity considered as an important factor for stimulating creep feed intake (Sulabo et al. 2010). Similarly, Fraser et al. (1994) and Pajor et al. (2002) also reported that complex diets had advantages on post weaning performance.

In the research of Fraser et al. (1993), piglets provided high complex creep feed consumed significantly higher amount of creep feed and showed greater weaning weight than piglets provided simple corn-SBM based creep feed. Sulabo et al. (2010) showed that providing complex creep feed to litters improved creep feed consumption twice more than providing simple creep feed, and piglets consumed complex creep feed had 4.1% and 5% better total weight gain and daily weight gain than piglets consumed simple creep feed during suckling period, respectively. Moreover, providing complex creep feed also affected proportion of piglets consume creep feed from 28 to 68%. Therefore, diet complexity has an important role in stimulating individual creep feed intake. Definitely, complex creep feed could improve creep feed intake and weight gain than simple creep diet, but complexity generally requires expensive feed materials which young piglets could utilize with the undeveloped digestive system (Okai et al., 1976).

2.3.3.2 Cereal grains in creep feed

In the previous study of Fraser et al. (1993), when high complex feed changed to low-quality diet at two weeks after weaning, pigs had provided high-quality feed showed a growth lag by changing diet. These results mean highly complex diet could improve piglet performance but adaptation to grain based diet still results detrimental effect on performance even two weeks after weaning.

Grain based diet have an important role in development of digestive system. Owsley et al. (1986) demonstrated that intestinal trypsin activity dramatically increased two days after weaning. Similarly, de Passile et al. (1989) reported that consumption of solid feed induced secretion of amylase and protease. Effects of solid diet on gut development also reported by Cranwell et al. (1976) which showed creep feed stimulate acid production, and by de Passille et al. (1989) which demonstrated creep feed enhance net absorption of the small intestine.

Furthermore, weaning is a gradual process in nature (Wattanakul et al., 2004). As likely as in nature, piglets could learn consumption of solid feed from their dam when sows eat scattered feed from the ground in the outdoor rearing system. Furthermore, though farrowing facility of the indoor rearing system prevents piglets to learn solid feeding, but Maner et al. (1959) demonstrated that piglets could access to sow feed after three weeks of age, and Wallenbeck et al. (2005) also reported that piglets could consume the sow feed for compensating poor milk production at later week before weaning.

Therefore, rough feed formulated with cereal grains also might be provided piglets as creep feed for development of digestive system to prepare weaning.

2.3.3.3 Nutrient composition

Although, feed materials have an important role in creep feed, but nutrient compositions in creep feed have seen less important for piglet performance. In the study of Whitelaw et al. (1966), changes of dietary protein level from 14 to 22% in creep feed did not affect suckling piglet performance from 21 to 56th day of age, and they concluded that high level of protein in creep diet is unnecessary. Whitelaw et al. (1966) also mentioned about protein : energy ratio in creep feed, but no research has been conducted focused on protein : energy ratio of creep feed after this research. In case of energy contents, Yan et al. (2011) demonstrated that sow and piglet performances were not affected by energy density of creep feed. Several researches showed that piglets acquire most of the energy from consumption of maternal milk, and acquire only small part of the energy from creep feed at 3rd or 4th week of age (English et al., 1988; Okai et al., 1976). Therefore, little effect of nutrient compositions in creep feed on suckling piglets due to the sufficient milk consumption during suckling period.

2.3.4 Preservation methods

2.3.4.1 Feeding facility and feed wastage

Imitative learning is one of the important factors to initiate creep feeding, and pre-weaning experiences also affect adaptation to the post-weaning environment (Appleby et al., 1991; Cox and Cooper, 2001). In modern sow management, sows have been reared in farrowing crate for protecting piglets from injury. However, this system restricts movement of sow and prevents piglets to learn solid feeding behavior. Therefore, piglets are more dependent on sow's teat activity and less dependent on finding solid edible materials. In outdoor system, piglets could see and learn how to eat solid feed from their dam when sows eat scattered feed from the ground. But in indoor system, sow provided their feed through a feeder, so piglets have little opportunity to contact sow feed and learn how to consume solid feed (Cox and Cooper, 2001).

Morgan et al. (2001) represented that piglets experience to solid feed could stimulate other un-experienced penmates to consume more feed after weaning. Sulabo et al. (2010c) demonstrated that piglets provided creep feed through a tray type feeder spent more time to consume creep feed than hopper type, and this result was induced by experience of seeing other pig’s feeding. In addition, they also showed that piglets consume more creep feed with a tray feeder than with hopper type feeder. Similarly, Wattanakul et al. (2005) also reported that feeding space and accessibility to feed affected creep feed consumption. In this study, piglets consumed more creep feed and spend more time to consume creep feed when creep feed provided through a tray type feeder than hopper type feeder. Therefore, creep feed consumption has a relationship with feeding environment, and creep feed consumption of suckling piglets can be improved when proper feeding space is allowed.

Feed wastage is an important factor for estimating creep feed intake. Increase of wastage could be led to underestimation of creep feed digestibility and efficiency. Okai et al. (1975) mentioned that complex creep feed could be caked in feeder, and this may lead to overestimation of creep feed intake of piglets provided complex creep feed. Mathew et al., (1994) also reported that increased interest in creep feed of suckling piglets may increase feed wastage. Wattanakul et al. (2005) observed increase of creep feed disappearance by using tray type feeder, but increase of average daily gains of suckling piglets were not observed. In other case, Sulabo et al. (2010c) reported that hopper type creep feeder showed reduced creep feed disappearance but proportion of eaters among litter was increased. These results mean that lots of creep feed was wasted than consumed when creep feed has preserved by tray feeder. Therefore, both of Wattanakul et al. (2005) and Sulabo et al. (2010c) concluded that these observances were due to the increase of feed wastage.

2.3.4.2 Intermittent suckling

To improve creep feed intake, intermittent suckling has been introduced. Intermittent suckling is a management which separate piglets with their dam for several hours a day during suckling period. This temporary weaning induces stress to suckling piglets, and increases the blood glucocorticoid level. Glucocorticoid has been suggested that has a role in promoting absorption of water and sodium in small intestine, and is known to accelerate maturation of villus (Nabuur et al., 1996).

Nabuurs et al. (1996) showed providing creep feed with intermittent suckling prevents villus atrophy and improves net absorption in the small intestine after weaning. Similarly, Kuller et al. (2007) also reported that intermittent suckling improved net absorption of the small intestine at four days after weaning.

Kuller et al. (2004, 2007) showed intermittent suckling doubled creep feed intake during suckling period, and improved post-weaning average daily gain when piglets separated from their dam 12 hours/day during 11 days before weaning at 27th day of age. In this experiment, piglet's average daily gain during suckling period was decreased by diminished milk intake by separation of 12 hours/day, but lowered weaning weight did not negatively affect post-weaning growth. In other cases, Newton et al. (1987) separated piglets from their dam for six hours a day, but they did not observe lowered weaning weight by intermittent suckling. Furthermore, Kuller et al. (2004) observed piglets had consumed a small amount of creep feed with intermittent suckling also had higher feed intake after weaning than creep fed piglets without intermittent suckling. This meafns weaning is a less stressful event for piglets, if piglets experienced separation from their dam during suckling period.

Although intermittent suckling is one of the effective managements to piglet adaptation to sold feed, but introduction of intermittent suckling need a careful approach. Intermittent suckling decreases piglet's suckling behavior during separation. Intermittent suckling reduces prolactin secretion of sow, and this hormone prevents LH secretion during lactation. Consequently, intermittent suckling can cause ovulation during lactation. Kuller et al. (2004) actually observed incidence of lactational ovulation during experimental period, and mentioned that incidence of lactational ovulation could be increased with lactating length and separating duration.

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Chapter III: Effects of early feeding of highly digestible creep feed on pre-weaning piglet growth, gut development and lactation performance of sow

ABSTRACT: This experiment was conducted to evaluate the effect of creep feeding duration on growth performance, feed consumption and intestinal development of suckling piglets and lactating sow performance. A total of 40 multiparous sows and their litters were allotted to one of treatments according to creep feeding duration in a completely randomized design (CRD). Eight litters per treatment were allowed to access creep feed from 4, 11, 18 or 25 d postpartum, while 8 litters were not provided creep feed during the 28 days of lactation. Sow feed and creep feed were provided *ad libitum* during the experimental period. Providing creep feed did not affect body weight and weight gain of piglets until 17 d. From 18 to 24 day, average daily gain was improved linearly as creep feeding duration increased (linear, $P<0.05$). However, from 25 to 28 days, average daily gain tended to increase then decrease as creep feeding duration increased (quadratic, $P=0.06$). Piglets consumed creep feed (eaters) did not show differences with non-eaters, but both of piglets showed higher weight gain than piglets not provided creep feed after 18 d significantly ($P<0.05$). In each treatments, number of eaters and creep feed consumption were increased as piglets aged. The lowest creep feed intake was observed when piglets provided creep feed from 4 d postpartum ($P<0.05$). As piglets consumed creep feed from 18 d postpartum, body weight of sow was increased during lactation, and tended to shorten weaning to estrus interval ($P=0.06$). Milk compositions of sow were not altered by creep feeding duration, but creep feeding increases milk citric acid at 28 d ($P<0.05$). Six piglets of each treatment were slaughtered to determine intestinal morphology and intestinal microflora at the end of suckling period. Linear reductions of duodenal villus height and crypt depth were observed as creep feeding duration decreased ($P<0.1$). In microflora population, Linear increase of Ct values of *Lactobacillus casei* were observed in ileum ($P<0.05$), colon ($P<0.05$) and rectum ($P<0.05$) as creep feeding duration increased. In contrast, Ct values of *Lactobacillus plantarum* were linearly decreased in cecum, colon and rectum as creep feeding duration increased ($P<0.05$). In conclusion, providing highly digestible creep feed during lactation could improve suckling piglet performance but early allowance to creep feed decline further creep feed intake during late lactation period.

Key words: Creep feed, Sow, Lactation, Gut development

INTRODUCTION

Because of limited milk yield for maximizing piglet performance during later days of suckling period and expectation for easy adaptation to solid feed after weaning, creep feeding has been settled as common practice in the modern pig management. However, beneficial effects of creep feed are still controversial.

Several studies showed positive effects of creep feeding such as increasing weaning weight and help adaptation to solid feed after weaning (English, 1980; Bruininx et al., 2002; Klindt, 2003; Kuller et al., 2004; Pluske et al., 2007). However, Fraser et al. (1994) observed that beneficial effects of creep feeding during suckling period diminished after weaning, and the other studies did not report any beneficial effects of creep feeding (Barnett et al., 1989; Sulabo et al., 2010ab).

To maximize piglet performance with creep feed, one of the major concerns is variation of creep feed consumption within litters (Barnett et al., 1989). Because of high variety of creep feed consumption between and within littermates, a few researchers tried to explain these inconsistent results with creep feed consumption of suckling piglets (Barnett et al., 1989; Pajor et al., 1991). Besides, researchers also tried to promote creep feed consumption based on feed materials (Okai et al., 1976; Fraser et al., 1994), feeder types (Sulabo et al., 2010c) or managements (Smith, 1960; Wattanakul et al., 2004; Kuller et al., 2007). Several studies focused on individual creep feed intake, and compared piglet performances of eaters with non-eaters (Bruininx et al., 2002; Kuller et al., 2007; Sulabo et al., 2010).

Starting age of creep feeding is one of the considerable factors to apply creep feed. Barnett et al. (1989) observed that piglets started to consume creep feed from 11th day of age. In recent study, Sulabo et al. (2010a) also revealed that creep feed consumption was related to maturity of suckling piglets. However, pig producers commercially provide creep feed from very early days. Commercial creep feeds are generally formulated with highly digestible ingredients to promote creep feed consumption of piglets. Therefore, creep feeding increases production costs, but beneficial effects of creep feeding in early days has not been assured. Furthermore, creep feeding affects feed intake of sows and body reserves, which could influence later reproductive performance of sows (Smith, 1960; Foxcroft, 1992; Kuller et al., 2004).

Consequently, this experiment was conducted to evaluate the effects of creep feeding length on piglet growth and sow performance during suckling period with highly digestible creep feed.

MATERIALS AND METHODS

Experimental animals and managements

A total of 40 multiparous sows and their litters were used in this experiment. Sows were allotted to farrowing crate (2.5 × 1.8 m) at 110 d of gestation. Initial body weights of sows and their litters were recorded within 12 h after parturition, and iron injection (Fe-dextran, 150ppm), ears notching and clipping needle teeth and tail docking were done to neonatal piglets. Cross-fostering was performed to standardize number of piglets in litters, litter weight and gender ratio. After cross-fostering, each sow had 11 or 12 piglets with an average body weight of 1.58 ± 0.48 kg. Male piglets were castrated at 3 d of age. Sows were arranged one of five treatments considering their body weight and back-fat thickness in completely randomized design (CRD). One group was not fed creep feed, and each group of other four treatments was provided highly digestible antigen free commercial creep feed (Supremo, Sunjin, Korea) from 4, 11, 18 and 25 d to 28 d when piglets were weaned. Four-hole stainless still feeder (60 × 20 × 25 cm) was used to provide creep feed. The creep feed contained with 45% whey product, and had 3,830 ME kcal/kg, 19.81% crude protein, 1.93% lysine, 0.38% methionine, 0.56% Ca and 0.50% total P. Chromic oxide was mixed 1% in creep feed to categorize piglets as eaters or non-eaters. Sows were fed corn-SBM based diet contained with 3,265 ME kcal/kg, 16.8% crude protein, 1.08% lysine, 0.28% methionine, 0.9% Ca and 0.7% total P. Sow feed and creep feed were provided *ad libitum*, and water was supplied through nipples and water cups, which were installed in sow crate and piglet area.

Sample collections and analysis

Body weight, back-fat thickness and feed intake of sows were recorded at 12 h, 11, 18, 25 and 28 d postpartum. At the same time, milk samples were obtained from second to third teats after an intravascular injection of 5 IU oxytocin on the ear vein. Milk composition was analyzed with Milk analyzer (MilkoScan FT20, FOSS Electric Co., Denmark). Backfat thickness was measured at P2 position using Lean-Meter (Renco Co., MN, USA). Piglet weight and creep feed intake were measured after recording sow parameters. Creep feed eater or non-eater was categorized by observance of chromic oxide in feces checked with cotton bud in a rectum at each recording day. At the end of suckling period at 28 d, 6 piglets (3 male and 3 female) of non-creep feed treatment and 6 piglets within eaters of the other 4 treatments with an average body weight of 7.56 ± 0.78 kg were selected and slaughtered for analyzing intestinal morphology and intestinal microflora. Two cm of specimens were excised from duodenum, mid-jejunum and ileum, then rinsed with physiological saline and preserved in 10% neutral buffered formalin. Samples were dehydrated with alcohol, cleared with xylend and embedded with paraffin wax. Slides were prepared with samples as 4㎛ thickness and stained with hematoxylin and eosin. Villus height and crypt depth were measured using LEICA DM500 microscope with Leica DFC 250 camera (Leica, Solms, Germany). Intestinal microflora of digesta in ileum, cecum, colon and rectum were analyzed using quantitative real-time PCR technique. Digesta samples were collected in sterilized 50 ml conical tube, stored in liquid nitrogen immediately and submitted to freeze-drying. Total genomic DNA was extracted and isolated by bead-beating method using the Ultra CleanTM Fecal DNA Kit (MoBioTM, CA, USA) and G-spinTM Genomic DNA Extraction Kit (Intron, Korea). Species-specific primers were designed for *E.coli K88+*, *Lactobacillus casei*, *Lactobacillus plantarum* and *Bacillus subtilis*, and tested for species-specificity (Table 1). The standard for real-time PCR was established by serial dilution plasmid of DNA concentration from pure cultured transgenic *E.coli* which contained target DNA sequence. Quantitative real-time PCR was performed using an iCycler® iQ Real time PCR Detection System (Bio-Rad, CA, USA) and threshold cycle (Ct) was recorded for each bacterium.

Statistical Analysis

All of collected data were analyzed using Mixed GLM procedure of SAS (SAS Institute, 2004). For analyzing sow performance and litter performance, sows and litters served as experimental unit and linear quadratic polynomials were used to determine the effect of creep feeding duration. Provider vs. non-provider analysis was conducted to evaluate the effect of creep feeding at recording day without considering creep feeding duration. Creep feeding was considered as fixed effect, and parity, total born were considered as random effect. In eater vs. non-eater analysis, each piglet served as experimental unit, and their dam was considered as random effect. Statistical differences were analyzed by least squares mean comparisons in PDIFF option. Differences and suggestive differences between treatments and categories were considered at $P < 0.05$ and $P < 0.10$, respectively.

RESULTS

Providing creep feed did not affect body weight gains of suckling piglets until 17 d (Table 2). From 18 to 24 d, average daily gain was linearly increased as creep feeding duration increased (linear, $P<0.05$), but from 25 to 28 d, average daily gain was increased then decreased by increasing creep feeding duration (quadratic, $P=0.06$). In provider vs. non-provider analysis, creep feeding improved average daily gains of litters from 18 d to weaning ($P<0.05$).

Results of creep feeding duration on creep feed intake and number of eaters are presented in Table 3. From 11 to 17 d, litters were provided creep feed from 4 d showed significantly less creep feed intake than litters were provided creep feed from 11 d ($P<0.05$). Moreover, creep feeding from 4 d showed the lowest feed intake during each recording period. In the number of eaters, quadratic effect ($P<0.05$) was observed from 18 to 24 d. Although increase of creep feeding duration led more piglets to consume creep feed ($P<0.01$), but creep feed intake of each eater was linearly decreased from 25 to 28 d ($P<0.05$).

Growth performances of eater, non-eater and non-provided piglets are presented in Table 4. There were no differences between eater and non-eater during the suckling period, but both of piglets showed significantly higher weaning weight than non-provided piglets at the end of suckling period ($P<0.05$). From 18 to 24 d, regardless of eater or non-eater, providing creep feed tended to improve body weight gains of piglets ($P<0.1$). Similarly, from 25 to 28 d, piglets were provided creep feed also showed greater average daily gain than non-provided piglets ($P<0.05$).

In sow performance, final body weight and backfat thickness were not affected by creep feeding duration (Table 5). However, body weight change of lactating sow was increased then decreased by increasing creep feeding duration (quadratic, $P<0.05$). Sows started creep feeding from 18 d showed increased body weight gain during lactation, and tended to show decreased weaning to estrus interval (quadratic, P=0.06). Results of feed intake of sows are presented in Table 5. Creep feeding duration did not affect feed intake of lactating sows. However, in provided vs. non-provided contrast, providing creep feed from 4 d and 11 d tended to increase feed intake of sow from 11 to 17 d (P=0.07). However, this tendency was disappeared after 18 d, and creep feeding tended to decrease feed intake of sow from 25 to 28 d (P=0.09).

Milk compositions at 28 d are presented in Table 6. Providing creep feed significantly decreased milk citric acid contents regardless of feeding duration at 28 d of suckling period (P<0.05). However, other measurements such as milk fat, protein, lactose, total solid and solid not fat contents were not altered by creep feeding and feeding duration. In addition, milk samples obtained before 28 d did not show any differences by creep feeding and feeding duration, which are not presented in table.

At 28 d, villus height and crypt depth of duodenum, jejunum and ileum were measured to investigate intestinal morphology (Table 7). In duodenum, piglets were provided creep feed showed higher villus height (P=0.07) and deeper crypt depth (P<0.05) than piglets were not provided creep feed. Moreover, increase of creep feeding duration also tended to increase duodenal villus height (linear, P=0.09) and crypt depth (linear, P=0.06). Relatively, morphologies of duodenum and ileum were not affected by creep feeding.

Threshold cycle (Ct) of real time PCR of intestinal microfloras are presented in Table 8. Only one third of piglets showed presence of *E.coli K88+*, and no differences were observed by creep feeding and feeding duration. As creep feeding duration was increased, Ct values of *Lactobacillus casei* were linearly increased in digestas of ileum (P<0.05), cecum (P=0.06), colon (P<0.05) and rectum (P<0.05). However, Ct values of *Lactobacillus plantarum* in the digestas of cecum, colon and rectum were linearly decreased by increasing creep feeding duration ($P<0.05$). However, *Bacillus subtilis* was not altered by creep feeding or feeding duration.

DISCUSSION

Creep feed consumption of piglet increase with age. Barnett et al. (1989) reported that piglets started to consume creep feed from 11 d postpartum and creep feed consumption had increased linearly until weaning. Pluske et al. (2007) also represented that creep feed consumption rapidly increased after 18 d and 25 d of suckling period. Moreover, Fraser et al. (1994) and Bruininx et al. (2002) demonstrated that piglets consumed 60% and 80% of total creep feed consumption during last week of suckling period when weaning was performed at 28 d. As likely as previous studies, results of the current study showed an increase of creep feed consumption as piglets aged, and before 18 d, providing highly digestible creep feed also failed to improve growth performance of suckling piglets.

One specific result was observed when creep feeding started from 4 d postpartum. In the previous study of Barnett et al. (1989), they represented longer exposure to creep feed increases opportunity to consume creep feed. And Appleby et al. (1991) also mentioned that when piglets initiate consuming creep feed and consume more amount of creep feed on one day than other littermates, they consume more creep feed on the other day. However, in current study, though litters were provided creep feed from 4 d had the longest creep feeding duration, but these litters consumed the lowest amount of creep feed during 25 to 28 d. This observation was probably explainable with highly digestible creep feed and water availability of piglets during early days of lactation. Consumption of solid feed gave thirst for water to piglets. However, in early days, piglets are hard to use nipples for water supply, and quench their thirsty through maternal milk. In this reason, litters consumed creep feed in early days could not recognize creep feed as edible materials. Moreover, only 0.9 piglets were categorized as eaters per litter from 4 to 10 d, but these eaters consumed an average of 31g/day of creep feed. This amount was even higher than creep feed consumption of eaters from 11 to 17 d. Therefore, this result indicated that early eaters diminish or stop to consume creep feed, and recorded as non-eater at 10 d when creep feed intake was recorded. Therefore, the allowance of creep feed in too early stage such as 4 d postpartum may decline the opportunity to aquire benefits from additional nutrient supply via creep feed.

Increase of creep feed consumption is related to maturity of digestive system and poor milk production of their dam (Pajor et al., 1991). In the research of Algers et al. (1989), piglets suckled low-producing teats consume creep feed more frequently than piglets suckled high producing teats. Likewise, Pluske et al. (2007) represented that piglets suckled anterior teats showed less number of non-eaters than piglet suckled posterior treats from 24 to 28 d during suckling period. In the current study, both of eaters or non-eaters showed similar growth performances but piglets categorized as non-eaters maintained numerically heavier body weight than eaters during entire experimental period. This result indicates that lighter piglets were tried to compensate poor milk yield with creep feed consumption. Similarly, Sulabo et al. (2010a) reported higher piglet weight of non-eaters than eaters. In this reason, either eaters or non-eaters showed better body weight and weight gain than non-providers during lactation period.

Relatively, effect of creep feed on sow performances has not been well documented. Smith (1960) and Kuller et al. (2004) represented reduction of body loss by providing creep feed with intermittent suckling. In contrast, Sulabo et al. (2010b) reported that creep feeding did not show any alteration of body weight and back-fat thickness of sow. In the present experiment, body loss during lactation and weaning to estrus interval were decreased then increased as creep feeding duration increased.

Inducing sows to consume an amount of feed for maintain body weight during lactation is difficult (Williams, 1985). However, sows provided creep feed to suckling piglets from 18 d of lactation even showed increased body weight during lactation. This result indicated that highly digestible creep feed could effectively diminish body loss of sows during lactation. However, sows mobilize body reserves during lactation and recover them during next gestation period. Therefore increasing body weight during lactation could induce obesity in later parity, and in this case, additional managements might be needed for further progeny. Generally, feed intake of sow related to milk yield (Noblet and Etienne, 1986). Furthermore, piglet’s consumption of creep feed decreases demand for maternal milk which affects feed intake of sow. Therefore, in the current study, creep feeding sows showed tend to decreased feed intake during the last 4 days before weaning.

Milk composition was not affected by creep feeding duration, but sows provided creep feed to suckling piglets showed lower citric acid contents in milk than sows not provided creep feed at 28 d ($P<0.05$). Peaker and Linzell (1975) referred to citric acid as a harbinger of lactogenesis. Therefore, this result indicates a reduction of milk production by creep feeding. Oppositely, creep feeding tended to increase feed intake of sow from 10 to 17 d. Increase of feed intake of sow with creep feed has not been reported in the previous studies. This increase of feed intake of sow could be derived from stimulus of creep feed eaters in early age which tried to quench their thirsty through maternal milk.

Bruininx et al. (2004) represented that consumption of creep feed did not affect intestinal morphology and microbial activity in colon during suckling period. However, in the present study, villus height and crypt depth of suckling piglets were increased by creep feeding duration especially in duodenum. Van Beers-Schreurs et al. (1998) reported that villus atrophy after weaning caused by solid feed and amount of feed intake. Piglets could access to sow feed after 3 weeks postpartum (Maner et al., 1959), and piglets could compensate sow feed for poor milk production at later week before weaning (Wallenbeck et al., 2005). Therefore, decrease of villus height and crypt depth by decreasing creep feeding duration might due to consumption of sow feed of piglets which was not provided creep feed.

Mathew et al. (1994) reported that creep feeding from 15 to 29 d had little effect on microbial population of piglet's intestine because creep feed consumption possessed only little part than maternal milk suckling. However, in the present study, increase of Ct value of *Lactobacillus casei* and decrease of Ct value of *Lactobacillus plantarum* were observed in digesta of hindgut by creep feeding duration. Ct value indicates number of cycles at which fluorescence exceeds a fixed threshold. Therefore, these results mean gut environment had changed to dominant for *Lactobacillus platarum* than *Lactoabcillus casei*. Considering bile-salt resistance of *Lactobacillus plantarum*, these results might be derived from development of digestive system by consumption of creep feed. Flores et al. (1992) reported that bile acid secretion increased with age and diet. Therefore, with the results of intestinal morphology, increase of creep feeding duration with highly digestible creep feed could improve gut environment during suckling period.

CONCLUSION

Creep feeding with highly digestible creep feed efficiently improved piglet performance during suckling period. However, providing creep feed from 4 d reduced access to creep feed during late lactation, and providing highly digestible creep feed still failed to promote growth of suckling piglets before 18 d postpartum. Furthermore, piglets fed creep feed only 4 days before weaning also showed similar performance compared to piglets fed creep feed for longer duration. Therefore, creep feeding from early days postpartum does not show beneficial effects in lactating sow management. In the result of intestinal morphology, piglets tried to compensate lack of milk yield with sow feed, so providing highly digestible creep feed to suckling piglets could satisfy piglet's demands during late lactation period.

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Table 1. Specific real-time PCR primers for analyzing microflora population in intestinal digesta

		Primer sequence	Genbank accession number	PCR product size, bp
E.coli K88+,	Forward	CGGTGTGTTAGGGAGAGG	U19784	192
	Reverse	CTTTGAATCTGTCCGAGAATATC		
Lactobacillus casei	Forward	CCGTCACACCATGAGTTT	AB102854	106
	Reverse	CCTTGTTACGACTTCACCCT		
Lactobacillus plantarum	Forward	CCCGTCACACCATGAGAGAGTT	AB102857	110
	Reverse	GGCTACCTTGTTACGACTTC		
Bacillus subtilis	Forward	GTGCAGAAGAGGAGAGTGG	DQ112340	104
	Reverse	TCAGCGTCAGTTACAGAC		

Table 2. Effect of creep feeding duration on litter performance

	Initial day of creep feed providing						P-value[2]		
	4	11	18	25	Non	SEM[1]	Creep	Lin	Quad
Piglet body weight, kg									
Initial	1.57	1.58	1.60	1.59	1.58	0.008	-	-	-
10^{th} day	3.11	3.23	3.07	3.16	3.07	0.039	0.65	0.85	0.63
17^{th} day	4.52	4.69	4.42	4.64	4.55	0.072	0.92	0.55	0.75
24^{th} day	6.16	6.22	5.97	6.09	5.90	0.096	0.65	0.64	0.75
Weaning[3]	6.97	7.18	6.74	7.10	6.66	0.102	0.23	0.62	0.49
Average daily gain, g									
1 - 10 day	153	165	147	157	149	4.2	0.65	0.90	0.72
11 - 17 day	201	209	193	211	210	6.4	0.86	0.71	0.96
18 - 24 day	235	218	221	206	194	5.8	0.05	0.03	0.77
25 - 28 day	201	240	193	251	190	8.0	0.02	0.80	0.06

[1] Standard error of means.

[2] Probability values. Creep - provider vs. non-provider; Lin - linear effect by creep feeding duration; Quad - quadratic effect by creep feeding duration.

[3] Weaning was performed at 28^{th} day of age.

Table 3. Effect of creep feeding duration on creep feed consumption of suckling piglets

	Initial day of creep feed providing					P-value[2]	
	4	11	18	25	SEM[1]	Lin	Quad
Creep feed intake , g/litter/day							
1 - 10 day	27	-	-	-	9.2	-	-
11 - 17 day	116[b]	198[a]	-	-	30.7	-	-
18 - 24 day	322	426	442	-	55.2	0.93	0.07
25 - 28 day	466[b]	691[a]	581[b]	630[ab]	43.6	0.66	0.47
No. of piglets consumed creep feed (eaters)							
1 - 10 day	0.9	-	-	-	0.44	-	-
11 - 17 day	5.5	6.6	-	-	0.67	-	-
18 - 24 day	8.3	8.8	7.1	-	0.56	0.53	0.04
25 - 28 day	9.4[a]	10.1[a]	9.6[a]	7.8[b]	0.40	0.01	0.13
Creep feed intake , g/eater/day							
1 - 10 day	31	-	-	-	12.0	-	-
11 - 17 day	21	30	-	-	4.5	-	-
18 - 24 day	39	49	62	-	6.4	0.51	0.61
25 - 28 day	50[b]	68[ab]	60[b]	81[a]	4.5	0.03	0.51

[1] Standard error of means.

[2] Probability values. Lin - linear effect by creep feeding duration; Quad - quadratic effect by creep feeding duration.

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

Table 4. Effect of providing creep feed on piglet performance categorized as eater, non-eater and non-provided

	Eater		Non-eater		Not provided		SEM[1]
Body weight, kg (no. of piglets)[2]							
Initial					1.58	(468)	0.013
10^{th} day	2.88	(7)	3.13	(87)	3.14	(372)	0.034
17^{th} day	4.52	(98)	4.71	(90)	4.56	(273)	0.051
24^{th} day	6.06	(194)	6.30	(83)	5.99	(183)	0.069
Weaning[3]	6.95^{a}	(294)	7.28^{a}	(72)	6.66^{b}	(93)	0.077
Average daily gain, g							
1-10 day	124		156		155		2.7
11-17 day	210		201		204		3.3
18-24 day	222^{c}		227^{c}		201^{d}		3.4
25-28 day	226^{a}		218^{a}		189^{b}		4.6

[1] Standard error of means.

[2] Bracket after data means number of piglets at recording day.

[3] Weaning was performed at 28^{th} day of age.

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

[c d] Means in a same row with different superscript letters were significantly different (p<0.10).

Table 5. Effect of creep feeding duration on lactating performance and feed intake of sow

	Initial day of creep feed providing						P-value[2]		
	4	11	18	25	Non	SEM[1]	Creep	Lin	Quad
Body weight, kg									
Initial	234.3	231.4	231.0	231.5	230.5	3.49	-	-	-
28^{th} day	232.2	229.9	234.4	225.4	226.2	3.43	0.44	0.81	0.13
BW change	-2.1	-1.5	3.4	-6.1	-4.3	1.78	0.40	0.74	0.04
Back-fat thickness, mm									
Initial	20.8	20.1	20.1	20.9	21.1	0.74	-	-	-
28^{th} day	20.0	18.9	19.0	19.6	19.4	0.72	0.99	0.65	0.57
BF change	-0.8	-1.1	-1.1	-1.3	-1.6	0.22	0.42	0.32	0.95
Average daily feed intake, kg/day									
1 - 10 day	4.83	4.97	4.67	4.57	4.94	0.112	0.92	0.75	0.69
11 - 17 day	6.08	6.33	5.24	5.52	5.72	0.210	0.07	0.39	0.97
18 - 24 day	6.93	6.37	6.16	6.09	5.94	0.249	0.37	0.96	0.62
25 - 28 day	5.84	6.42	6.03	5.45	6.76	0.247	0.09	0.58	0.86
Overall	5.70	5.87	5.38	5.31	5.64	0.147	0.84	0.93	0.98
Weaning to estrus, days									
	4.46	4.48	3.67	5.05	5.04	0.17	0.47	0.14	0.06

[1] Standard error of means.

[2] Probability values. Creep - provider vs. non-provider; Lin - linear effect by creep feeding duration; Quad - quadratic effect by creep feeding duration.

Table 6. Effect of creep feeding duration on milk composition of sow at 28th day of lactation

	Initial day of creep feed providing						P-value[2]		
	4	11	18	25	Non	SEM[1]	Creep	Lin	Quad
Fat, %	6.01	5.97	5.68	6.28	6.25	0.173	0.92	0.59	0.47
Protein, %	5.05	4.90	5.07	4.98	5.29	0.077	0.16	0.36	0.36
Lactose, %	5.71	5.69	5.70	5.69	5.50	0.053	0.16	0.33	0.45
Total solid, %	18.29	18.01	17.98	18.43	18.68	0.207	0.35	0.47	0.34
Solid not fat, %	10.98	10.86	11.05	10.89	11.13	0.060	0.23	0.48	0.55
Cirtic acid, mmol/l	0.095	0.098	0.091	0.091	0.115	0.0075	0.03	0.15	0.41

[1] Standard error of means.

[2] Probability values. Creep - provider vs. non-provider; Lin - linear effect by creep feeding duration; Quad - quadratic effect by creep feeding duration.

Table 7. Effect of creep feeding duration on small intestinal morphology of suckling piglet at 28th day of lactation

	Initial day of creep feed providing						P-value[2]		
	4	11	18	25	Non	SEM[1]	Creep	Lin	Quad
Duodenum									
Villus height, ㎛	979	897	888	909	772	32.9	0.07	0.09	0.80
Crypt depth, ㎛	498	531	525	484	425	16.1	0.04	0.06	0.17
V:C ratio	2.08	1.74	1.68	1.91	1.86	0.075	0.82	0.95	0.37
Jejunum									
Villus height, ㎛	691	894	771	793	779	33.3	0.92	0.72	0.26
Crypt depth, ㎛	395	407	377	403	367	10.8	0.32	0.50	0.73
V:C ratio	1.79	2.18	2.16	2.00	2.20	0.105	0.54	0.41	0.49
Ileum									
Villus height, ㎛	564	532	576	538	497	22.7	0.29	0.37	0.79
Crypt depth, ㎛	350	314	331	287	300	14.0	0.45	0.09	0.57
V:C ratio	1.66	1.70	1.74	1.93	1.66	0.061	0.55	0.51	0.55

[1] Standard error of means.

[2] Probability values. Creep - provider vs. non-provider; Lin - linear effect by creep feeding duration; Quad - quadratic effect by creep feeding duration.

Table 8. Effect of creep feeding duration on microflora population of suckling piglet in ileum and large intestine at 28th day of lactation[1]

	Initial day of creep feed providing						P-value[3]		
	4	11	18	25	Non	SEM[2]	Creep	Lin	Quad
E. coli K88+									
Ileum	20.97	25.55	19.62	15.35	20.93	1.323	0.87	0.29	0.89
Cecum	18.86	19.89	19.31	12.84	11.77	1.735	0.31	0.20	0.43
Colon	20.94	27.36	19.59	18.58	26.14	1.267	0.11	0.94	0.55
Rectum	24.80	21.28	21.39	15.64	18.62	1.246	0.63	0.11	0.75
Lactobacillus casei									
Ileum	27.81	22.03	20.52	19.67	22.36	1.101	0.75	0.02	0.03
Cecum	21.28	22.06	20.85	19.36	19.03	0.852	0.17	0.06	0.58
Colon	23.42	24.10	21.92	19.32	16.64	0.859	0.01	0.01	0.08
Rectum	22.16	21.18	21.02	18.87	17.62	0.811	0.03	0.01	0.43
Lactobacillus plantarum									
Ileum	18.99	19.22	19.92	20.35	20.98	0.851	0.32	0.26	0.62
Cecum	11.32	17.03	18.23	18.82	18.86	0.861	0.14	0.01	0.08
Colon	13.54	13.79	17.55	18.14	15.97	0.700	0.86	0.01	0.15
Rectum	11.47	14.23	15.35	17.40	15.41	0.918	0.67	0.03	0.28
Bacillus subtilis									
Ileum	27.38	30.82	28.60	29.23	24.48	1.113	0.10	0.53	0.24
Cecum	23.01	28.07	24.12	26.53	25.85	0.600	0.67	0.25	0.32
Colon	25.63	24.58	23.81	25.32	22.95	0.895	0.43	0.53	0.96
Rectum	22.97	26.29	22.05	23.49	23.36	0.689	0.87	0.82	0.61

[1] Microflora populations are presented with Ct value of real time PCR.

[2] Standard error of means.

[3] Probability values. Creep - provider vs. non-provider; Lin - linear effect by creep feeding duration; Quad - quadratic effect by creep feeding duration.

Chapter IV: Effects of feeding different creep feeds on pre- and post-weaning performance and gut development in pigs

ABSTRACT: This experiment was performed to determine the effects of supplementation of different creep feeds on suckling piglet performance and further adjustment to solid feed after weaning. A total of 24 multiparous sows and their litters were allotted to one of three treatments according to completely randomized design (CRD) at 14 d postpartum. Eight litters were fed highly digestible creep feed (Creep treatment), another eight litters were fed weaning pig diet (Weaner treatment) and the others consumed sow feed as creep feed until weaning (Sow treatment). After weaning, a total of 96 piglets were selected to evaluate their post-weaning performance, and same weaner diet was provided to every treatment. In pre-weaning performance, different creep feeds did not affect a number of eaters which consumed creep feeds, but Creep treatment group tended to perceive higher creep feed intake than Sow treatment group from 14 to 21 d ($P=0.12$). In addition, Creep treatment group demonstrated significantly higher average daily gain than piglets fed other treatment diets from 21 to 28 d ($P<0.01$). However, after weaning, Weaner treatment group represented significantly higher feed intake than other treatment groups from 0 to 14 d after weaning ($P<0.05$), and also showed significantly higher average daily gain than Creep treatment group ($P<0.05$). From 14 to 35 d post-weaning, Sow treatment group tended to note higher G:F ratio than other treatment groups ($P=0.06$). At 4 d after weaning, 3 male and female piglets (7.67 ± 0.72 kg) were slaughters for analyzing their intestinal morphology and microflora. Creep treatment group tended to show lower duodenal villus height ($P=0.07$) and the lowest V:C ratio ($P=0.11$) than Weaner or Sow treatment group. Higher ileal crypt depth was observed in Sow treatment group ($P=0.10$). In intestinal microfloras, higher Ct values of *Lactobacillus plantarum* in rectum in Sow treatment group was remarked than Creep treatment group ($P<0.05$). Similarly, Sow treatment group tended to show higher Ct values of *Bacillus subtilis* in colon ($P=0.07$), and represented the highest Ct values of *Bacillus subtilis* through ileum and large intestine numerically. In conclusion, highly digestible creep feed could improve pre-weaning performance, but grain based creep feed could be recommended on the purpose of adjustment to solid feed after weaning.

Key words: Suckling piglet, Weaning pig, Creep feed, Creep feed quality

INTRODUCTION

Creep feed has been provided in swine farm to compensate for poor milk production during later lactation and help adaptation to solid feed after weaning. In Korea, piglets are generally weaned approximately at 3 to 4 weeks after birth and creep feed is also provided before their weaning. When piglets are fed creep feed during lactation, swine producers need to consider several factors such as digestibility, palatability and antigen properties (Sulabo et al., 2009) for maximizing feed intake and improving growth performance of young piglets. Generally, creep feed has been formulated with expensive ingredients such as milk by-products and plasma protein to help utilization of nutrients with undeveloped digestive system of piglets (Okai et al., 1976), and several researchers used creep feed with highly digestible ingredients to maximize piglet growth until weaning (Fraser et al., 1994; Pajor et al., 2002; Sulabo et al., 2009). However, when piglets are fed highly digestible creep feed, it's not sure if weaning pigs could adjust grain-based feed after weaning.

Wallenbeck et al. (2005) demonstrated that lower milk consumption of piglets due to poor milk production of dam could be compensated for by feeding of sow's feed during lactation. Moreover, grain-based sow diet stimulated digestive enzyme secretion subsequently induced development of gastrointestinal tract (Owsley et al., 1986). These results demonstrated that suckling piglets could also utilize nutrients in grain-based diet and their consumption might help adaptation to grain feed after weaning. When piglets are utilize grain-based creep feed efficiently rather than milk-byproducts, swine producers are able to save feed cost without any negative response in growth performance.

Consequently, this experiment was conducted to investigate the effect of different types of creep feed such as highly digestible creep feed, weaner diet and sow diet, on performance of nursing and weaning pigs.

MATERIALS AND METHODS

Experimental animals and managements

A total of 24 multiparous sows and their litters were used in this experiment. At 114 d gestation, sows were allotted to farrowing crate (2.5 × 1.8 m) and 4 hole stainless still feeder (60 × 20 × 25 cm) was installed to each farrowing crate to provide creep feed. At 12 h postpartum, body weight of sows and their litters were recorded, and iron injection (Fe-dextran, 150ppm), ears notching and clipping needle teeth and tail docking were done to neonatal piglets. Male piglets were castrated at 3 d postpartum. Experiment was begun at 14 d after birth, and each sow and their litters were arranged to one of three treatments based upon body weight, backfat thickness and litter growth. To equalize average litter growth of each treatment at 14 d, cross-fostering was performed to standardize piglet number (11 piglet/litter), piglet weight (1.60 ± 0.32 kg) and gender ratio within 24 h postpartum. Each groups were provided one of three different diets as creep feed. One group was provided creep feed which contained 61.8% milk product (Creep), another group was provided weaner pig diet (Weaner) and the other group was provided sow feed (Sow) through the creep feeder. At weaning, 4 males and 4 females piglets of each group were selected, and 3 males and 3 females of them (7.67 ± 0.72 kg) were slaughtered for analyzing their gut condition at 4 d after weaning. In the same time, a total of 96 piglets were selected to evaluate their adaptation to feed after weaning. 32 piglets of each group were arranged 8 piglets per pen according to body weight and sex. During lactation, sow feed and creep feed were provided ad libitum, and water was provided through nipples and water cups installed in sow crate and piglet area.

The Creep group was fed diet containing 61.8% milk product, and had 3,372 ME kcal/kg, 21.00% crude protein, 1.66% lysine, 0.43% methionine. Weaner group was provided diet containing 12.50% milk product, and contained 3,265 ME kcal/kg, 23.7% crude protein, 1.35% lysine and 0.35% methionine. Sow group was fed lactating sow diet containing 3,265 ME kcal/kg, 16.8% crude protein, 1.08% lysine, 0.28% methionine, 0.9% Ca and 0.7% total P. Chromic oxide was mixed 1% to each creep feed to figure out creep feed eaters. From weaning to 2nd week after weaning, all of groups provided same weaner diet which was previously provided to Weaner group. From 3rd to 5th weeks after weaning, weaner diet was changed to weaner II diet containing 3,265 ME kcal/kg, 20.90% crude protein, 1.15% lysine, 0.30% methionine. Nutrients of sow diet and weaner diets were met or exceeded the nutrient requirement of NRC (1998). The formula and chemical composition of creep diets used in this experiment were presented in Table 1.

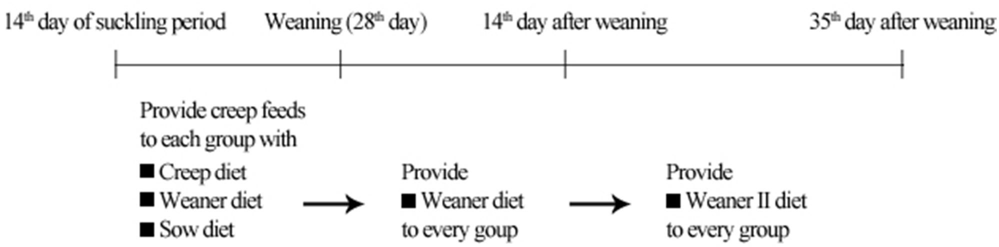

Figure 1. Feeding scheme of experiment

Sample collections and analysis

Sows and litters performance were recorded at 14, 21 and 28 d postpartum. Body weight, back-fat thickness and feed intake of sows were measured, and piglet weight and creep feed intake were also recorded. Backfat thickness of sow was measured at P2 position using Lean-Meter (Renco Co., MN, USA). To categorize creep feed eater and non-eater, fecal color was checked with cotton bud in a rectum. Body weight and feed intake of weaner pigs were recorded at 2nd and 5th week post-weaning. Individual body weight of each piglet was recorded, and individual feed intake was calculated from feed intake of each pen by the method of Lindemann and Kim (2007). Intestinal morphology and intestinal microflora were analyzed at 4 d after weaning. From duodenum, mid-jejunum and ileum, 20 mm of specimens were excised and rinsed with physiological saline. Then samples were preserved in 10% neutral buffered formalin until analysis. Samples were dehydrated and cleaned with alchole and xylend, and embedded with paraffin wax. After that, samples were sliced with 4㎛ thickness and stained with hematoxylin and eosin for prepare sample slides. Pictures of each samples were captured using LEICA DM500 microscope with Leica DFC 250 camera (Leica, Solms, Germany) for analyze villus height and crypt depth. For measuring intestinal microflora count, threshold cycles (Ct) of *E.coli K88+*, *Lactobacillus casei*, *Lactobacillus plantarum* and *Bacillus subtilis* in ileum, cecum, colon and rectum were observed using quantitative real-time PCR technique. Digesta samples of each digestive track fraction were collected in sterilized 50 ml conical tube and immediately frozen with liquid nitrogen. After submitted to freeze-drying, genomic DNA was extracted and isolated by bead-beating method with Ultra CleanTM Fecal DNA Kit (MoBioTM, CA, USA) and G-spinTM Genomic DNA Extraction Kit (Intron, Korea). Species-specific primers of microflora was designed and tested for species-specificity (Table 2). The standards for real-time PCR were obtained by serial dilution plasmid of DNA concentration from pure cultured transgenic *E.coli* which contained target DNA sequence. Quantitative real-time PCR was performed using an iCycler® iQ Real time PCR Detection System (Bio-Rad, CA, USA).

Statistical analysis

All of collected data were analyzed using Mixed GLM procedure of SAS (SAS Institute, 2004). For analyzing sow performance and litter performance, sows and litters served as experimental unit. Creep feed types were considered as fixed effect, and parity, total born were considered as random effect. For data of weaner period, each of piglets served as experimental unit, and their dam were considered as random effect. Statistical differences were analyzed by least squares mean comparisons in PDIFF option. Differences and suggestive differences between treatments and categories were considered at $P < 0.05$ and $P < 0.12$, respectively.

RESULTS

Lactation and pre-weaning performance

Effect of creep feeds on suckling piglet performance and creep feed intake were presented in Table 3. In creep feed intake, litters of Creep treatment group tended to show higher creep feed intake than Sow treatment group from 14 to 21 d ($P=0.12$). Although there were no significant differences, Creep treatment group showed the highest creep feed intake among groups, and Sow treatment group showed the lowest creep feed intake among groups from 22 to 28 d. Moreover, Creep treatment group showed numerically higher creep feed intake compared to other groups from 14 to 21 d, resulted in higher body weight gain from 21 to 28 d ($P<0.01$). Differences of creep feed did not affect number of eaters which consumed creep feeds, and almost of all piglets consumed creep feed at 28 d regardless of creep feed types. As likely as litter creep feed intake, eaters of Creep treatment group tended to consume more creep feed compared to eaters of Weaner and Sow treatment groups from 14 to 21 d ($P=0.10$), and also maintained numerically the highest creep feed consumption among groups until weaning.

During the whole lactating period, difference of creep feed did not affect sow performance including body weight, back-fat thickness, feed intake and weaning to estrus interval (Table 4).

Post-weaning performance and gut development

Although the highest weaning weight was obtained in Creep treatment group, lower feed intake and weight gain were observed after weaning (Table 5). Weaner treatment group showed significantly higher feed intake than other treatment groups from weaning to 14 d ($P<0.05$), resulted in higher average daily gain than Creep treatment group ($P<0.05$). Furthermore, Sow treatment group tended to show higher feed efficiency than other treatment groups from 14 to 35 d after weaning ($P=0.06$).

In small intestinal morphology, weaning pigs of Creep treatment group tended to show shorter duodenal villus height than Weaner or Sow treatment group ($P=0.07$) at 4 days after weaning, and subsequently showed the lowest V:C ratio ($P=0.11$) (Table 6). Sow treatment group tended to show higher ileal crypt depth than other treatment groups ($P=0.10$).

Threshold cycle (Ct) of real time PCR of microfloras in ileum and large intestine were presented in Table 7. Sow treatment group showed the highest Ct value of *E. coli K88+* in ileum, colon and rectum numerically, but no significant differences were observed among treatment. Sow treatment group showed significantly higher Ct values of *Lactobacillus plantarum* in rectum than Creep treatment group ($P<0.05$). Similarly, Sow treatment group tended to observe higher Ct values of *Bacillus subtilis* than other treatment groups in colon ($P=0.07$), and also showed the highest Ct values of *Bacillus subtilis* through ileum and large intestine, numerically.

DISCUSSION

In the present experiment, piglets fed highly digestible creep feed showed higher creep feed intake than other piglets fed weaner diet or sow diet as creep feed from 14 to 21 d, and their growth promoting effect was observed from 21 to 28 d during sucking period. Fraser et al. (1993) observed similar results that complex creep diet improved creep feed consumption from 3rd week but average daily gain was increased during 4^{th} week. Moreover, several studies demonstrated complex creep feed with highly digestible ingredients had an advantage on creep feed consumption at 3^{rd} week of age, but improved growth was also not observed during 3^{rd} week (Fraser et al., 1993; Pajor et al., 2002; Sulabo et al., 2009). Generally, creep feed consumption increases as piglets are getting old, and Barnett et al. (1989) observed linear increase of creep feed consumption from 21 to 28 d during suckling period. Pajor et al. (1991) represented that creep feed consumption was increased by digestive maturity and poor milk yield. Therefore, providing highly digestible creep feed could improve creep feed consumption of suckling piglets, but growth promoting effect of suckling piglets could not be expected when piglets weaned earlier than 3 weeks even though highly digestible creep feed was provided.

In the present study, weaner diet also contained 12.5% of milk byproducts but significant difference with Weaner or Sow treatment group was not observed in creep feed intake and average daily gain during suckling period. Therefore, small amount of milk products in weaner diet of this experiment might be not enough for attraction of piglets to consume creep feed. Whitelaw et al. (1966) revealed that creep feed consumption and growth of suckling piglet was not altered by dietary protein levels from 14 to 22% until 3^{rd} week. And Yan et al. (2011) also demonstrated suckling piglet performance was not related to energy density (4,000 versus 5,000 DE kcal/kg) of creep feed until weaned at 21 d. Therefore, creep feed formulation with highly digestible ingredients is more important than chemical composition of creep feed to improve creep feed intake and growth performance of suckling piglets until weaning.

Consequently, results of piglet performance during suckling period indicated that providing highly digestible creep feed had the advantage on creep feed consumption and growth performance of suckling piglet until weaned at 28 d.

Smith (1960) and Kuller et al. (2004) revealed a decrease of milk production caused by creep feeding prevented body loss of sow. However, in this study, providing highly digestible creep feed increased creep feed consumption of suckling piglets, but none of the parameters of sow performance showed significant differences. These results are in agreement with study of Sulabo et al. (2010) which also demonstrated providing creep feed did not affect changes of body weight and backfat thickness in lactating sow.

Okai et al.(1976) mentioned pre-weaning creep feed quality did not affect post-weaning performance when pigs were weaned at 21 d, and Aherne et al. (1982) showed post-weaning performances were not altered by creep feeding even though piglets were weaned at 35 d. However, in the present experiment, Weaner treatment group showed significantly higher feed intake than other treatment groups during the first 2 weeks after weaning. In addition, Creep treatment group had the highest initial body weight at weaning, but the lowest average daily gain was detected from 0 to 2nd week after weaning. Furthermore, from 14 to 35 d after weaning, Sow treatment group tended to have higher G:F ratio than other treatment groups, and showed numerically improved average daily gain. In the study of Fraser et al. (1993), pigs provided a high-quality diet before and after weaning had better average feed intake and weight gain during 14 days after weaning. However, after changing diet from high-quality to low-quality diet at 42 d, lower average daily gain and G:F ratio was observed compared to low-quality treatment. This result indicated that adaptation to low-quality diet still cause strong detrimental effects even after 2 weeks after weaning.

As mentioned in introduction, apply to solid feeding stimulates acid production and digestive enzyme activity (Cranwell et al., 1976; Owsley et al., 1986), and Plusky et al. (2002) showed that non-digestible carbohydrate fraction affects gut development. Also, Okai et al. (1976) observed pigs fed a complex diet during suckling period had higher incidence of diarrhea after weaning. Therefore, increased G:F ratio in Sow treatment group after weaning could be explainable with development of digestive organs during suckling period.

In the present study, after weaning, there was no additional advantage by feeding of highly digestible creep feed during suckling. This result was in agreement with Fraser et al. (1993) which concluded creep feeding had an advantage on improvement of weaning weight than adjustment after weaning. However, results of the present study also indicated that relatively low-quality creep feed during suckling period could improve solid feed utilization after weaning, and providing same diet around weaning had an advantage on adjustment to solid feed after weaning.

Generally, pigs have severe changes in gastrointestinal track after weaning including shortening and thickening of small intestinal villus and deepening of crypt depth during adjustment to solid feed. Beers-Schreurs et al. (1998) showed feed type affects post-weaning villus atrophy. In current study, decrease of duodenal villus height was observed when pigs were fed highly digestible creep feed during suckling period, and they had the lowest V:C ratio than other treatment groups. In addition, Sow treatment group tended to have deepest crypt depth in ileum, and also numerically the highest in duodenum and jejunum. These results indicated that low-quality diet could prevent detrimental intestinal challenges after weaning, and could help adjustment to solid feeding instead of dam's milk. A few studies were conducted to evaluate the effects of creep feed quality on intestinal microflora of piglets. Mathew et al. (1994) observed a decrease of *lactobacilli* and hemolytic *E. coli* count in feces at 2 days after weaning by providing rough corn-SBM creep diet with antibiotics. In current study, Sow treatment group showed an increase of Ct values in the most of small intestine fraction even though creep feeds did not contain antibiotics. Ct value indicates number of cycles at which fluorescence exceeds a fixed threshold. Therefore, a decrease of microfloras in digestive track was detected when piglets were fed non-antibiotics sow feed, but diminish of microflora had no detrimental influence on growth performance of piglets after weaning.

CONCLUSION

Providing highly digestible creep feed for suckling piglets could be adapted purpose on improving creep feed consumption and pre-weaning growth, but this management was the least efficient method for adjustment to solid feed and post-weaning growth. For adjustment to solid feed after weaning, weaner diet will be desirable creep feed which will be fed to piglets after weaning. And if suckling piglets could freely access to sow feed, piglet could consume sow feed as creep feed, and it might help improving gut development during suckling period. In conclusion, providing highly digestible creep feed to piglets seems to improve growth performance during suckling period, but rough grain based creep feed has relative advantage to accelerate feed consumption after weaning.

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Table 1. Formula and chemical composition of experimental feed

Ingredients (%)	Creep	Weaner	Weaner II	Ingredients	Sow
Suprex corn	16.90	20.88	42.86	Corn	79.61
SBM-44	3.10	30.96	28.16	SBM-45	14.99
HP 300*	6.70	8.36	4.38	Sugar molasse	0.50
Whey powder	28.88	3.50	-	Soy oil	0.51
WPC*	13.24	-	-	L-Lysine-HCl	0.24
Cheese powder	6.78	-	-	DL-Met	0.04
Fish meal	4.80	-	-	DCP	2.49
Lactose	12.90	9.00	4.00	Limestone	0.85
Whole grain barley	3.39	24.11	18.10	Vit. Mix[3]	0.20
Soy Oil	1.00	0.43	-	Min. Mix[4]	0.10
MCP*	0.22	0.97	0.85	Salt	0.32
Limestone	0.79	0.98	0.90	Choline-Cl(50%)	0.15
L-Lysine-HCl	0.33	0.14	0.15		
DL-met	0.07	0.03	0.00		
Vit. Mix[1]	0.25	0.12	0.10		
Min. Mix[2]	0.25	0.12	0.10		
Salt	0.20	0.20	0.20		
Choline-Cl(25%)	0.10	0.10	0.10		
ZnO	0.10	0.10	0.10		
Sum	100.00	100.00	100.00		100.00
Chemical compositions[5]					
ME (Kcal/kg)	3372.08	3265.01	3265.01		3265.07
Crude Protein (%)	21.00	23.70	20.90		16.80
Lys (%)	1.66	1.35	1.15		1.08
Met (%)	0.43	0.35	0.30		0.28
Ca (%)	0.90	0.80	0.70		0.90
Total P (%)	0.70	0.65	0.60		0.70

* HP300 : Fermented soybean meal; WPC : Whey protein concentrate; MCP: Mono-calcium phosphate

1 Vitamins per kg premix : Vitamin A, 6,666,667 IU; Vitamin D3, 1,333,333 IU; Vitamin E, 26,666 IU; Vitamin B2, 2.667 mg; Biotin, 53,333 mg; Pantothenic acid, 6,667 mg; Niacin, 13,333 mg; Vitamin B12, 10,000 mg.

2 Minerals per kg premix : Se, 100 mg; I, 300mg; Mn, 24,800 mg; $CuSO_4$, 54,100 mg; Fe, 127,300 mg; Zn, 84,700 mg; Co, 300mg.

3 Vitamins per kg premix : Vitamin A, 8,666,667 IU; Vitamin D3,1,333,333 IU; Vitamin B1, 4,000 mg; Vitamin B2, 8,000 mg; Vitamin B6, 4,000 mg; Vitamin B12, 33 mg; Tocopherol, 66,667; Vitamin K3, 4,000 mg; Panthothenic acid, 26,667 mg; Biotin, 333 mg; Folic acid, 3,667 mg; Niacin, 33,333 mg.

4 Minerals per kg premix : Fe, 75,000 mg; Mn, 20,000 mg; Zn, 30,000 mg; Cu, 55,000 mg; Se, 100 mg; Co, 250,000 mg; I, 250,000 mg.

5 Calculated values.

Table 2. Specific real-time PCR primers for analyzing microflora population in intestinal digesta

		Primer sequence	Genbank accession number	PCR product size, bp
E.coli K88+,	Forward	CGGTGTGTTAGGGAGAGG	U19784	192
	Reverse	CTTTGAATCTGTCCGAGAATATC		
Lactobacillus casei	Forward	CCGTCACACCATGAGTTT	AB102854	106
	Reverse	CCTTGTTACGACTTCACCCT		
Lactobacillus plantarum	Forward	CCCGTCACACCATGAGAGAGTT	AB102857	110
	Reverse	GGCTACCTTGTTACGACTTC		
Bacillus subtilis	Forward	GTGCAGAAGAGGAGAGTGG	DQ112340	104
	Reverse	TCAGCGTCAGTTACAGAC		

Table 3. Effect of feeding different creep feeds on piglet growth and creep feed intake during suckling period

	Creep feed				
	Creep	Weaner	Sow	SEM[1]	P-value
Average body weight, kg					
Initial (14th day)	3.88	3.84	3.87	0.053	0.97
21st day	5.43	5.26	5.24	0.097	0.81
28th day	7.43	6.83	7.00	0.134	0.41
Average daily gain, g					
14 to 21 day	221	202	196	8.2	0.47
21 to 28 day	286[A]	225[B]	251[B]	9.8	0.01
No. of piglet consumed creep feed, number of piglets/litter					
21st day	5.5	6.8	5.3	0.63	0.62
28th day	10.3	10.0	10.3	0.32	0.92
Average daily creep feed intake of litters, g/day					
14 to 21 day	197.7[a]	143.2[ab]	94.2[b]	19.99	0.12
21 to 28 day	684.6	642.3	533.3	63.65	0.58
Average daily creep feed intake of eaters[2], g/day					
14 to 21 day	36.1[a]	22.9[b]	23.5[b]	3.01	0.10
21 to 28 day	65.8	61.7	50.9	5.81	0.54

[1] Standard error of means.

[2] Average value of Feed intake / No. of Eaters of each litter.

[A B] Means in a same row with different superscript letters were significantly different ($p<0.05$).

[a b] Means in a same row with different superscript letters were significantly different ($p<0.12$).

Table 4. Effect of providing different creep feeds to suckling piglets on lactating sow performance

	Creep feed				
	Creep	Weaner	Sow	SEM[1]	P-value
Body weight, kg					
Initial (14th day)	235.7	235.1	235.8	3.88	0.88
21st day	233.8	234.1	233.8	4.16	0.96
28th day	231.1	229.4	230.8	3.97	0.85
Body weight change	-4.6	-5.8	-5.0	0.91	0.96
Back-fat thickness, mm					
Initial (14th day)	21.4	22.4	22.4	1.05	0.91
21st day	20.7	22.1	21.2	1.00	0.85
28th day	20.1	21.4	20.3	0.98	0.85
Back-fat change	-1.3	-1.0	-2.1	0.27	0.48
Average daily feed intake, kg					
14 to 21 day	5.55	5.71	6.03	0.22	0.46
21 to 28 day	6.34	5.88	6.67	0.19	0.26
Weaning to estrus interval, day	5.19	4.86	4.81	0.13	0.44

[1] Standard error of means.

Table 5. Effect of feeding different creep feeds during suckling period on growth performance of pigs after weaning

	Creep feed				
	Creep	Weaner	Sow	SEM[1]	P-value
Body weight, kg					
At weaning	7.87	7.38	7.53	0.170	0.48
14th day	10.91	11.04	10.76	0.210	0.87
35th day	19.74	19.94	20.19	0.302	0.83
Average daily weight gain, kg					
0 to 14 day	217^{B}	261^{A}	231^{AB}	7.0	0.03
14 to 35 day	421	424	449	7.5	0.23
Overall	339	359	362	6.0	0.24
Average daily feed intake, kg					
0 to 14 day	328^{B}	369^{A}	333^{B}	6.7	0.02
14 to 35 day	784	799	814	12.0	0.60
Overall	602	627	621	8.8	0.46
G:F ratio					
0 to 14 day	0.65	0.70	0.67	0.010	0.23
14 to 35 day	0.53^{b}	0.53^{b}	0.55^{a}	0.003	0.06
Overall	0.56	0.57	0.58	0.003	0.14

[1] Standard error of means.

$^{A\,B}$ Means in a same row with different superscript letters were significantly different ($p<0.05$).

$^{a\,b}$ Means in a same row with different superscript letters were significantly different ($p<0.12$).

Table 6. Effect of feeding different creep feeds during suckling period on morphology of small intestine at 4 days after weaning

	Creep feed				
	Creep	Weaner	Sow	SEM[1]	P-value
Duodenum					
Villus height, ㎛	572[b]	738[a]	733[a]	35.7	0.07
Crypt depth, ㎛	455	481	536	21.5	0.31
V:C ratio	1.26[b]	1.54[a]	1.39[ab]	0.056	0.11
Jejunum					
Villus height, ㎛	518	574	670	33.0	0.17
Crypt depth, ㎛	374	410	449	17.8	0.24
V:C ratio	1.39	1.41	1.50	0.052	0.68
Ilium					
Villus height, ㎛	464	463	566	27.2	0.24
Crypt depth, ㎛	332[b]	318[b]	390[a]	14.2	0.10
V:C ratio	1.39	1.46	1.45	0.041	0.85

[1] Standard error of means.

[a b] Means in a same row with different superscript letters were significantly different ($p<0.12$).

Table 7. Effect of feeding different creep feeds during suckling period on microflora population* in ileum and large intestine at 4 days after weaning

	Creep feed				
	Creep	Weaner	Sow	SEM[1]	P-value
E. coli K88+					
Ileum	20.85	21.04	32.01	3.006	0.17
Cecum	25.75	26.32	24.48	2.548	0.98
Colon	27.46	21.14	29.36	2.510	0.43
Rectum	20.94	27.80	30.86	2.404	0.22
Lactobacillus casei					
Ileum	15.95	18.02	17.26	1.100	0.77
Cecum	16.07	16.37	18.03	0.677	0.30
Colon	17.05	17.35	18.73	0.432	0.25
Rectum	17.16	17.30	18.02	0.616	0.85
Lactobacillus plantarum					
Ileum	16.54	16.02	14.84	0.600	0.37
Cecum	14.82	15.70	15.09	0.510	0.75
Colon	15.14	15.19	16.52	0.560	0.54
Rectum	13.53^{B}	14.35^{AB}	16.76^{A}	0.574	0.04
Bacillus subtilis					
Ileum	26.70	23.03	32.38	1.812	0.31
Cecum	25.18	26.52	28.01	1.421	0.78
Colon	24.75^{b}	25.17^{b}	31.89^{a}	1.384	0.07
Rectum	26.69	24.85	30.26	1.104	0.50

* Microflora populations are presented with Ct value of real time PCR.

[1] Standard error of means.

[a b] Means in a same row with different superscript letters were significantly different (p<0.12).

Chapter V: Effects of supplementation of SBM during suckling period on pre- and post-weaning hematological property and immunological parameter

ABSTRACT: This experiment was conducted to determine the effects of supplementation of soybean meal (SBM) as creep feed during suckling period on pre- and post- weaning immune response and growth performance. A total of 10 multiparous lactating sows and 80 piglets were used in this experiment. At 21 d, four male piglets and four female piglets were randomly selected from each litter, and one of male and female piglets were grouped and assigned to one of four treatment considering body weight and body weight gain from birth to 20 d. The treatments were 1) Control (Suckled maternal milk only), 2) Fed 50g of milk powder/day, 3) Fed 37.5g of milk powder and 12.5 g of soybean meal/day and 4) Fed 25g of milk powder and 25g of soybean meal/day. After weaning at 28 d, pigs were allotted to weaner facility with 4 pigs per each pen according to treatment and weaning weight. Feed and water were provided *ad libitum* through feeder and nipple during the whole experimental periods. In growth performance, piglets supplemented only milk powder showed the highest average daily gain, and both of piglets supplemented 12.5g and 25g/day of SBM showed numerically higher daily body weight gain than control group during suckling period. After weaning, piglets supplemented soybean meal during suckling period had higher average daily gain and G:F ratio than other treatments. However, significant differences were not observed in pre- and post-weaning performances. In haematological properties, supplementation of soybean meal during suckling period tended to increase plasma neutrophil proportion (P=0.06) and decrease lymphocyte proportion (P=0.06) at 7 d after weaning. Plasma IgA and IgG concentration was increased with age, and supplementation of soybean meal during suckling period significantly increased both of immunoglobulins at 7 d before and after weaning ($P<0.05$). Consequently, consumption of soybean meal during suckling period induces increase of immune response but immune response had little effects on piglet performance.

Key words: Suckling piglet, Soybean meal, Soy protein, Creep feed

INTRODUCTION

Soybean meal (SBM) which is one of most widely used protein source in swine diet, contains several anti-nutritional factors such as trypsin inhibitor, glycinine and B-conglycinin. Numerous researches demonstrated allergenic reaction induced by soybean protein after weaning such as villus atrophy, immune disorder, occurrence of diarrhea and growth retardation (Barnett et al., 1989; Miller et al., 1983; Strokes et al., 1984; Dreau et al., 1994; Li et al., 1990). Consumption of antigenic soybean protein could induce gut hypersensitivity in young animal (Barnett et al. 1989; Li et al., 1990; Dréau et al., 1994), and Miller et al. (1983) showed hypersensitivity prolonged for 2 weeks after weaning. Barnett et al. (1989) observed decrease of flow-rate in small intestine at 6 days after induction of soybean antigen and this reduction of flow-rate prolonged up to 24 days. Therefore, consumption of antigenic soybean proteins has responsibility on post-weaning growth retardation and digestive disturbance (Dréau et al., 1994, Li et al., 1990).

Newby et al. (1984) reported hypersensitivity to antigens can occur after weaning, when piglet was accessed to creep feed for short time or was fed creep feed less than 100g during suckling period. Similarly, Barnett et al. (1989) mentioned that longer exposure or higher creep feed consumption during suckling period could induce piglet tolerance to antigens. In addition, Xu et al. (2009) observed that peripheral blood lymphocyte was promoted by glycinin and B-conglycinine, which increased specific IgA secretion. Therefore, introduction of soybean meal during suckling period may induce tolerance to antigens in cereal grain based feed which will be provided after weaned.

In Chapter IV, positive role of cereal based creep feed on adaption to solid feed after weaning is presented. Immunological approach to evaluate the effects of grain based creep feed may provide answer for improved accessibility to solid feed after weaning. Consequently, this experiment was conducted to evaluate the effects of creep feeding on pre-and post-weaning immune development of pigs with supplementation of soybean meal as an important ingredient of grain based creep feed.

MATERIALS AND METHODS

Experimental animals and managements

A total of 10 multiparous lactating sows and their 80 piglets were used in this experiment. At 12 h postpartum, body weights of piglets were measured, and iron injection (Fe-dextran, 150ppm), ears notching and clipping needle teeth and tail docking were done to neonatal piglets. Cross-fostering was performed to standardize piglet number (10 piglets/litter), piglet weight (1.59 ± 0.4 kg) and gender ratio before 24 h postpartum. Male piglets were castrated at 3 d postpartum. In each litter, four male piglets and four female piglets were selected and arranged to 4 treatments (one male and one female per treatment) at 21 d postpartum. After arrangement, unselected piglets were removed from each litter (Figure 1).

The treatments were 1) Control (Suckled maternal milk only), 2) Fed 50g of milk powder/day, 3) Fed 37.5g of milk powder and 12.5 g of soybean meal/day and 4) Fed 25g of milk powder and 25g of soybean meal/day. Experimental feeds were formulated with mixture of SBM (45.6 % protein, 3,283 ME kcal/kg) and commercial milk powder (25.0 % protein, 4,950 GE kcal/kg; Seoul milk, Korea), and divided into 3 pieces and fed 3 times a day at approximate 8:00AM, 12:00AM and 4:00PM.

Before feeding, experimental feeds were mass up to 50 ml with water, and forced feeding was performed with needless syringe and plastic tube. If sows were lactating at feeding time, feeding times were delayed until piglets finished suckling. Amount of creep feed intake was established from the previous results of Chapter III and Chapter IV. Piglets were weaned at 28 d of age, and moved to weaner facility

(Concrete-slot floor, 0.90 x 2.15 m^2). Pigs were arranged 4 pigs per each pen according to treatment and body weight. After weaning, every pig was fed commercial weaner feed (Dodram, Seoul, Korea) regardless of treatment. Feed and water were provided *ad libitum* through feeder and nipple during pre- and post-weaning periods.

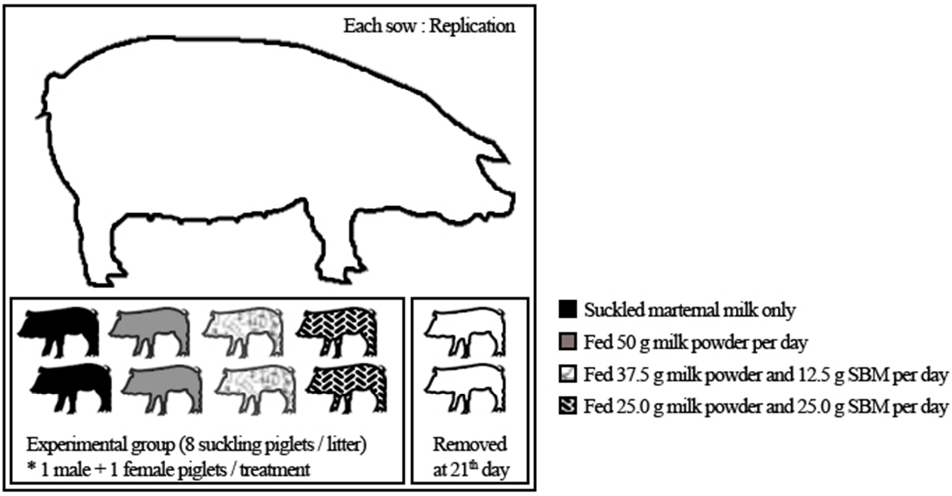

Figure 1. Arrangement of suckling piglets to four treatments in each litter

Sample collections and analysis

Body weight was measured at 21 d of suckling period, 28 d at weaning and 5 weeks after weaning. One piglet near average body weight of each treatment was selected at 21 d of suckling period, and blood samples were obtained from jugular veins at 21 d and 28 d of suckling period, and at 7 d and 35 d of post-weaning period. Blood samples were obtained from anterior vena cava. To measure hematological properties, whole blood samples were transferred to ETDA tube and white blood cell count, platelet count, neutrophil proportion, lymphocyte proportion, monocyte proportion and eosinophil proportion were analyzed. Hematological properties were measured in Green cross Corp. (Suwon, Korea), and analysis was performed fallowing their protocol. To measure plasma immunoglobulin concentration, blood samples were transferred to EDTA tube and centrifuged for 15 min at 3,000 rpm on 4°C (Eppendorf centrifuge 5810R, Germany). Plasma samples were transferred to 1.5 ml plastic tubes and stored at -20°C until analysis. Before analysis, each sample was diluted 1:5000 for IgA and 1:15000 for IgG, respectively. Plasma IgG and IgA were determined by ELISA assay followed by manufacturer's protocols (Pig IgA ELISA Quantification Set, Pig IgG ELISA Quantification Set; Bethyl, Texas, USA).

Statistical analysis

All of collected data were analyzed using Mixed GLM procedure of SAS (SAS Institute, 2004). For analyzing pre-weaning performance, two piglets within litter fed same diet were served as experimental unit, and each litter was considered as replication. After weaning, each pen was served as experimental unit. In hematological properties and plasma immunoglobulin, each piglet was served as experimental unit. Replications were considered as random effect in pre-weaning performances and blood analysis. Statistical differences were analyzed by least squares mean comparisons in PDIFF option. Differences and suggestive differences between treatments and categories were considered at $P < 0.05$ and $P<0.10$, respectively.

RESULTS

Pre- and post-weaning performance

Effects of consumption of milk powder and SBM during suckling period on pre- and post-weaning performance are presented in Table 1. During 7 days before weaning, piglets supplemented additional milk powder showed the highest average daily gain, and piglets supplemented 12.5g and 25g/day of SBM with milk powder showed numerically higher daily body weight gain than piglets only suckled maternal milk. After weaning, pigs had supplemented soybean meal during suckling period demonstrated numerically higher average daily gain and gain:feed ratio than other groups. However, significant differences were not observed in all of the measurements.

Hematological properties

Effects of consumption of milk powder and SBM during suckling period on pre- and post-weaning hematological properties are presented in Table 2. At 7 day after weaning, both of pigs had supplemented 12.5 g and 25 g of soybean meal/day during suckling period tended to show higher plasma neutrophil proportion than pigs only suckled maternal milk during suckling period ($P=0.06$). In contrast, at the same day, plasma lymphocyte proportion was decreased by supplementation of soybean meal during suckling period ($P=0.06$). There were no significant differences in white blood cell count, platelet count, eosinophil proportion, monocyte proportion and basophil proportion.

Plasma immunoglobulin

Figure 2 and Figure 3 present the effects of consumption of milk powder and SBM during suckling period on plasma IgA and IgG concentration around weaning. At 28th d, pigs fed 25 g of soybean meal/day had higher plasma IgA concentration than control group significantly ($P<0.05$). Furthermore, at 7 day after weaning, both of piglets consumed 12.5 g and 25 g of soybean meal/day showed significantly higher plasma IgA concentration than control group ($P<0.05$). Similarly, piglets fed 50 g of soybean meal/day during suckling period showed higher plasma IgG concentration than piglets did not supplemented soybean meal at 7 days before and after weaning ($P<0.05$). In contrast, pigs only suckled maternal milk showed the lowest plasma IgG concentration among treatment during the entire experimental period.

DISCUSSION

In the present study, during 7 days before weaning, piglets were fed 350g of feed except control group. Numerical improvement of weight gain during suckling period may be derived by these additional nutrients consumption. However, significant differences were not observed by supplementation of both of milk powder and soybean meal. Mathew et al. (1994) demonstrated that creep feeding possessed only little part of daily food consumption of piglets from 15 to 29 d of suckling period. Furthermore, increase of creep feed consumption reduce demand for maternal milk. Smith (1960) and Kuller et al. (2004) observed decrease of body loss of lactating sow by creep feeding, which means providing additional nutrient source diminishes milk production. Therefore, statistically equal weight gain in this study may be induced by countervailing of additional feed with reduced consumption of maternal milk.

Increase of lymphocyte and neutrophil can be an indicator of immune response (Shim et al., 2005). Increase of blood neutrophil is the first indicator of infection (Roth, 1999). Morrow-Tesch et al. (1994) reported that several stressful environments such as temperature and social stress during weaning elevate neutrophil proportion in blood. Similarly, Metz et al. (1990) observed increase of Neutrophil : Lymphocyte ratio when pigs weaned at early age, and Niekamp et al. (2007) also showed increase of Neutrophil : Lymphocyte ratio, neutrophil phagocytosis and IgG concentration when pigs weaned at 14 d than 28 d. Lymphocyte count increases with age but neutrophil count does not altered by age (Hoskinson et al., 1990). In the present study, pigs supplemented soybean meal during suckling period had higher proportion of neutrophil (P=0.06) and lower proportion of lymphocyte (P=0.06) than other pigs which caused increase of Neutrophil : Lymphocyte ratio. This result indicated that consumption of soybean meal induces piglet's stress and increases immunological challenges.

After weaning, gut damage induced by consumed solid feed promotes immune response to produce antibodies. Increase of blood immunoglobulin level reflects humoral immunity. Xu et al. (2009) observed gradual increase of IgA level by addition of soybean protein in the culture of peripheral blood monocyte, and represented β-conglycinin promote peripheral blood monocyte count which produce certain cytokines and immunoglobulins.

Increases of immunoglobulins may indicate hypersensitivity to soybean protein. Newby et al. (1984) mentioned that short-term access to creep feed and low creep feed intake under 100g during lactation may sensitize piglets to feed antigens which cause intense immune response and gut damage after weaning. However, Barnett et al. (1989) observed ovalbumin antibody tighter of piglets suddenly increased with injection of ovalbumin when piglets were not exposed to ovalbumin contained creep feed during suckling period. In contrast, piglets consumed ovalbumin contained creep feed showed only slightly increased antibody titer after injection. These results demonstrated that creep feeding could give piglets tolerance to feed antigen before weaning. Therefore, increase of plasma immunoglobulin also indicates development of humoral immunity.

In the present experiment, piglets fed 87.5 g or 175 g of SBM during suckling period, and plasma immunoglobulins were increased with consumption of soybean meal. However, hypersensitivity was not occur in piglets fed SBM during suckling period, because they showed numerical increase of body weight gain and feed intake after weaning.

In summary, results of current study indicates that consumption of soybean meal during suckling period induce immune response around weaning. However, piglets consumed soybean meal during suckling period showed similar or slightly higher growth performance before and after weaning than piglets not fed soybean meal before weaning. Therefore, results of the present study were in agreement with

Barnett et al. (1989) which observed immune function related to creep feeding but concluded immune response had little effects on piglet performance.

CONCLUSION

Increases of neutrophil and plasma immunoglobulins indicated that consumption of SBM before weaning activated immune function around weaning. However, immune response of weaning pigs did not altered pre- and post-weaning growth performance significantly. Consequently, though feeding soybean meal before weaning induces immune response after weaning, but this immunological challenge is not a major concern for the adaptation to solid feed and growth retardation of pigs after weaning.

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Table 1. Effects of consumption of milk powder and SBM during suckling period on pre- and post-weaning performance

	Con	Daily Milk powder, SBM consumption, g			SEM[1]	P-value
		50, 0	37.5, 12.5	25, 25		
Body weight, kg						
21st day (Initial)	4.77	4.77	4.77	4.78	0.178	
28th day (Weaning)	6.27	6.42	6.35	6.40	0.237	0.94
63th day (35 day after weaning)	17.37	17.35	18.31	18.61	2.371	0.23
Average daily gain, g						
21 to 28 day	215	236	226	231	11.3	0.86
28 to 63 day	313	312	340	349	7.9	0.18
Average daily feed intake after weaned, g						
28 to 63 day	462	459	472	476	8.7	0.74
Gain : Feed ratio after weaned						
28 to 63 day	0.68	0.68	0.72	0.74	0.013	0.26

[1] Standard error of means.

Table 2. Effects of consumption of milk powder and SBM during suckling period on hematological properties

	Con	Daily Milk powder, SBM consumption, g			SEM[1]	P-value
		50, 0	37.5, 12.5	25, 25		
White blood cell, $10^3/\mu\ell$						
21st day	11.6	12.5	10.2	9.1	0.52	0.11
28th day	8.8	10.8	11.3	11.2	0.49	0.25
35th day	16.0	15.0	15.0	16.8	0.68	0.77
63th day	16.3	16.2	15.5	14.6	0.59	0.62
Platelet, $10^3/\mu\ell$						
21st day	364.9	464.6	438.6	481.0	25.41	0.46
28th day	439.1	490.0	369.6	433.9	29.08	0.55
35th day	500.4	505.4	501.3	505.4	17.98	1.00
63th day	490.1	469.3	411.1	448.0	17.81	0.38
Neutrophil, %						
21st day	32.73	34.42	32.92	30.10	1.317	0.67
28th day	27.58	30.24	30.36	24.41	1.617	0.56
35th day	36.89^{b}	41.35^{ab}	46.93^{a}	45.81^{a}	1.496	0.06
63th day	41.41	40.60	43.99	38.46	1.259	0.49
Lymphocyte, %						
21st day	59.52	57.56	57.53	60.37	1.484	0.88
28th day	59.60	59.83	53.14	60.48	1.675	0.40
35th day	57.76^{a}	51.53^{ab}	47.42^{b}	45.71^{b}	1.720	0.06
63th day	48.36	47.54	44.78	52.31	1.402	0.30
Eosinophil, %						
21st day	3.16	4.03	2.86	3.10	0.304	0.53
28th day	5.90	4.04	5.93	5.90	0.525	0.47
35th day	1.57	2.23	1.42	2.12	0.160	0.21
63th day	4.43	5.49	5.73	5.05	0.301	0.47

(Continue)

Monocyte, %						
21st day	3.95	3.53	4.06	3.76	0.180	0.74
28th day	3.89	3.73	4.48	3.84	0.229	0.69
35th day	3.21	3.09	3.34	2.90	0.149	0.73
63th day	3.20	3.35	4.22	3.57	0.192	0.23
Basophil, %						
21st day	0.64	0.79	0.57	0.80	0.095	0.25
28th day	0.70	0.57	0.60	0.71	0.052	0.46
35th day	0.73	0.67	0.50	0.68	0.023	0.46
63th day	1.13	0.74	0.53	0.61	0.030	0.16

[1] Standard error of means.

[a b] Means in a same row with different superscript letters were significantly different ($p<0.10$).

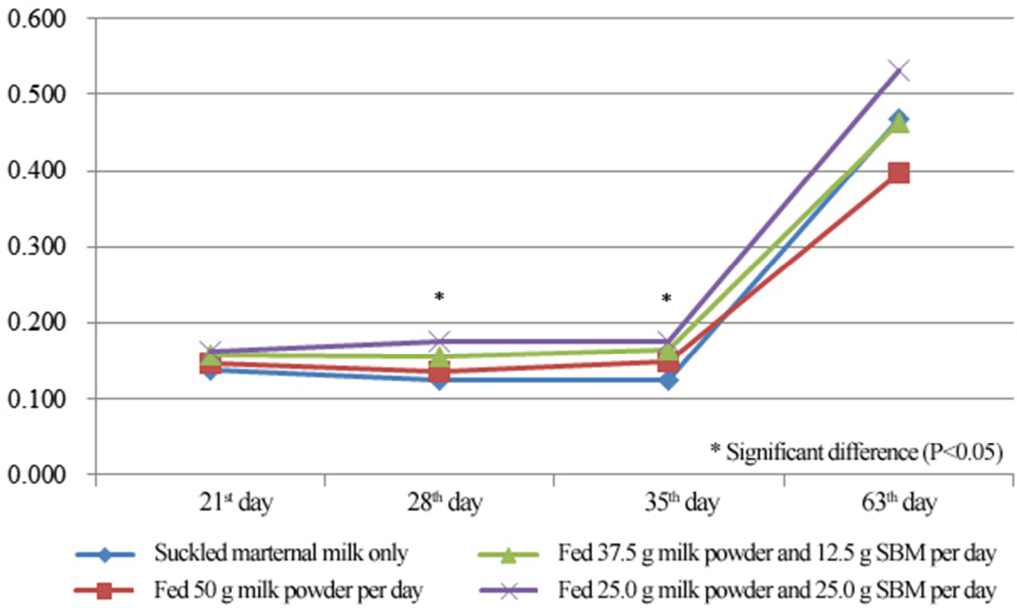

Figure 2. Effects of consumption of milk powder and SBM during suckling period on plasma IgA concentration (mg/ml)

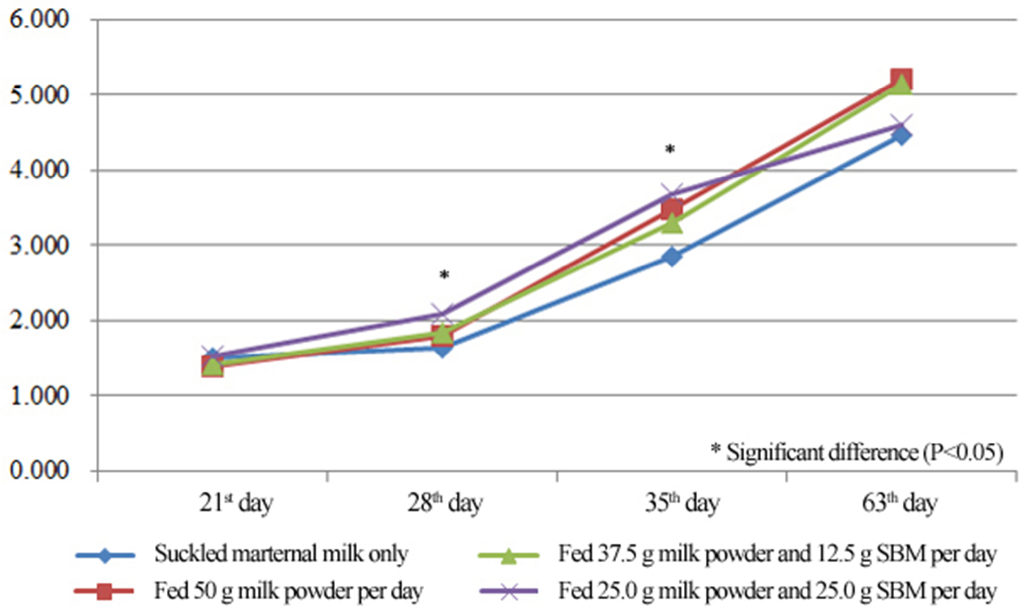

Figure 3. Effects of consumption of milk powder and SBM during suckling period on plasma IgG concentration (mg/ml)

Chapter VI. Overall Conclusion

Despite of controversial results of creep feeding, creep feed has been introduced to modern sow management. In Korea, creep feed is provided to piglets in the early days of nursing period which causes a decrease of sow productivity and increase of production cost. Consequently, three experiments were conducted to suggest proper application about creep feeding based on creep feeding duration, creep feed quality and immunological disorder by creep feeding.

In the first study, creep feed consumption of piglets did not improve even though highly digestible creep feed was provided until 17 days postpartum. One considerable observation was a decrease of creep feed consumption during late suckling period when piglets were fed highly digestible creep feed from 4^{th} day of postpartum. Moreover, providing highly digestible creep feed from 11 d could acceptable for maximizing improve piglet weaning weight, but piglets providing creep feed only 4 days before weaning also noted statistically similar performance with piglets provided creep feed for longer duration. These results indicated that early supplementation of creep feed is meaningless or even harmful for piglet's usage of creep feed and later growth of piglets after weaning. Furthermore, lactating sow performance revealed that abundant use of creep feeding during lactation could induce obesity of sow. Therefore condition of sow should be considered when swine producers are applied creep feeding.

This result represented familiarity to feed might be the most important factor to improve feed consumption after weaning. Consumption of milk based creep feed elevated pre-weaning performance of piglets but it caused the lowest feed efficacy after weaning subsequently poor growth performance was observed. When creep feed is provided on the purpose of adjustment to solid feed after weaning, weaner diet is able to apply effectively during lactation. When piglets were fed sow diet as a creep feed, feed consumption of piglets were similar compared with weaner feed. This result demonstrated that sow diet can be utilized efficiently when piglets are weaned after 4^{th} week of age. Moreover, when enough space was not available in farrowing facility, sow diet can be supplied easily instead of conventional type of creep feed. Therefore, highly digestible creep feed could introduced on the purpose of improving creep feed intake and pre-weaning growth, but rough cereal based creep feed also has beneficial effects on post–weaning performance with very low cost.

The third experiment was conducted to evaluate the potential detrimental effect of creep feeding. In the results, increase of Neutrophil : Lymphocyte ratio, plasma IgA and IgG were observed, so it is certain that creep feeding induces immune response to piglets before and after weaning. When soybean meal was provided as a creep feed, any detrimental effect on growth performance was not observed. Immunity can be acquired through challenges of antigens, so increase of immune response also can be account for immune development. However, immune response which observed in this study showed challenge to antigens by creep feeding could not be a major concern regardless of creep feed.

Consequently, creep feeding can be introduced to improve weaning weight of piglets, but its providing from early days of postpartum is not recommendable management for lactating sow due to poor growth performance of weaning pigs and expensive feed cost without additional benefits to swine producers.

Chapter VII. Summary in Korean

본 연구는 저 일령부터 유제품 기반의 입붙이사료의 급여 및 입붙이 급여기간이 포유모돈과 자돈의 성장에 미치는 영향을 규명하고, 유제품 기반의 입붙이사료와 곡물 기반의 입붙이 사료의 급여가 포유자돈의 성장과 이유 후 사료적응성에 미치는 영향을 분석하기 위해 수행되었다. 그리고 대표적인 곡물사료인 대두박을 이용하여 곡류기반의 입붙이사료가 이유 전 후 자돈의 면역성상에 미치는 영향을 조사하여 입붙이사료의 바른 활용방안을 제시하기 위해 수행되었다.

실험 1. 고품질 입붙이 사료의 급여시기가 모돈의 포유성적 및 자돈의 이유전 성장과 장발달에 미치는 영향

첫 번째 실험은 유제품 기반의 입붙이 사료의 급여가 포유 모돈의 포유성적과 자돈의 포유기 성장에 미치는 영향을 규명하기 위해 수행되었다. 총 40두의 F1 경산돈을 공시하여 완전임의배치법에 의거하여 각 입붙이 기간에 배치하였다. 한 처리당 8두의 모돈을 배치하였으며 입붙이의 시작일령은 분만 4일령, 11일령, 18일령 및 25일령에 입붙이 사료를 급여하기 시작하여 28일령에 자돈을 이유하고 실험을 종료하였다. 실험의 결과 입붙이사료의 급여는 유제품 기반의 입붙이 사료를 급여하여도 17일 이전까지는 성장증진효과가 나타나지 않았다. 18일령에서 24일령까지는 입붙이사료의 급여 기간에 따라 자돈의 성장이 유의적으로 증가하였으며 (linear, $P<0.05$). 하지만 25일령에서 28일령의 성장성적에서는 입붙이사료의 급여기간이 길어짐에 따라 성장률이 높아지다가 낮아지는 결과가 도출되었다 (quadratic, $P=0.06$). 입붙이사료를 섭취한 자돈과 입붙이 사료를 섭취하지 않은 자돈의 성장성적에는 차이가 없었지만, 18일령 이후 두 그룹 모두 입붙이사료를 급여하지 않은 자돈들에 비해서 높은 성장률을 나타냈다 ($P<0.05$). 각 처리구에서 입붙이사료를 섭취한 자돈의 수는 입붙이사료의 섭취기간의 증가에 따라 늘어났으나, 입붙이사료 섭취량은 4일령부터 입붙이 사료를 급여한 처리구의 자돈들이 가장 낮은 입붙이사료 섭취량을 보였다 ($P<0.05$). 모돈의 포유성적에서는 모돈의

재귀발정일이 입붙이사료 급여기간의 증가에 따라 감소하다가 다시 증가하는 경향이 나타났으며 (P=0.06), 포유 중 체중변화 또한 유사한 결과를 보였다 (P<0.05). 입붙이사료를 11일령 이전에 급여한 경우 11일령에서 17일령 사이 모돈의 사료섭취량이 증가하는 경향이 나타났지만 (P=0.07), 25일령에서 28일령까지는 반대로 감소하는 경향이 도출되었다 (P=0.09). 입붙이사료를 급여하지 않은 모돈처리구의 모유에서 구연산의 함량이 높게 검출되었다 (P<0.05). 28일령에 각 처리구에서 6두의 자돈을 선발하여 해부실험이 진행되었다. 입붙이사료 급여 기간이 감소할수록 자돈의 소장융모의 길이와 융와의 깊이가 감소하는 경향이 발견되었고 (P<0.1). 장내 미생물 균총의 경우 회장 (P<0.05) 및 맹장 (P=0.06), 결장 (P<0.05) 그리고 직장 내용물에서 *Lactobacillus casei* 의 Ct value가 높게 나타났으며, 반대로 맹장, 결정 및 직장 내용물의 *Lactobacillus plantarum* 의 Ct value가 낮게 나타났다 (P<0.05). 결론적으로 유제품 기반의 입붙이 사료의 급여는 자돈의 성장률을 높일 수 있으나 저 일령부터 유제품 기반의 입붙이 사료의 급여는 포유 후기 자돈의 입붙이 사료 섭취량을 감소시킬 수 있다.

실험 2. 입붙이사료의 품질이 자돈의 이유 전 후의 성장과 장 발달 및 이유 후 사료 적응성에 미치는 영향

두 번째 실험은 유제품 기반의 입붙이 사료와 곡물 기반의 입붙이 사료가 이유 전 후의 성장성적과 이유 후 고형 사료에 대한 적응성을 평가하기 위해 수행되었다. 총 24두의 F1 경산돈을 공시하여 완전임의배치법에 의거하여 14일령에 3개의 다른 형태의 입붙이사료를 공급하였다. 처리구는 3처리였으며 처리구에 따라 유제품 기반의 입붙이사료, 이유 후 섭취할 자돈사료 그리고 모돈사료를 각각 공급하였다. 이유 후에는 입붙이를 섭취한 자돈 96두를 선발하여 이유 후 사양성적을 조사하였다. 포유기 성적에서는 입붙이사료의 종류가 입붙이사료를 섭취한 자돈의 수를 증가시키지 않는 것으로 나타났다. 17일령에서 21일령까지 유제품 기반의 입붙이사료를 섭취한 자돈의 성장이 모돈사료를 섭취한 자돈에 비해 높은 경향이 나타났다 (P<0.12). 또한 21일에서 28일령 사이에도 유제품 기반의 입붙이사료의

이용성이 모돈 사료에 비해 유의적으로 높은 것으로 나타났다 (P<0.05). 하지만 이유 후부터 14일령까지 포유기 동안 자돈사료를 공급받은 자돈들의 성장과 사료섭취량이 다른 처리구들에 비해 유의적으로 높게 나타났으며 (P<0.05), 이유 후 14일령에서 35일령사이에는 포유기에 모돈사료를 섭취한 자돈들의 사료효율이 다른 사료를 섭취한 자돈들보다 높은 경향이 발견되었다 (P=0.06). 이유 후 4일령에 소장의 형태학적 변화와 장내 미생물 균총을 관찰하기 위해 각 처리구에서 암수 3두씩의 자돈 (7.56 ± 0.78 kg) 을 선발하여 해부 실험이 진행되었다. 포유기에 유제품 기반의 입붙이사료를 섭취한 자돈들의 경우 자돈사료와 모돈사료를 섭취한 자돈들에 비해 십이지장 융모의 길이가 짧아지는 경향이 나타났으며 (P=0.07), V:C 비율 또한 낮게 나타났다. 모돈 사료를 섭취한 자돈들의 회장 융와의 깊이가 더 깊은 것이 관찰되었다 (P=0.1). 장내 미생물 균총의 분석결과 모돈 사료를 섭취한 자돈들의 직장내용물에서 *Lactobacillus plantarum* 의 Ct value가 유제품 기반의 입붙이 사료를 섭취한 자돈들에 비해 높았다 (P<0.05). 마찬가지로 모돈사료를 섭취한 자돈들의 결장에서 *Bacillus subtilis* 의 Ct value가 높아지는 것이 발견되었으며 (P=0.07), 회장과 대장에서 수치상으로 모두 높은 관찰값을 보였다. 결론적으로 유제품 기반의 입붙이 사료는 자돈의 포유기 성장을 증가시킬 수 있지만, 사료에 적응성을 높이고 이유 후 성장성적을 높이기 위해서는 곡물기반의 입붙이사료를 사용하는 것도 적극 검토할 필요가 있는 것으로 나타났다.

실험 3. 포유기 대두박의 급여가 자돈의 이유 전 후 사양성적, 혈액성상 및 면역지표에 미치는 영향

세 번째 실험은 대두박 (SBM)을 이용하여 입붙이사료 대용으로 곡물사료의 급여가 자돈의 면역발달에 미치는 영향을 규명하기 위해 수행되었다. 총 10두의 F1 경산돈과 80두의 자돈을 공시하여 21일령부터 4개의 처리에 완전임의 배치법을 통해 배치하였다. 21일령에 각 모돈에서 암컷과 수컷 4두씩을 선발하여 체중과 실험 전까지의 증체량을 기준으로 2두씩 그룹으로 만들고 그룹에 따라 각각의 실험사료를 공급하였다. 처리구는 1) Control (모유만 섭취), 2) 50g of milk powder/day 급여, 2)

37.5g of milk powder and 12.5 g of soybean meal/day 급여, 4) 25g of milk powder and 25g of soybean meal/day 급여였다. 자돈들은 28일령에 이유가 되었으며 이유 자돈사에서 각 돈방에 4두씩 체중을 고려하여 배치하였고 물과 사료는 자유롭게 섭취할 수 있도록 하였다. 자돈의 성장에서 대용유만을 급여받은 자돈의 포유기 성장률이 다른 처리구에 비해 가장 높게 나타났고, 대용유를 급이한 자돈들의 성적 또한 아무것도 급여하지 않은 자돈들에 비해 높아졌지만 모든 성장지표에서 유의차는 발견되지 않았다. 혈액분석의 결과 포유기에 대두박을 급여받은 자돈들의 이유 전후 7일의 호중구 비율이 높은 경향이 나타났으며 (P=0.6), 반대로 임파구의 비율은 감소하였다 (P=0.06). 혈중 immunoglobulin 농도의 경우 이유 전 후 7일령에서 포유기에 대두박을 급여받은 자돈들이 IgA와 IgG 농도 모두가 유의적으로 높게 나타났다. 결론적으로 대두박의 포유기 급여는 자돈에게 면역반응의 원인이 되지만, 면역적 요인이 자돈의 성장이 미치는 효과는 적은 것으로 사료된다.

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