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# Effect of Starch Sources Extrusion on Performance of Young Pig

# 전분 원료의 익스트루젼이 자돈 성장에 미치는 영향

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이 논문을 농학석사 학위논문으로 제출함

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**노 수 덕**

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**위 원 장** ______________________ (인)

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# Summary

At weaning, the young pig is subjected to myriad of stressors (e.g. change in nutrition, separation from mother and littermates, new environment) which cause a reduction of growth. Reduced feed intake, limited digestive enzyme development and challenges to the digestive tract may all have serious consequences for the development and survival of the young pig. These factors often lead to the post-weaning `growth check' commonly observed during this period of time, which can have a major impact on subsequent performance. Starch is the main source of energy in piglet diets, but native starch is not completely digested in the small intestine of young pigs. Undigested starch enters the large intestine where it can be fermented, resulting in increasing the incidence of diarrhea and reducing piglet performance. More digestible source of the starch and heat processing of the cereal can improve digestibility in piglet, and reduce growth check. An experiment was conducted to evaluate the effects of starch sources and extrusion on growth performance, nutrient digestibility of weaning pigs. This study was a 2 x 3 factorial arrangement of treatments conducted in a randomized complete block (RCB) design. The first factor was ingredient processing method and the second factor was three different carbohydrate sources (corn, barley or rice). A total of 144 weaning pigs ([Yorkshire × Landrace] × Duroc) averaging 7.02 ± 1.07 kg body weight, weaned at 28 ± 3 days of age were allotted to 6 treatments in 6 replicates with 4 pigs per pen. All nutrients of experimental diets were met or exceeded NRC requirements (1998). During the whole experimental period, pigs fed raw carbohydrate sources had improved

ADG (625 vs 545 g; P<0.01 and 469 vs 416 g; P<0.01), and G/F ratio was also increased when pigs were fed no extruded cereals (0.711 vs 0.652 g; P<0.01 and 0.695 vs 0.645 g; P<0.01). Among raw cereals, raw rice treatment tended to increase growth performance compared to raw corn treatment at 2-5 week (corn 593 vs rice 661; P<0.1), Protein digestibility of barley and rice was increased when extruded sources were provided but nitrogen retention was numerically decreased as pigs were fed extruded sources. Growth performance of weaning pigs was improved when raw carbohydrate sources were provided. This results demonstrated that extrusion of carbohydrate sources in weaning pigs' diet did not show any positive response on nutrient digestibility. Consequently, raw carbohydrate sources rather than processed sources can be utilized in weaning pigs' diet without detrimental effects on nutrient digestibility or growth performance.

**Key Words: Weaning, Starch, Extrusion, Corn, Barley, Rice.**

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# List of Abbreviation

| | | |
|---|---|---|
| ADFI | : | Average daily feed intake |
| ADG | : | Average daily gain |
| AOAC | : | Association of official analytical chemists |
| BGL | : | Blood Glucose Level |
| BUN | : | Blood Urea Nitrogen |
| BW | : | Body weight |
| CP | : | Crude protein |
| G/F ratio | : | Gain : Feed ratio |
| GLM | : | General liner model |
| Lys | : | Lysine |
| ME | : | Metabolic energy |
| NRC | : | National Research Councile |
| RCB | : | Randomized complete block |
| SAS | : | Statistical Analysis System |
| SG | : | Starch Gelatinization |

# I. Introduction

At weaning, the young pig is subjected to myriad of Stressors (e.g. change in nutrition, separation from mother and littermates, new environment) which cause reduced growth. It is clear that numerous factors can present major challenges to the weaned piglets. Reduced feed intake, limited digestive enzyme development and challenges to the digestive tract can all have serious consequences for the development and survival of the young pig. These factors often lead to the post-weaning `growth check' commonly observed during this time, which can have a major impact on subsequent performance. At weaning, milk is replaced by diets containing starch as the main energy source.

Starch which is consist of amylose and amylopectin, is accumulated in granules in the endosperm of cereal or legume. The granule is composed of alternating semi-crystalline and amorphous. In non-ruminant animals, starch digestion generally occurs in the small intestine by the action of α-amylase, dextrinase and glucoamylase. Starch's digestibility is affected by granule dimension and shape, compound (protein, lipid, mineral, and so on), amylose content, and others. But, each cereal's characteristics are variable, and it is difficult to deduce each cereal's digestibility. When starch is gelatinized, starch become digestible by amylase.

Starch is the main source of energy in weanig pig diets, but native starch is not completely digested in the small intestine of young pigs (Vicente et al., 2009). Undigested starch enters the large intestine where it can be fermented, increasing the incidence of diarrhea and reducing weaning pig performance. Source of the starch (Hongtrakul et al., 1998; Medel et al., 2004) and heat processing of the cereal (Aumaitre, 1976; Huang et al., 1998; Medel et al., 2002) are 2 major factors affecting starch digestibility. In the conclusion, it seems to improve growth performance in weaning pig to feed higher digestible starch source and extruded starch to improve digestibility.

# II. Review of Literature

## 1. Weaning

Weaning is an important step and gives the young piglet many challenges. In the wild, weaning is a slow process which takes 3 or 4 months (Jensen, 1986; Jensen and Recen, 1989). During this time, the piglet will become accustomed to feed besides milk and its digestive enzymes will gradually adapt accordingly (English et al., 1988). Weaning suddenly occurs at 21 or 28 day age. The abrupt change to wean at this early age gives the piglet some stresses. Because of the many challenges at weaning, even though carefully manage, the process is very stressful to the young animal. The major stresses can be divided into three areas. The first is psychological stress. The piglet is separated with the sow. The piglet has lost the reassurance of its mother's presence and is often mixed with animals from other litters. This means it has to determine its place within a new hierarchical structure, and this often leads to an increased incidence of fighting (Friend et al., 1983; Worobec et al., 1999). The second is environmental stress. The transition from a farrowing house to a nursery is also a major stress for the young animal. Piglets reared in a poor environment have been found to behave more aggressively and exhibit higher basal cortisol levels than those reared in an enriched environment (De Jonge et al., 1996). The last is nutritional stress. There is abrupt change from a warm liquid diet (milk), which the sow fed to the piglet, several times a day on a regular basis, to a dry feed which is usually only available via a feeder. This dietary change from milk to a dry solid feed requires rapid adaptation of the piglet's digestive system. In addition, the piglet must now also learn to drink water, usually from a hard steel nipple.

### 1.1. The reduction factor of piglet performance at weaning

#### 1.1.1. Low feed Intake

The major reduction factor of piglet performance at weaning is voluntary feed intake. At weaning, the piglet is faced with an unfamiliar diet, which is solid and dry. Bark et al. (1986) reported that early-weaned piglets failed to intake an enough amount of diets during the initial three days post-weaning in an unfamiliar environment. This post-weaning anorexia is common and piglets often fail to intake enough feed to satisfy their energy requirements. Before the piglet has been accustomed with the dry diet, it usually is a high level of hunger. This can lead to abnormal feed intake patterns, which often result in digestive upsets on the immature digestive system (Mavromichalis and Varley, 2003). The first few days after weaning are typically characterized by low or even zero feed intake. This inadequate intake of feed can lead to detrimental changes in gut structure and function.

The energy system used present requirements for pigs has developed from using total digestible nutrients (NRC, 1971) to metabolizable energy (ME) and net energy (NE). ME has been used the most in Korea. The utilization of the energy by the pig is expressed in Figure 1.

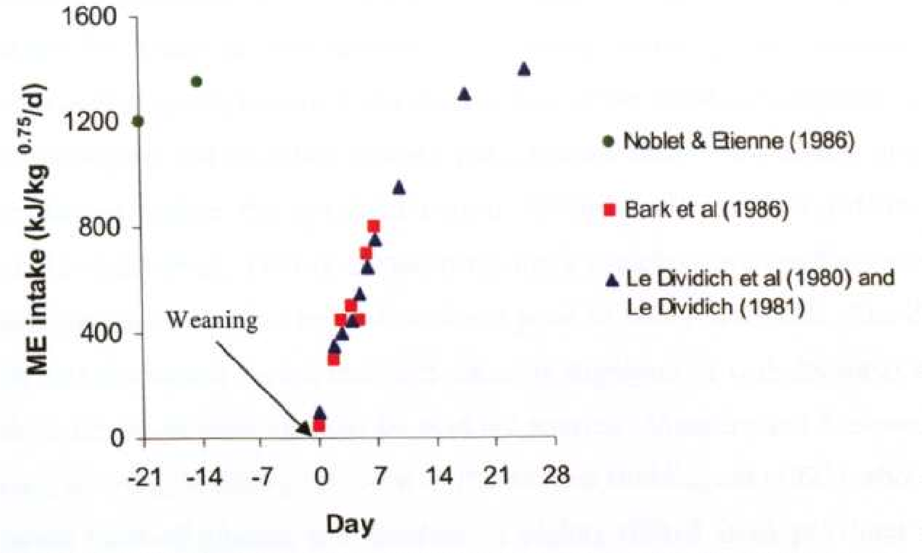


Figure 1. The voluntary feed intake of piglets before and after weaning (LeDividch and Herpin, 1994)

### 1.1.2. Digestive enzyme development

Digestive enzymes are good for sows' milk at birth of piglets. High levels of the lactase are secreted, along with enough proteases and lipases to breakdown the proteins and fats in the milk. Over the following weeks of the piglet's life, the amount and activity of these enzymes will be changed, in order to adapt to a solid dry diet. As the piglet grows and the nutritional composition of the diet changes, the digestive system will mature, and adapt to more complex proteins and carbohydrates (primarily starch). An important component of the digestive process is the breakdown of dietary carbohydrates by intestinal disaccharides.

#### 1.1.2.1. Lactase

During suckling, lactase is the most active of the intestinal enzymes. Lactose is readily hydrolyzed and absorbed through the intestinal wall. As a result, subsequent absorption occurs at the proximal region of the small intestine (Manners and Stevens, 1972; Kelly et al., 1991a). This enzyme has been recorded in the piglet fetus as early as day 105 of gestation (Aumaitre and Corring, 1978). Consequently, high levels are present in the newborn, with levels peaking during the first week of life. Activity then gradually declines with age, and eventually reaches a relatively constant level by finisher (Manners and Stevens, 1972). Weaning has been reported to influence lactase activity; Miller et al. (1986) found the activity of lactase was significantly (2 to 5 fold) lower five days after weaning 21d old piglets, than those of similar age still left to suckle on the sow. A comparable effect was also reported in piglets weaned at two weeks of age (Kelly et al., 1991a), when lactase activity was only 40% of that found in unweaned counterparts a week later.

#### 1.1.2.2. Sucrase

Activity of this enzyme is rarely detectable at birth. Manners and Stevens (1972) were only able to detect activity in one of six newborn piglets. After the first week, however, sucrase activity was found to be present in all of the piglets. Activity typically rises progressively through to maturity. Studies have shown that the act of weaning piglets at three weeks of age typically induces a temporary reduction in sucrase activity (Hampson and Kidder, 1986; Miller et al, 1986). This depression appears to be short-lived however, and enzyme levels in the post weaned piglet are typically greater in the following weeks than in animals left on the sow (Kelly et al., 1991a), even up to eight weeks of age (Kidder and Manners, 1980).

#### 1.1.2.3. Maltase

This enzyme's role is the hydrolysis of maltose into two glucose molecules. Enzyme activity is very similar with that of sucrase and although present in low levels at birth, goes up progressively with age. Maltase activity has been shown to increase significantly (x 143) by eight weeks (Aumaitre and Corring, 1978), before reaching a plateau by around 200 days of age (Kidder and Manners, 1980).

#### 1.1.2.4. Trypsin and Chymotrypsin

Trypsin and chymotrypsin are initially secreted from the pancreas in their inactive forms (trypsinogen and chymotrypsinogen). Trypsinogen is converted into its active form (trypsin) by enterokinase in the intestinal mucosa. Trypsin is then able to activate chymotrypsinogen into chymotrypsin. These two enzymes continue the process of protein digestion, which is started in the stomach. It appears from the literature that enzyme levels are closely linked with pancreatic tissue development in the weeks following birth. Corring et al (1978) identified rapid pancreatic growth in piglets during the first week of life, and again from the fourth to the eighth week. Enzyme activities were closely linked with these two stages of growth and development. From the third to fourth week of age, total enzymatic activities were found to markedly increase, which was attributed to the intake of solid feed by the piglets. Other authors have also reported a significant increase of enzyme levels, in relation to intake of solid feed at weaning (Efird et al., 1982; Lindemann et al., 1986).

#### 1.1.2.5. Pancreatic lipase

This enzyme's role is the hydrolysis of dietary fats (triglycerides) into fatty acids and glycerol. In a study with unweaned piglets, it was reported by Corring et al. (1978) that specific activity increased with age up to six weeks, when it peaked. In weaned piglets there appears to be a temporary decrease in activity post-weaning. Lindemann et al. (1986) reported that the concentration of lipase in the pancreas and digesta fell by between 30 and 60% of pre-weaning levels. It is suggested that the piglet does not have the ability to increase enzyme secretion immediately after weaning (Jensen et al., 1997) and utilization of fat will therefore be limited by this reduction in pancreatic lipase activity (Thacker, 1999). This decreased secretion would correlate with a change in the piglet's diet at this time; the transition from a diet high in fat (sows' milk), to a weaning diet with lower levels would be accompanied with the usual drop in feed intake at weaning. These two factors would commonly result in a reduced level of dietary fat intake by the piglet around this time, which would explain reduced pancreatic lipase levels.

#### 1.1.2.6. Pancreatic amylase

This enzyme is also secreted in its active form and hydrolyzes starch into the disaccharide sugar maltose. Several studies have reported that pancreatic amylase activity increases with age (Corring et al., 1978; Lindemann et al., 1986; Owsley et al., 1986; Kelly et al., 1991a). In unweaned piglets, amylase appears to undergo a two stage development of activity, consistent with other pancreatic enzymes. Corring et al. (1978) found specific activity at three weeks was higher (x 2.8) than at birth. This increased more rapidly up to six weeks (x 27.5), where it remained unchanged through to eight weeks of age. Although one study has reported a marked increase in activity in unweaned piglets up to four weeks, it was suggested that the unexpectedly high amylase levels were probably due to the piglets gaining access to the sows' feed, as she was not removed from the crate during the experimental period (Lindemann et al., 1986). This increase in amylase activity with age appears significantly greater in weaned piglets than in unweaned animals and has been shown to occur rapidly. Kelly et al. (1991a) observed a dramatic increase in total amylase activity even at three days post-weaning, which had doubled by seven days.

#### 1.1.2.7. General patterns in digestive enzyme activity

From the above studies, it can be concluded that, with the exception of lactase, the majority of digestive enzymes are present in the piglet at low levels at birth. Enzyme levels rise progressively with age, although the capacity of the piglet to secrete these enzymes can be significantly reduced by the process of weaning. The decrease in enzyme levels around this time is often linked to a reduction in feed intake by the piglet. It has been shown that digestive enzyme development is related to appetite, with greater feed intakes resulting in enhanced enzyme activity (Makkink et al., 1994). Following the adaption to diets after weaning, enzyme levels increase again, and often at a greater rate than before (Lindemann et al., 1986). There is strong evidence that this marked increase in enzyme activity is in response to the change in diet at weaning. McCracken (1984) stated that the nature of the dietary carbohydrate can alter the extent of enzyme induction in the immediate post-weaning period. Amylase activity, for example, significantly increases in order to digest starch that would now be present in significant amounts in the weaner diet. The notion of enzyme induction is further supported by the work of Kelly et al. (1991a) who observed dramatic increases in both maltase and amylase activities, even by three days post-weaning.

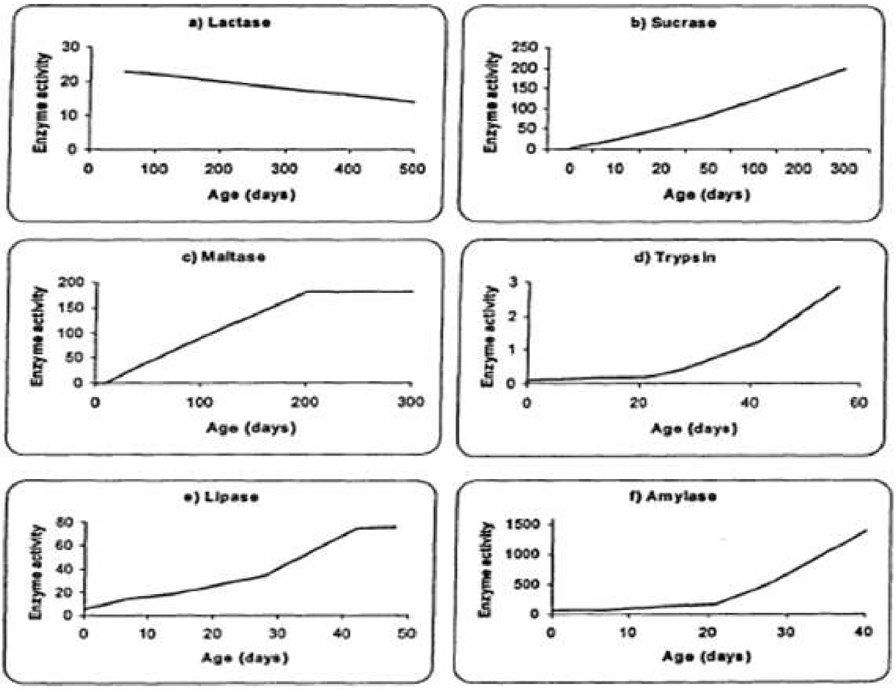


Figure 2. Digestive enzyme develpoment in the young piglet (Corring et al., 1978, and Kidder and Manners, 1980)
(Enzyme units for lactase, sucrase and maltase are μmol/min per g protein. Specific activities for trypsin, lipase and amylase are /mg protein)

### 1.1.3. Gut structure and function

The structure of the small intestine are typically changed in the immediate post-weaning period. Many articles have reported a decline in villus height and an increase in crypt depth after weaning (Hampson, 1986; Miller et al., 1986; Cera et al., 1988; Pluske et al., 1996b; Spreeuwenberg et al., 2001). In a study involving piglets weaned at 21 days of age, Hampson (1986) reported that villus height was declined by 25% within 24 hours. By the fifth day post-weaning, villus height was decreased to 50% of milking piglets' those. Similar reductions were observed by Miller et al. (1986) in pigs weaned at either four or six weeks of age. Crypt depth is also known to increase although this may not be affected significantly until around five days after weaning (Hampson, 1986). Measurements of villus height to crypt depth ratio in the period immediately after weaning are therefore suggested to be primarily the result of villus reduction (Miller and Slade, 2003).

The villi cell (enterocyte) originates from the division of crypt cells and is initially secretory in function. As the cell matures and migrates up the side of the villus, its function changes to become absorptive. Hampson (1986) proposed that villus atrophy at weaning was caused by a reduction in the number of enterocytes lining the villus, and not due to villus contraction. If the villi tips are damaged , the ability to absorb nutrients is considerably reduced (Buddle and Bolton, 1992).

Weaning has also been shown to affect the morphological structure of the villi; Cera et al. (1988) reported that suckled piglets exhibited villi that were long and slender. The result of weaning was a dramatic reduction in villus height within three days, which lasted seven days in duration. Although villus height increased after this period, the villi exhibited a flatter `tongue shaped' appearance. This structural change has also been reported by Hampson (1986) with three-week-old weaned piglets. It was concluded that this change in villus shape increase the surface area. It has been reported by numerous studies (Kidder and Manners, 1980; Hampson, 1986; Cera et al., 1988; Pluske et al., 1996a) that villus height is greatest at the proximal section of the small intestine, with a decreasing height gradient along the proximal to distal sections. It is suggested that this mirrors the nutrient concentration gradient along the gut, and therefore the requirement for absorption would be greatest at the proximal section (Cera et al., 1988; Pluske et al., 1996b). Hampson (1986) examined the effects of weaning on gut structure, in piglets aged between 21 and 32 days of age and found the loss of villus height was greatest at the proximal section of the small intestine. This was also noted by Spreeuwenberg et al. (2001) and by Boudry et al. (2004) where piglets weaned at three weeks exhibited greatest villus atrophy in the proximal part of the small intestine shortly after weaning (1-2d), with morphological changes in the ileum only apparent a few days later. There is now a large body of evidence to suggest that the physical presence of feed within the gastrointestinal tract plays a strong role in the integrity of the structure and function of the small intestine after weaning (Kelly et al., 1991b; Pluske et al., 1996b; McCracken et al., 1999; Spreeuwenberg et al., 2001; Vente-Spreeuwenberg et al., 2003).

McCracken et al. (1999) demonstrated that villus atrophy and inflammatory responses correlated with weaning anorexia where piglets weaned at three weeks exhibited a decrease in villus height and an increase in CD8+ T-cell numbers. As appetite returned after four days, these measurements returned to day zero values. The link between luminal nutrition and gut structure is further supported with work involving gastric incubation of piglets weaned at 14 days (Kelly et al., 1991b). There is evidence that the structure and function of the small intestine can be preserved by the provision of a milk diet immediately post-weaning; Pluske et al. (1996a) showed that feeding piglets whole cows' whole milk at regular intervals for five days after weaning maintained villus height and crypt depth integrity. Further work (Pluske et al., 1996b) reported that piglets weaned at 28 days of age onto a diet of cows' milk also maintained villus height and crypt depths equal to those observed in pre-weaned animals. Significant correlations were found between feed intake, proximal villus height and body weight gain. It has been suggested that the effect of dietary composition on intestinal integrity is not as important as that of low feed intake in the first four days after weaning (Spreeuwenberg et al., 2001). A more recent trial (Vente-Spreeuwenberg et al., 2003) found that villus architecture in weaned piglets was not affected by carbohydrate source (glucose, lactose or starch), when fed in a liquid form.

It is apparent from these studies that weaning often presents major challenges to the digestive system of the piglet, leading to commonly observed villus atrophy and increased crypt depth within the small intestine. Although gut structure typically recovers, there is a period where the shortened villi surface area will mean reduced enzyme development, and absorptive capacity within the small intestine. It is in this period that the piglet could be predisposed to malabsorption, diarrhoea and enteric infection (Cera et al., 1988; Buddle and Bolton, 1992). As nearly all non-infectious pig diseases and performance depressions are caused by intestinal microbes (Bolduan et al., 1988), weaning is a critical period for the piglet. Overgrowth by the gut flora at this time can open niches for pathogenic bacteria, leading to enteric infection and even mortality.

#### 1.1.4. Post-weaning growth check

It is clear that numerous factors can present major challenges to the weaned piglet. Reduced feed intake, limited digestive enzyme development and challenges to the digestive tract can all have serious consequences for the development and survival of the young pig. These factors often lead to the post-weaning `growth check' commonly observed during this time, which can have a major impact on subsequent performance. A reduction in voluntary feed intake is the main characteristic, as weaning anorexia has a negative impact on growth and leads to mobilization of fat stores (Bark et al., 1986). This growth check can greatly compromise the overall growing and finishing performance of the piglet, and represents a major production loss in many swine industry (Pluske et al., 1997).

## 2. STARCH

During photosynthesis, plants utilize carbon dioxide, water and sunlight to produce oxygen and simple sugars such as glucose. Any glucose not needed in the short-term is converted into the polysaccharide starch which forms the major storage carbohydrate in plants. Starch is used by plants as an energy reserve and is found mainly in the seeds, roots and tubers. Starch in cereals is the most abundant energy source for most domestic animals. To maximize starch utilization, high small intestinal digestibility of cereal starch is desirable for mono-gastric animals. Especially in the weaning pig diets, starch digestion is more important.

### 2.1. Starch structure

There are two distinct populations of starch. Amylopectin consists of α1-4 glucose chains with frequent branches due to α1-6 bonds, while amylose is characterized by very few branches. Usually, less than half the amylose will be branched and the amount of branch points will be less than 20 per molecule, while for amylopectin the average amount of branch points will be approximately once per 20 glucose units (Hizukuri et al., 1997). Starch is accumulated in granules in the endosperm, and the starch is deposited in layers with various amylose and amylopectin content. Starch organization in the granule of cereals has been reviewed by Bul´eon et al. (1998) and Donald (2001). The starch granule consists of alternating semi-crystalline and amorphous layers. The semi-crystalline layer is believed to consist of alternating 9 nm crystalline layers of double-helical α-glucans extending from intermittent branches of amylopectin, and the amorphous layers of amylopectin branch points. It has been hypothesized that one growth ring is laid down per day due to variation in photosynthetic activity and thus access to glucose (Tester, 1997; Smith, 2001).

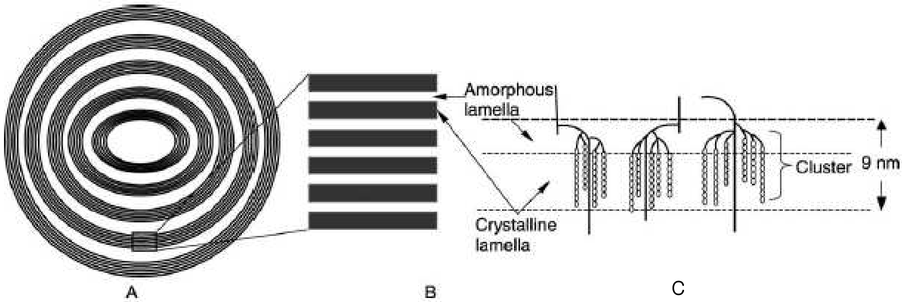


Figure 3 Diagrammatic representation of the lamellar structure of a starch granule according to Donald et al. (1997).
(A) Stacks of microcrystalline lamellae separated by amorphous growth rings.
(B) Magnified view of the amorphous and crystalline regions.
(C) Double helical structures formed by adjacent chains of amylopectin give rise to crystalline lamellae. Branching points constitute the amorphous regions.

## 2.2. Starch digestion

In non-ruminant animals, starch digestion generally occurs in the small intestine by the action of α-amylase, dextrinase and glucoamylase. A limited extent of swelling of starch granules may take place in segments of the alimentary canal anterior to the small intestine. Some animal species also have α-amylase activity present in saliva, but this is not considered to have a major effect on starch digestibility due to the short retention time of feed in the oral cavity.

## 2.3. Starch digestibility

There are many factor to affect starch digestibility, Like Table 1, each cereal sources have multiple factor. It is difficult to calculate each cereal's digestibility.

### 2.3.1 Granule dimensions

Starch is synthesised in the form of roughly spherical granules in cellular organelles called amyloplasts in a range of different plant tissues. Native starch granules are resistant to amylase hydrolysis (Kimura and Robyt, 1996). It is widely known that the shape and size of starch granules varies (Tester and Karkalas, 2002; Tester et al., 2004a) with botanical source. The larger the granules the smaller the surface area to volume ratio and hence potential surface to be attached to and hydrolyzed by enzymes encountered in the digestive tract. So the surface area to volume ratio is (reflecting botanical origin) with respect to controlling the rate and extent of granular starch digestion.

### 2.3.2. Granule shape

Although starch granules are roughly spherical, the shape varies. This affects the surface area to volume ratio significantly and hence the potential for amylase digestion. This is how amylase molecules interact with native starch granules.

### 2.3.3. Compound granules

A further complication with respect to the surface area to volume ratio and its impact with respect to amylase binding to starch, is that some granules exist as compound granules built from individual granules (Buttrose, 1960). These compound granules reduce the capacity for amylases to bind to granule surfaces and potentially restrict hydrolysis.

### 2.3.4. Amylose content

The amount of native starch hydrolysis by amylase is reported to be inversely related to the amylose content, where high amylose starches are especially resistant (Gallant et al., 1992), which fits with the view that amylose represents amorphous starch. However, the other papers are reported that both the amylose and amylopectin fractions are hydrolyzed at the same time (e.g. Manelius and Bertoft, 1996). Lauro et al. (1999) do report that at the early stages of barley starch granule hydrolysis both amorphous and crystalline parts of barley starch granules are equally solubilised by amylase. Rendleman (2000) published some very eloquent work on the digestion of native starches from different botanical origins and showed that the rate of digestion of waxy maize > normal maize > high amylose maize using salivary amylase.

### 2.3.5. Other contents (Lipid, Protein, Phosphate)

Lipid, protein and phosphate in starch granule can reduce rate of enzymatic digestion of starch (Cui and Oates, 1999). The complex of the amylose and these contents makes the amylose chains much less readily accessible to the active site of the α-amylase enzyme although it does not confer complete resistance to hydrolysis, just a prolonged hydrolysis profile.

### 2.3.6 Crystallinity and double helices

In starch granules double helices associate to form crystalline regions (Tester and Karkalas, 2002; Tester et al., 2004a,b) which are responsible for generating gelatinization endotherms by differential scanning calorimetry, (reflecting hydrogen bond dissociation of double helices), and resist the hydrolysis of the granules by digestive enzymes (Gallant et al., 1992; Karkalas et al., 1992; Zhang and Oates, 1999; Tester et al., 2004b). Starches can be defined as one of two crystallite types (by wide angle X-ray scattering), A- and B-type, although there is a mixed form called C-type (Tester and Karkalas, 2002; Tester et al., 2001, 2004a,b). Most cereal starches are A-type and tuber starches B-type (Tester and Karkalas, 2002; Tester et al., 2001, 2004a,b). Iit is reported that B- (and C-) type starches resist enzymatic hydrolysis more than A-type (Gallant et al., 1992).

Table 1. Characteristics of starch grnules from different sources (adapted from Tester and Karkalas, 2004)

| | Shape | Size (μm) | Surface :Volume ratio | Amountof doublehelical amylopectin(%) | Amountof crystalline amylopectin(%) |
|---|---|---|---|---|---|
| Corn | Spherical/polyhedral | 2-30 | 0.2-3.0:1 | 43 | 43 |
| Rice | Polyhedral | 3-150 | 0.8-2.0:1 | 49-63 | 47-51 |
| Barley | Lenticular(A-type) | 15-25 | 0.2-0.4:1 | | 20-24 |
| | Spherical(B-type) | 2-5 | 1.2-3.0:1 | | 20-24 |
| Wheat | Lenticular(A-type) | 2-10 | 0.17-0.4:1 | 32-46 | 36 |
| Oat | Polyhedral | 3-80 | 0.17-1.2:1 | | 28-37 |
| Tapioca | Spherical/lenticular | 5-45 | 0.17-1.2:1 | 44 | 38 |
| Rey | Lenticular(A-type) | 10-40 | 0.15-0.6:1 | | |
| | Spherical(B-type) | 5-10 | 0.6-1.2:1 | | |
| Sorghum | Spherical | 5-20 | 0.3-1.2:1 | | |

### 2.3.7. Gelatinization

When starch is gelatinized the semi-crystalline nature of granules becomes totally amorphous and the starch becomes digestible by amylases (Slaughter et al., 2001a,b; Tester et al., 2004a,b). The gelatinization process involves a number of stages of granule expansion when progressively heated in excess in water, the morphology of which varying between different starches, where granules (i) hydrate progressively, (ii) double helices undo as hydrogen bonds are ruptured, (iii) crystalline regions are converted to amorphous regions as a consequence of (ii), (iv) granules continue to imbibe water and swell and (v) ultimately the granules swell so much that granular form is lost and they tend towards gelation (～4% solids) and/or solubilisation (ъ4% solids). The α-amylase molecules can progressively digest starch granules more and more as they gelatinise (Tester and Sommerville, 2000) although this is dependent on the moisture content available to support the gelatinization process and the temperature profile the starch is exposed to (Tester and Sommerville, 2000; Slaughter et al., 2001a,b). Many foods, especially animal feeds, are not processed and hence the starch remains in its native and relatively less digestible form.

### 2.3.8. Retrogradation

Wiseman et al. (2001) explained retrogradation. When starch gels are held for prolonged periods, retrogradation develops. Applied to starch, this means a returen from a solvated, dispersed amorphous state to an insolubel, aggregated or crystalline condition. Retrogradation is due largely to crystallization of amylose, which is much more rapid than that of amylopectin, yield of resistant starch.

### 2.4. Extrusion (Processing to increase starch digestibility)

This processing technique involves applying heat and pressure, by means of friction to the feed material, starch sources. It is a high temperature, short time process where the material is passed through a tapered screw by an auger-like rotor. It is then forced through a narrow opening under pressure. Extrusion may be dry (no moisture added) or wet (moisture added in variable amounts). Moisture added to the material is unable to evaporate during the process, but upon the return to sudden atmospheric pressure, flashes off as steam. During extrusion, starch granules are physically torn apart by shear forces and allow rapid entrance of water into the starch molecules (Kokini et al., 1992). The use of extrusion processing produces a very homogenous, end product and has been shown to thoroughly gelatinize starch, thereby improving its digestibility, even at low moisture levels (Gomez and Aguilera, 1983). As with many other processing techniques, variables from the feed ingredients (particle size and moisture content) as well as those from the process itself (screw speed, temperature, size and shape of die etc), can have a significant effect upon the nutritive value of the end product (Dahlin and Lorenz, 1993).

## 3. Effect of Starch sources and their extrusion on weaning pig diets

Starch is the main source of energy in weaning pig diets, but native starch is not completely digested in the small intestine of young pigs (Vicente et al., 2009). Undigested starch enters the large intestine where it can be fermented, increasing the incidence of diarrhea and reducing piglet performance. Source of the starch (Hongtrakul et al., 1998; Medel et al., 2004) and heat processing of the cereal (Aumaitre, 1976; Huang et al., 1998; Medel et al., 2002) are 2 major factors affecting starch digestibility.

### 3.1. Starch sources

#### 3.1.1. Corn

Corn is the main cereal used in weanling diets although other cereals are also used, because of its low comparative fiber and high energy contents.

#### 3.1.2. Rice

Rice is characterized by its high starch content and low fiber content, thus, it may have a major impact on the digestibility of dietary nutrients and microbial populations by providing fewer substrates for bacterial fermentation in the large intestine. Indeed, rice-based diets have greater apparent ileal and total tract nutrient digestibilities than diets based on other cereal grains (Pluske et al., 2007; Kim et al., 2008; Menoyo et al., 2011). Also, rice, when compared with other cereal grains, including barley, may improve pig health as it reduces intestinal colonization of pathogens and the severity of enteric bacterial diseases (Hampson et al., 2000; Lindecrona et al., 2004). The better growth performance, which was observed in pigs fed the diets containing rice compared with those fed the diets containing barley, is likely a result of an increased ADFI because the G/F of pigs fed rice was not different from those pigs fed barley. Li et al. (2002) observed that replacement of raw corn with 50 or 100% raw brown rice in post-weaning diets for pigs did not affect ADG (400 or 350 vs. 360 g/d). In a 5-wk study by Mateos et al. (2006), nursery pigs fed cooked rice had greater ADG and ADFI than those fed cooked corn. However, these improvements were largely due to the addition of oat hulls (a source of fiber) to the rice and corn diets because there were no differences in ADG (307 vs. 306 g/d) between pigs fed cooked rice and those fed cooked corn if oat hulls were not included.

### 3.1.3. Barley

Barley contains a high proportion of partly soluble dietary fiber polysaccharides, which consists predominantly of mixed-linked (1.3), (1.4)-β-d-glucan (β-glucan). β-Glucans act through increasing the gastrointestinal viscosity and their partial destruction by β-glucanase supplementation greatly enhances the nutritional value of barley for chickens (White et al., 1983). This increased gastrointestinal viscosity is responsible for the growth depression and poorer nutrient utilization of chickens fed on barley-based diets (Almirall et al., 1995). It has been demonstrated that supplementation of chicken diets with enzymes improves growth performance and nutrient utilization (White et al., 1983; Pettersson et al., 1990; Guenter, 1993). Enzyme supplementation reduced digesta viscosity, which is considered to be responsible for these responses. As for pigs, since significant quantities of β-glucans are digested prior to the terminal ileum, a high gastrointestinal viscosity is not as likely to be a major problem (Thacker et al., 1991). Bedford et al. (1992) reported that no reduction was found in intestinal viscosity in piglets fed barley-based starter diets supplemented with β-glucanase. Thacker et al. (1992) suggested that any alterations in digestibility as a result of enzyme supplementation were the result of enzymatic degradation of β-glucans present in the feed rather than from a reduced intestinal viscosity. In a 5-wk study by Mendel et al., 2004, piglets fed on maize-based diets had better feed G/F ratio (1.20 versus 1.41; $P<0.01$) than piglets fed on barley-based diets. He explained that high levels of fiber decreased digesta transit time in pigs. This could allow a higher feed intake, and therefore, a higher growth rate. But, in the study of Mendel et al., 1999, maize-based diets had higher DMD (dry matter digestibility, 0.908 versus 0.871; $P < 0.001$), OMD (organic matter digestibility, 0.921 versus 0.880; $P < 0.001$), ED (energy digestibility, 0.905 versus 0.863; $P < 0.001$), and CPD (crude protein digestibility, 0.886 versus 0.860; $P < 0.04$), than barley-based diets. The barley's effects on the pig are variable.

### 3.2. Effect of starch sources' extrusion

Extrusion of cereals gelatinizes the starch portion of the grain, which may result in improved nutrient utilization. In evaluating the studies that have examined the use of extrusion processing in the diets of weaned piglets, conclusions have been somewhat mixed; Jansen (1992) fed diets containing either `strongly' or `weakly' extruded wheat and reported increased feed intake levels and live weight gains for three weeks post-weaning. Medel et al. (1999) found that processing of barley and maize (by micronization and extrusion) significantly improved DLWG and G/F when compared to diets based on the raw cereals. Benefits have also been reported from feeding an extruded, rather than pelleted diet, resulting in increases in DLWG and G/F by 8% and 6% respectively (Sauer et al., 1990). Other studies have reported variable effects when providing the animals with feed in an extruded form (Tomchuk, 1989; Hongtrakul et al., 1998; Lizardo et al., 1999). The information available on the beneficial effects of extrusion on apparent total tract digestibility (ATTD) of dietary components and pig growth also is contradictory. Medel et al. (2002, 2004) showed that HP of cereals improves ATTD of nutrients in young pigs, but Van der Poel et al. (1990) did not show any effects of extrusion on digestibility. Moreover, no effects of increased starch gelatinization (SG) resulting from extrusion were observed on ATTD of dietary components (Zarkadas and Wiseman, 2002). These discrepancies might be explained, at least in part, because the type of cereal used and the conditions applied during extrusion varied among experiments. An excess of heat increases SG but might also increase the proportion of resistant starch (RS), reducing its digestibility (Sagum and Arcot, 2000). Vicente et al. (2008) was that feeding rice-based diets improves digestibility and ADG as compared with feeding corn-based diets and that degree of extrusion of rice would not further improve any digestive or performance trait.

## 4. Conclusion

The effects of starch sources and extrusion could be summarized like Table 2. The newly-weaned piglet receives a number of stressors. Weaning pigs were fed the diets made by the starch for major energy source. It might improve the performance of piglet to feed higher digestible starch source or extruded starch to improve digestibility.

Table 2. Summary of the effect of starch sources and their extusion.

| Author | Cereal | Cereal effect | Heat Processing effect | Discussion |
|---|---|---|---|---|
| Mateos et al., 2006 | Corn<br>Rice | -<br>ADI,ADG | | Corn's high NSP level might reduce voluntary intake.<br>Rice feeding might increase the glycemic index of piglet. |
| Li et al., 2007 | Corn<br>Rice | ADI,ADG,FCR<br>- | | Dietary sources of starch have a impact on N utilizaion. |
| Vicente et al., 2007 | Corn<br>Rice | -<br>ADI,ADG | No effect | Rice has high starch content and low level of NSP and smaller size of starch granule |
| Medel et al., 1999 | Corn<br>Barley | TTAD<br>ADG | ADG,FCR | High level of fiber decrease digesta transit time, can allow a higher feed intake |
| Medel et al., 2004 | Corn<br>Barley | ADG,FCR<br>- | ADG<br>(by 32th day) | |

# Ⅲ. Effect of Starch source Extrusion on the performance of young pig.

**Abstract** : An experiment was conducted to evaluate the effects of starch sources and extrusion on growth performance, nutrient digestibility of weaning pigs. This study was a 2 x 3 factorial arrangement of treatments conducted in a randomized complete block (RCB) design. The first factor was ingredient processing method and the second factor was three different carbohydrate sources (corn, barley and rice). A total of 144 weaning pigs ([Yorkshire × Landrace] × Duroc) averaging 7.02 ± 1.07 kg body weight, weaned at 28 ± 3 days of age were allotted to 6 treatments in 6 replicates with 4 pigs per pen. All nutrients of experimental diets were met or exceeded NRC requirements (1998). During the whole experimental period, pigs fed raw carbohydrate sources had improved ADG (625 vs 545 g; P<0.01 and 469 vs 416 g; P<0.01), and G/F ratio was also increased when pigs were fed no extruded cereals (0.711 vs 0.652 g; P<0.01 and 0.695 vs 0.645 g; P<0.01). Among raw cereals, raw rice treatment tended to increase growth performance compared to raw corn treatment at 2-5 week (corn 593 vs rice 661; P<0.1), Protein digestibility of barley and rice was increased when extruded sources were provided but nitrogen retention was numerically decreased as pigs were fed extruded sources. Growth performance of weaning pigs was higher when raw carbohydrate sources were provided. This results demonstrated that extrusion of carbohydrate sources in weaning pigs' diet did not show any positive response on improve nutrient digestibility. Consequently, raw carbohydrate sources rather than processed sources can be utilized in weaning pigs' diet without detrimental effects on nutrient digestibility or growth performance.

**Key Words: weaning, starch, extrusion, corn, barley, rice.**

# Introduction

Weaning of piglets is associated with an extreme change in their physical and nutritional environment. In addition, there has been a trend to reduce weaning age to 21 or 28 days, to increase sow productivity and decrease the risk of piglet infection through the sow (Alexander et al., 1980). However, at these early ages the digestive system is immature (Lindemann et al., 1986, Aumaitre et al., 1995 and Jensen et al., 1997). At birth the digestive tract of piglets is well adapted to digest sow milk, which is very rich in highly digestible fat and lactose (Partridge and Gill, 1993). At weaning, milk is replaced by diets containing starch as the main energy source but an insufficient secretion of α-amylase (Owsley et al., 1986) and the fact that starch is stored in plants in a crystalline complex structure, might impair its digestion in piglets (Cunningham, 1959). Each cereals have variable characteristics. The structure of starch can be modified by heat or by physical treatment, inducing a change in the crystalline structure or degree of gelatinization (Atwell et al., 1988), thereby facilitating its enzymatic degradation (Holm and Bjorck, 1988 and Osman et al., 1990). The modification of starch granules depends on the treatment (Holm et al., 1988) and the starch source (Farber and Gallant, 1976 and Faulks and Bailey, 1990). Improvements of performance or digestibility due to cereal processing in piglets has been reported by some workers (Aumaitre, 1976 and Skoch et al., 1983), whereas slight or no benefits at all were found by others (Van der Poel et al., 1989 and Vestergaard et al., 1990). Heat treatment of cereals also partly solubilizes the non-starch polysaccharides fraction (Fadel et al., 1988), and might increase digesta viscosity. A high viscosity of feed reduced the digestibility of nutrients in broilers (Petterson et al., 1991), but the effects on pigs are not well understood.

The aim of this study was to evaluate the effect of starch sources (corn, barley or rice) and their extrusion on performance for early-weaned pigs.

# Materials and Methods

***Experimental Animals and Design***

A total of 144 weaning pigs ([Yorkshire × Landrace] × Duroc) averaging 7.02 ± 1.07 kg body weight, weaned at 28 ± 3 days of age were allotted to 6 treatments based upon sex and body weight in 6 replicates with 4 pigs per pen in randomized complete block (RCB) design. This experiment was conducted in the experimental farm of Seoul National University through 5 week feeding. The experiment was designed by a 2x3 factorial arrangement. The first factor was ingredient processing method and the second factor was three different carbohydrate sources (corn, barley or rice).

***Experimental Diets***

All of phase I and II experimental diets met or exceeded NRC (1998) requirements of metabolic energy (3,265 kcal/kg) and total lysine (phase I 1.19% and phase II 1.01%), Each diets were prepared from raw cereals or extruded cereals which were corn (USA), pearl barley (Australia), and broken rice (Korea). The extruded corn was processed for 1 min at 85℃, and had 75.4% starch gelatinization (SG). The extruded barley also were processed for 1.2 min at 70℃ (SG of 67.9%). Finally, the extruded rice were processed for 1 min at 85℃ (SG of 56.4%). Like table 2 and 3, to synchronize all diets' ME and amino acid, in consideration of each cereal's analysis data, all diets had basic 20% raw corn and 34~38% each cereal, which is for similar soybean meal and soy oil levels. In some cases, starter diets for piglets containing legumes induce transient growth check, lower digestibility of nutrients and/or an increase of endogenous nitrogen losses (Jansman et al., 1995). This could be attributed to structural characteristics of proteins and/or carbohydrates as well as to the presence of anti-nutritional factors (ANFs; Lallès and Jansman, 1998). Each cereals' analysis data are presented in Table 1. And, the formula and chemical composition of diets in all phases were presented in Tables 2 and 3.

***Animal Management***

All pigs were housed in slot-concrete pen (0.90 x 2.15$m^2$), equipped with a feeder and a nipple and allowed ad libitum throughout the experiment period. The temperature was maintained at 30℃ in phase I and phase II were kept at 28℃. The body weight and feed intake were recorded every phase(I: 0~2 weeks, II: 3~5 weeks) to calculated average daily gain (ADG), average daily feed intake (ADFI) and gain per feed ratio (G/F ratio).

***Digestibility Trial***

Nutrient digestibility trial was conducted to evaluate the digestibility and nitrogen retention in completely randomized design (CRD) with 6 replicates. A total of 24 weaning pigs averaging 12.63±0.40 kg were allotted to each treatment in an individual metabolic crate to collect feces and urine separately. After 5 days of adaptation period, 1% chromium oxide was added in experiment diets (110g) at only first time. Next during 5 day collection period, experimental diets were provided twice (7:00 and 19:00) per day. 1% ferric oxide was used as a finish marker. Feces and urine collections were started when chromium oxide appeared in the feces and kept until the next appearance of ferric oxide in the feces. During same period, total urine was collected daily in plastic container containing 50 ml of

4N $H_2SO_4$ to avoid evaporation of nitrogen from urine for nitrogen retention analyses. Feces and urine were stored at -20℃ and the feces was dried in a drying oven at 60℃ for 72h, and then ground to 1 mm in a Wiley mill for chemical analysis include moisture, protein, fat and ash contents by AOAC.

***Blood Sampling***

After 3 hours fasting, blood samples were taken from anterior vena cava of 5 pigs per treatment for measuring BUN (blood urea nitrogen). Collected blood samples were quickly centrifuged for 15 min at 3,000 rpm on 4 ℃ (Eppendorf centrifuge 5810R, Germany). The sera were carefully transferred to 1.5 ml plastic tubes and stored at -20 ℃ until analysis. To evaluate the efficiency of protein utilization in the body, total BUN concentration was analyzed using a blood analyzer (Ciba-Corning model, Express Plus, Ciba Corning Diagnostics Co.).

***Daily diarrhea incidence***

The incidence of diarrhea was recorded daily on a pen basis, and measured as the number of days upon which diarrhea was observed within a pen daily. This method of evaluating diarrhea has been documented previously by O'Grady (1978) and Rivera et aI. (1978).

***Chemical and statistical analysis***

Analysis of the experimental diets, excreta and urine was conducted according to the methods of the AOAC (1995). A 2 × 3 factorial analysis was used to determine significance and interaction between main effects of each experiment. The pen of each treatment was used as an experimental unit in growth performance, and each pig was regarded as an experimental unit in blood characteristics and digestive trial analysis. All data were analyzed using PROC MIXED procedures of SAS. The statistical model included two main effects, starch sourecs and extrusion. The PDIFF option of SAS was used for evaluate differences among treatments. A probability value under 0.05 was regarded as significant difference.

# Result and Discussion

***Growth performance and nutrient digestibility***

Starch gelatinization levels of each cereal were described at Table 1. Their levels were used in Korea commercially, and were similar with previous studies (Hongtragul et al., 1998; Medel et al., 1999; Mateos et al., 2006; Vicent et al., 2007).

Main effect of ADG and ADFI was observed when pigs were fed raw starch treatment diets (P<0.05, Table 4). Starch source effect tended to show when barley or rice starch treatment diet was provided. Although there were no significant difference in nutrient digestibility, improved G/F ratio was observed in raw starch treatments compared to extrusion ones (P<0.01). The current results are in the agreement of the of previous research studies (Van der Poel et al., 1989, 1990; Herkelman et al., 1990; Hongtragul et al., 1998; Mateos et al., 2006) that suggested no beneficial effect of extruding corn on growth performance. They explained these extruded corn's high bulk density had low water solubility, thus supporting the increased viscosity and long transit time along the digestive tract subsequently resulted in reducing feed intake. Current study also demonstrated that growth performance did not improved when pigs were fed processed starch treatment diets. Extrusion of each starch sources (corn, barley or rice) did not improve the piglet performance compared to raw cereals.

Among starch sources, ADG and ADFI of barley and rice tended to improve compared to corn regardless of processing. Digestibilities of crude protein of rice and crude fat of barley were higher than that of corn (P<0.05). Rice grain is characterized by its high starch content and has smaller size of starch granules (3 to 8 vs. 2 to 20 μm; Tester et al., 2004). Bardon and Fiaramonti (1983) reported that high levels of fibre decreased digesta transit time in pigs.

In Table 5, raw cereals showed improved grwoth performance such as ADG, ADFI and G/F ratio, compared to extruded cereals. Although digestibilities of crude protein and fat in barley treatment diet was improved, higher ADFI was observed in raw barley treatment diet, resulting in lower ADG in processed barley treatment.

Among starch sources, raw rice tended to be higher ADG compared to raw corn or barley treatment diets (Table 6). Among extruded starch sources, barley treatment diet showed improved ADG and G/F ratio compared to corn or rice treatment diets.

Nitrogen retention was decreased by extrusion regardless of starch sources (Table 7). Raw or extruded corn treatment diet showed the lowest N-retention compared to other starch sources. Higher fecal nitrogen excretion was observed in raw barley treatment but its excretion was lowest among starch sources after extrusion. This result demonstrated that dietary fiber in barley can be gelatinized by extrusion subsequently crude protein digestibility can be improved, resulting in higher urinary nitrogen excretion than raw barley treatment. And extruded cereals had decreased N-retention %, compared to raw cereals. Nitrogen excreted via feces is predominantly incorporated in bacterial protein, which is hard to be utilized. Nitrogen excreted via urine is mainly in the form of urea, which is easily converted into ammonia and carbon dioxide by the enzyme urease present in feces (Marie et al., 1997).

***Blood analysis***

Table 8 showed the effects of starch sources and their extrusion on blood analysis in weaning pigs. When pigs were fed raw corn or rice treatment diet, BUN tended to increased compared to its extruded treatment diets. When extruded barley treatment diet was provided, higher BUN value was observed than other treatment diets. In general, BUN may be an easily measured index or phenotypic marker of efficiency of amino acid use for maintenance and accretion of lean tissue applicable in selection programs. Blood urea nitrogen concentrations, as well as urinary excretion of urea, have been measured to estimate amino acid requirements (Brown and Cline, 1974; Coma et al., 1995; Chen et al., 1995). Nitrogen metabolism has been reported to have a rapid response to changes in dietary amino acid concentrations (Brown and Cline, 1974; Fuller et al., 1979). Thus, Wu and Morris, (1998) reported that a low concentration of blood urea may derive from reduced availability of ammonia caused by enhanced protein synthesis and reduced amino acid oxidation. When a limiting amino acid such as lysine was met, low BUN concentration represented maximal utilization of other amino acids as well as lysine in the body.

***Daily diarrhea incidence***

The incidence of diarrhea was not affected by dietary starch sources or processing method. But it was decreased when pigs were fed barley treatment diet regardless of extrusion. Presumably higher fiber content in barley influence lower influences of diarrhea.

### *Conclusion*

When pigs were fed raw starch sources, growth performance was higher than that of processed ones regardless of grain. The highest ADG was observed when raw rice treatment diet was provided but processed corn treatment showed the lowest growth performance. Nutrient digestibilities were also improved when pigs were fed raw starch treatment diets compared to processed starch treatment diets. Higher BUN value was observed when pigs were fed processed barley treatment diet among other treatments. These results demonstrated that growth performance of weaning pigs was improved when pigs were fed raw starch sources rather than processed starch treatments. Expensive ingredient processing such as extrusion for weaning pigs' diet did not show any beneficial effect compared to raw starch treatments.

Table 1. Major ingredients' analysis data

| Ingredients (%, Kcal/kg) | Moisture | Crude protein | Fat[4] | Fiber | Starch[5] | LYS[6] | ME[7] | Starch gelatinization | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Raw | Extruded |
| Corn[1] | 13.40 | 7.69 | 3.27 | 1.91 | 60.42 | 0.26 | 3,420 | 15.40 | 75.40 |
| Barley[2] | 8.81 | 9.07 | 1.78 | 5.00 | 54.50 | 0.41 | 2,910 | 5.90 | 67.90 |
| Rice[3] | 11.14 | 7.51 | 0.51 | 0.40 | 74.14 | 0.57 | 3,350 | 8.74 | 56.40 |

[1] Origin was United states. And extruded corn was processed for 1min at 85℃.

[2] Origin was Australia. Barley was pearl baerley which has hull. and extruded for 1.2min at 70℃.

[3] Origin was Korean rice was polished. And extruded rice was processed for 1min at 85℃

[4] Ether extract method.

[5] Polarimetric method.

[6,7] Data of NRC (1998).

Table 2. Formula and chemical composition of phase Ⅰ.

| | Corn | Barley | Rice |
|---|---|---|---|
| **Ingredients, %** | | | |
| Basic Corn, just raw[1] | 20.00 | 20.00 | 20.00 |
| Corn (raw or extruded) | 36.19 | - | - |
| Pearl barley (raw or extruded) | - | 38.30 | - |
| Rice (raw or extruded) | - | - | 36.36 |
| Soybean meal, 47% | 17.00 | 14.50 | 17.00 |
| Milk powder | 7.52 | 7.52 | 7.52 |
| Fish meal, 70% | 5.00 | 5.00 | 5.00 |
| Isolated soy protein concentrates | 4.00 | 4.00 | 4.00 |
| Fermented soybean meal | 3.50 | 3.50 | 3.50 |
| Soy oil | 2.82 | 3.21 | 2.68 |
| Rice protein concentrate | 2.00 | 2.00 | 2.00 |
| Dicalcium phosphate | 1.01 | 0.98 | 1.01 |
| Salt | 0.30 | 0.30 | 0.30 |
| ZnO, 78% | 0.25 | 0.25 | 0.25 |
| Vitamin premix[2] | 0.10 | 0.10 | 0.10 |
| Mineral premix[3] | 0.10 | 0.10 | 0.10 |
| Vitamin E | 0.10 | 0.10 | 0.10 |
| Lysine, 78% | 0.05 | 0.08 | 0.01 |
| Choline-Cl liquid, 50% | 0.03 | 0.03 | 0.03 |
| Methionine, 100% | 0.03 | 0.03 | 0.04 |
| **Chemical composition[4]** | | | |
| Total ME, kcal/kg | 3,270 | 3,268 | 3,271 |
| Total crude protein, % | 21.26 | 21.27 | 21.15 |
| Total lysine, % | 1.23 | 1.24 | 1.24 |
| Total methionine, % | 0.42 | 0.42 | 0.43 |
| Total fiber, % | 1.88 | 2.89 | 1.27 |
| Total Ca, % | 0.75 | 0.75 | 0.75 |
| Total P, % | 0.59 | 0.62 | 0.55 |

[1] To synchronize all diets' ME and amino acid, in consideration of each cereal's analysis data, all diets had basical 20% raw corn.

[2] Provided the following quantities of vitamins per kg of complete diet: A, 8,000 IU; D3, 1,600 IU; E, 32 IU; D-biotin, 64g; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; B12, 12g; K, 2.4 mg.

[3] Provided the following quantities of minerals per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu·SO4, 54.1mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.

[4] Calculated value

Table 3. Formula and chemical composition of phase Ⅱ.

| | Corn | Barley | Rice |
|---|---|---|---|
| **Ingredients, %** | | | |
| Basic Corn, just raw[1] | 20.00 | 20.00 | 20.00 |
| Corn (raw or extruded) | 35.56 | - | - |
| Pearl barley (raw or extruded) | - | 37.00 | - |
| Rice (raw or extruded) | - | - | 35.53 |
| Soybean meal, 47% | 29.00 | 27.00 | 29.00 |
| Soy oil | 4.12 | 4.75 | 4.01 |
| Fermented soybean meal | 3.00 | 3.00 | 3.00 |
| Milk powder | 2.93 | 2.93 | 2.93 |
| Fish meal, 70% | 1.50 | 1.50 | 1.50 |
| Sugar | 1.50 | 1.50 | 1.50 |
| Dicalcium phosphate | 1.08 | 0.88 | 1.16 |
| Limestone | 0.41 | 0.50 | 0.50 |
| ZnO (78%) | 0.25 | 0.25 | 0.25 |
| Lysine, 78% | 0.18 | 0.20 | 0.15 |
| Methionine, 100% | 0.13 | 0.14 | 0.14 |
| Salt | 0.10 | 0.10 | 0.10 |
| Vitamin premix[2] | 0.10 | 0.10 | 0.10 |
| Mineral premix[3] | 0.10 | 0.10 | 0.10 |
| Threonine, 100% | 0.04 | 0.05 | 0.03 |
| **Chemical composition[4]** | | | |
| Total ME, kcal/kg | 3,270 | 3,268 | 3,271 |
| Total crude protein, % | 20.15 | 20.16 | 20.22 |
| Total lysine, % | 1.26 | 1.27 | 1.27 |
| Total methionine, % | 0.45 | 0.45 | 0.45 |
| Total fiber, % | 2.03 | 2.90 | 1.41 |
| Total Ca, % | 0.80 | 0.80 | 0.81 |
| Total P, % | 0.55 | 0.55 | 0.54 |

[1] To synchronize all diets' ME and amino acid, in consideration of each cereal's analysis data, all diets had basical 20% raw corn.
[2] Provided the following quantities of vitamins per kg of complete diet: A, 8,000 IU; D3, 1,600 IU; E, 32 IU; D-biotin, 64g; riboflavin, 3.2 mg; calcium pantothenic acid, 8 mg; niacin, 16 mg; B12, 12g; K, 2.4 mg.
[3] Provided the following quantities of minerals per kg of complete diet: Se, 0.1 mg; I, 0.3 mg; Mn, 24.8 mg; Cu·SO4, 54.1mg; Fe, 127.3 mg; Zn, 84.7 mg; Co, 0.3 mg.
[4] Calculated value

Table 4. Effects of starch sources and extrusion on growth performance and nutrients digestibility in weaning pigs[1]

| Items | Processing effect | | | Source effect | | | | SEM[2] |
|---|---|---|---|---|---|---|---|---|
| | Raw | Extrusion | P-value | Corn | Barley | Rice | P-value | |
| **Body weight, kg** | | | | | | | | |
| Initial | 7.02 | 7.02 | | 7.02 | 7.02 | 7.02 | - | - |
| 2 week | 10.29 | 10.16 | 0.789 | 10.28 | 10.15 | 10.2 | 0.972 | 0.2 |
| 5 week | 23.42 | 21.58 | 0.080 | 22.01 | 22.78 | 22.7 | 0.791 | 0.5 |
| **ADG, g** | | | | | | | | |
| 0-2 wk | 234 | 224 | 0.517 | 233 | 223 | 230 | 0.870 | 7.1 |
| 2-5 wk | 625 | 544 | 0.006 | 558 | 602 | 594 | 0.392 | 15.3 |
| 0-5 wk | 469 | 416 | 0.011 | 428 | 450 | 448 | 0.592 | 10.4 |
| **ADFI, g** | | | | | | | | |
| 0-2 wk | 366 | 358 | 0.783 | 351 | 355 | 385 | 0.236 | 8.6 |
| 2-5 wk | 884 | 834 | 0.229 | 825 | 875 | 877 | 0.503 | 19.3 |
| 0-5 wk | 677 | 645 | 0.271 | 636 | 667 | 680 | 0.426 | 13.6 |
| **G/F ratio** | | | | | | | | |
| 0-2 wk | 0.638 | 0.621 | 0.549 | 0.662 | 0.627 | 0.600 | 0.204 | 0.014 |
| 2-5 wk | 0.711 | 0.652 | 0.005 | 0.677 | 0.689 | 0.679 | 0.850 | 0.011 |
| 0-5 wk | 0.695 | 0.663 | 0.005 | 0.673 | 0.676 | 0.660 | 0.696 | 0.009 |
| **Nutrient digestibility, %** | | | | | | | | |
| Dry matter | 92.60 | 92.42 | 0.742 | 92.04 | 92.58 | 92.91 | 0.450 | 0.48 |
| Crude protein | 90.91 | 91.05 | 0.856 | 89.90 | 90.72 | 92.34 | 0.040 | 0.65 |
| Crude fat | 91.91 | 91.99 | 0.089 | 91.89 | 93.39 | 90.58 | 0.030 | 0.89 |

[1] A total of 114 crossbred pigs were used from an average initial body weight of 7.02 ± 1.07kg.

[2] Standard error of mean.

Table 5. Effect of each sources' extrusion on weaning pig.

| Items | Corn | | | Barley | | | Rice | | | Interaction[2] |
|---|---|---|---|---|---|---|---|---|---|---|
| | Raw | Extrusion | P-value | Raw | Extrusion | P-value | Raw | Extrusion | P-value | |
| **Body weight, kg** | | | | | | | | | | |
| Initial | 7.04 | 7.01 | - | 7.01 | 7.03 | - | 7.00 | 7.03 | - | |
| 2 week | 10.52 | 10.05 | 0.187 | 10.17 | 10.13 | 0.911 | 10.17 | 10.30 | 0.813 | 0.869 |
| 5 week | 22.98 | 21.04 | 0.100 | 23.23 | 22.34 | 0.363 | 24.06 | 21.35 | 0.050 | 0.765 |
| **ADG, g** | | | | | | | | | | |
| 0-2 wk | 249 | 217 | 0.197 | 226 | 221 | 0.842 | 226 | 234 | 0.848 | 0.553 |
| 2-5 wk | 593 | 524 | 0.118 | 622 | 581 | 0.229 | 661 | 527 | 0.012 | 0.363 |
| 0-5 wk | 456 | 401 | 0.099 | 464 | 437 | 0.341 | 487 | 409 | 0.050 | 0.558 |
| **ADFI, g** | | | | | | | | | | |
| 0-2 wk | 368 | 335 | 0.100 | 351 | 359 | 0.619 | 380 | 390 | 0.779 | 0.519 |
| 2-5 wk | 855 | 795 | 0.079 | 900 | 849 | 0.275 | 896 | 858 | 0.083 | 0.972 |
| 0-5 wk | 660 | 611 | 0.038 | 680 | 653 | 0.385 | 689 | 671 | 0.358 | 0.896 |
| **G/F ratio** | | | | | | | | | | |
| 0-2 wk | 0.676 | 0.649 | 0.589 | 0.637 | 0.617 | 0.627 | 0.602 | 0.598 | 0.952 | 0.942 |
| 2-5 wk | 0.694 | 0.659 | 0.276 | 0.693 | 0.685 | 0.350 | 0.712 | 0.612 | 0.047 | 0.028 |
| 0-5 wk | 0.690 | 0.655 | 0.234 | 0.682 | 0.670 | 0.408 | 0.712 | 0.609 | 0.065 | 0.076 |
| **Nutrient digestibility, %** | | | | | | | | | | |
| Dry matter | 93.41 | 90.66 | 0.043 | 91.51 | 93.65 | 0.024 | 92.88 | 92.94 | 0.960 | 0.008 |
| Protein | 91.54 | 88.25 | 0.068 | 89.33 | 92.10 | 0.016 | 91.87 | 92.81 | 0.547 | 0.011 |
| Fat | 93.36 | 90.42 | 0.059 | 91.66 | 95.11 | 0.091 | 90.71 | 90.45 | 0.924 | 0.115 |

[1] Standard error of mean.

[2] Extrusion and Raw's Interaction.

Table 6. Effect of each cereals in raw or extrusion on weaning pig.

| | Raw | | | | Extrusion | | | |
|---|---|---|---|---|---|---|---|---|
| **Items** | **Corn** | **Barley** | **Rice** | **P-value** | **Corn** | **Barley** | **Rice** | **P-value** |
| Body weight, kg | | | | | | | | |
| Initial | 7.04 | 7.01 | 7.00 | - | 7.01 | 7.03 | 7.03 | - |
| 2 week | 10.52 | 10.17 | 10.17 | 0.508 | 10.05 | 10.13 | 10.30 | 0.660 |
| 5 week | 22.98 | 23.23 | 24.06 | 0.347 | 21.04 | 22.34 | 21.35 | 0.240 |
| ADG, g | | | | | | | | |
| 0-2 wk | 249 | 226 | 226 | 0.555 | 217 | 221 | 234 | 0.687 |
| 2-5 wk | $593^{b}$ | $622^{ab}$ | $661^{a}$ | 0.058 | $524^{b}$ | $581^{a}$ | $527^{ab}$ | 0.086 |
| 0-5 wk | 456 | 464 | 487 | 0.326 | 401 | 437 | 409 | 0.244 |
| ADFI, g | | | | | | | | |
| 0-2 wk | 368 | 351 | 380 | 0.194 | $335^{b}$ | $359^{ab}$ | $390^{a}$ | 0.044 |
| 2-5 wk | 855 | 900 | 896 | 0.612 | 795 | 849 | 858 | 0.313 |
| 0-5 wk | 660 | 680 | 689 | 0.613 | 611 | 653 | 671 | 0.172 |
| G/F ratio | | | | | | | | |
| 0-2 wk | 0.676 | 0.637 | 0.602 | 0.385 | 0.649 | 0.617 | 0.598 | 0.473 |
| 2-5 wk | 0.694 | 0.693 | 0.745 | 0.309 | $0.659^{ab}$ | $0.685^{a}$ | $0.612^{b}$ | 0.022 |
| 0-5 wk | 0.690 | 0.682 | 0.712 | 0.612 | $0.655^{a}$ | $0.670^{a}$ | $0.609^{b}$ | 0.015 |
| Nutrient digestibility, % | | | | | | | | |
| Dry matter | 93.41 | 91.51 | 92.88 | 0.279 | $90.66^{b}$ | $93.65^{a}$ | $92.94^{a}$ | 0.012 |
| Crude protein | 91.54 | 89.33 | 91.87 | 0.345 | $88.25^{b}$ | $92.10^{a}$ | $92.81^{a}$ | <.0001 |
| Crude fat | $93.36^{ab}$ | $91.66^{b}$ | $90.71^{a}$ | 0.046 | $90.42^{b}$ | $95.11^{a}$ | $90.45^{b}$ | 0.030 |

Table 7. Effect of starch source and extrusion on weaning pig's N-retention..

| | Raw | | | | Extrusion | | | | P-value | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Items** | **Corn** | **Barley** | **Rice** | **AVG**[3] | **Corn** | **Barley** | **Rice** | **AVG** | **Raw** | **Extruded** | **Raw *Extruded** |
| **Nitrogen retention, g/day** | | | | | | | | | | | |
| N intake | 7.60 | 6.93 | 7.63 | 7.39 | 7.03 | 6.99 | 8.03 | 7.35 | 0.35 | 0.94 | 0.71 |
| Fecal N | 0.61 | 0.75 | 0.60 | 0.65 | 0.82 | 0.55 | 0.58 | 0.65 | 0.13 | 0.92 | 0.01 |
| Urinary N | 3.67 | 2.34 | 1.92 | 2.64 | 3.38 | 2.91 | 3.38 | 3.22 | 0.21 | 0.22 | 0.31 |
| N retention[2] | 3.31 | 3.84 | 5.11 | 4.09 | 2.84 | 3.53 | 4.08 | 3.48 | 0.12 | 0.30 | 0.86 |
| N-retention, % | 43.13 | 55.42 | 66.57 | 55.04 | 39.23 | 50.90 | 50.35 | 46.83 | 0.09 | 0.20 | 0.66 |

[1] Standard error of mean

[2] N retention (g) = N intake (g) - Fecal N (g) - Urinary N (g)

[3] Average

Table 8. Effects of starch sources and their extrusion on BUN[1] and daily diarrhea incidence.

| Items | Corn | | | | Barley | | | | Rice | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Raw | Extrusion | SEM[2] | P-value | Raw | Extrusion | SEM | P-value | Raw | Extrusion | SEM | P-value |
| **BUN[1], m/dL** | | | | | | | | | | | | |
| Initial | 10.91 | 10.91 | - | - | 10.91 | 10.91 | - | - | 10.91 | 10.91 | - | - |
| 2 week | 11.38 | 13.08 | 0.58 | 0.870 | 10.07 | 11.20 | 0.77 | 0.060 | 12.00 | 12.47 | 0.29 | 0.960 |
| 5 week | 12.85 | 11.58 | 0.96 | 0.380 | 11.10 | 15.82 | 1.21 | 0.030 | 13.15 | 11.85 | 1.25 | 0.330 |
| **Daily diahhrea incidence / 4 pigs** | | | | | | | | | | | | |
| Phase I | 1.39 | 1.36 | 0.10 | 0.620 | 1.23 | 1.14 | 0.15 | 0.470 | 1.41 | 2.06 | 0.21 | 0.780 |
| Phase II | 1.01 | 1.15 | 0.06 | 0.100 | 0.78 | 0.73 | 0.07 | 0.590 | 1.35 | 1.50 | 0.10 | 0.440 |

[1] BUN : Blood urea nitrogen

[2] Standard error of the means.

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# Ⅴ. Summary in Korean

자돈은 많은 스트레스를 받는다. 양양소 변화, 모돈과의 분리, 자돈사로의 이동 등, 이러한 요인들은 성장을 저해시킨다. 섭취량 감소, 장관의 위해요소와 효소의 미발달은 자돈의 생존과 생장에 심각한 문제를 초래하기도 하고 이러한 요소는 차후 생장에도 영향을 미치는 성장정체로 이어지기도 한다. 전분은 자돈 사료내의 주요 에너지원이나 자돈의 소장에서 다 소화가 이루어지지 못하고 대장에서 발효되어 설사를 유발하고 성장을 저해할 수 있다. 소화력이 좋은 전분질 원료를 선택하고 가공하면 대장으로 넘어가는 전분 양을 줄여 설사를 방지하고 성장정체를 줄일 수 있을 것이다.

이 실험은 전분 원료의 익스투루젼이 이유 자돈의 성장과 영양소 이용에 미치는 영향에 대해 검증하기 위해 Randomized completed block(RCB) 방법을 통한 2x3 팩토리얼로 설계되었다. 첫 번째 요소는 곡류의 가공이며, 두 번째 요소는 전분 원료 (옥수수, 보리, 쌀) 이다. 28 ± 3일령에 이유한 7.02 ± 1.07 kg의 144마리의 자돈 ([Yorkshir x Landrace] x Duroc)을 공시하여 6처리 6반복 (반복당 4두) 로 분류하였다. 모든 영양소는 NRC (1998)의 요구량을 초과하여 설계되었다. 미가공 전분 원료를 급여한 돼지가 가공원료를 급여한 돼지 보다 높은 ADG (625 vs 545 g; P<0.01 and 469 vs 416 g; P<0.01) 와 G/F ratio (0.711 vs 0.652 g; P<0.01 and 0.695 vs 0.645 g; P<0.01)를 나타냈다. 미가공 원료 중, 쌀의 처리구가 2에서 5주차에 옥수수 첨가 사료 보다 빠른 성장을 보였다 (corn 593 ve rice 661; P<0.1). 가공한 쌀과 보리를 첨가한 사료의 단백 소화율은 높아졌으나 Nitrogen retention은 감소하였고 미가공 보리와 쌀을 첨가한 사료를 급여한 돼지의 성장이 더 우수했다. 이러한 결과는 전분원료의 익스투루젼이 영양소 소화율을

개선시키는 효과가 없으며, 미가공한 원료는 소화나 자돈 생장에 해로운 영향이 없음을 의미한다.

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