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Carbohydrate sources and maximizing the use of supplemental amino acids in diets for weanling pigs

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CARBOHYDRATE SOURCES AND MAXIMIZING THE USE OF SUPPLEMENTAL AMINO ACIDS IN DIETS FOR WEANLING PIGS

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DEDICATION

A mi padre por su apoyo incondicional y sus consejos
(To my father for his unconditional support and advices)

A mi madre por su infinito amor y constantes palabras de aliento
(To my mother for her infinite love and constant encouraging words)

A mi hermana Sandra por ser mi confidente y mejor amiga
(To my sister Sandra for being my confident and best friend)

A mi hermana Dianita por siempre enseñarme como ser una mejor persona
(To my sister Dianita for always teaching me how to be a better person)

A toda mi familia por creer en mí
(To all my family for believing in me)

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"When you want something, all the universe conspires in helping you to achieve it" Paulo Coelho

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ABSTRACT

The objectives of this research were 1) to determine the effect of partial or total replacement of dried whey (DW) or dried whey permeate (DWP) with milk chocolate product (MCP) or candy oats (CO) on wk-1 feed intake and growth performance of weanling pigs, 2) to determine the effect of replacing spray-dried plasma protein (SDPP) with a novel swine nutritional supplement (SNS) on growth performance of weanling pigs, and 3) to determine the maximum level of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp that can be added in diets for 6- to 12 and 13- to 23-kg pigs without negatively affecting growth performance. Three experiments were conducted to compare the feeding value of MCP (20% lactose and 60% sugars) and DW (70% lactose) in diets for weanling pigs. Results from these experiments indicate that partial or total replacement of DW with MCP did not affect wk-1 feed intake or growth performance of weanling pigs. Thus, MCP could be considered as a formulation alternative to DW. The efficacy of DW to stimulate growth performance was confirmed in these experiments. A similar experiment was conducted to compare the feeding value of CO (60% total sugars and 25% cooked oat-based cereals) and DWP (80% lactose). Results from this experiment indicate that a combination of DWP and CO, each providing 50% of the total sugar level of the diet, effectively stimulated wk-1 feed intake and growth performance of weanling pigs. Similarly, because total replacement of DWP with CO did not affect growth performance, CO can be considered as a formulation alternative to DWP. Two experiments were conducted to determine the effect of replacing SDPP with SNS (concentrated plasma fraction) on growth performance of weanling pigs. Results from these experiments indicate that the inclusion of SDPP or SNS did not affect growth performance of pigs compared with those fed a negative control diet housed under high sanitary conditions. A total of 8 experiments were conducted to determine the maximum level of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp that

can be added in diets for 6- to 12-kg and 13- to 23-kg pigs without negatively affecting growth performance. Results from these experiments indicate that supplemental L-Lys levels up to 0.298 (0.59% Lys·$SO_{4;}$ 0.38% Lys·HCl) or 0.198% (0.39% Lys·$SO_{4;}$ 0.25% Lys·HCl) can be added in diets for 6- to 12-kg pigs without negatively affecting ADG or G:F, respectively. The optimum SID Ile:Lys ratio may not be greater than 0.55 in diets containing low levels of red blood cells. In diets for 13- to 23-kg pigs, supplemental L-Lys levels up to 0.423 (0.83% Lys·$SO_{4;}$ 0.54% Lys·HCl) or 0.331% (0.65% Lys·$SO_{4;}$ 0.42% Lys·HCl) can be added in corn-soybean meal (SBM) diets without negatively affecting ADG or G:F, respectively. It seems that ratios of 0.56 or 0.62 for SID Ile:Lys and Val:Lys respectively, may be adequate for 13-kg pigs fed corn-SBM diets.

CHAPTER 1

INTRODUCTION

Since the 1950s, the swine industry has experienced structural changes and continuous improvements in efficiency of production. In most pork producing countries, there has been a trend for fewer and larger operations; therefore, applying economies of scales and reducing costs of production. Specialized operations and multisite production schemes have been adopted, improving animal health and reproductive performance (Hollis and Curtis, 2001). In the USA, there has been a continuous improvement in litter size and annual sow productivity (NASS, 2009). The average weaning age has declined to 3 or less weeks of age, reducing the farrowing interval of sows and therefore, increasing the number of pigs produced per sow per year. However, reducing weaning age also increases the challenges for managing and feeding the early-weaned pig.

The weaning period is considered the most stressful event in the pork production cycle. At weaning, pigs are confronted by multiple social, environmental, and nutritional stresses that result in reduced feed intake, poor growth rate, and increased susceptibility to enteric diseases. A period of anorexia or low feed intake during the first week post-weaning has been identified as the main cause for the poor growth performance and also for the negative alterations in intestinal integrity and function. Consequently, a mixture of highly digestible and palatable ingredients, that provide nutrients in a chemical form that are in accordance with the digestive capacity of the weanling pig, have been used to stimulate feed intake and to reduce the growth lag after weaning. However, the cost of these standard ingredients is usually high and in some instances, their availability is limited. Thus, novel feed ingredients capable to support similar or greater performance are needed.

Milk derived products such as dried whey (**DW**) and dried whey permeate (**DWP**) have been shown to stimulate feed intake and growth performance of weanling pigs (Mahan, 1993; Naranjo et al., 2010). Mahan (1992) demonstrated that the lactose component of DW is the main ingredient responsible for the enhanced growth performance of weanling pigs. Although consistent responses have been reported with DW or DWP, other carbohydrate sources containing different sugar profiles may be just as effective (Mavromichalis et al., 2001; Naranjo et al., 2010). Milk chocolate product (**MCP**) and candy oats (**CO**) are novel carbohydrate products that are typically less expensive than DW or DWP (Dean, 2010, *personal communication*); however, more research is needed to determine their efficacy to stimulate wk-1 feed intake and growth performance of weanling pigs.

Spray-dried plasma protein (**SDPP**) is a highly digestible and palatable protein source commonly used in diets for weanling pigs in the USA. The efficacy of SDPP to stimulate feed intake and ADG during the first 2 wk post-weaning is well documented (van Dijk et al., 2001). The mode of action by which SDPP improves growth performance is not completely known, but increased evidence suggest that its immunoglobulin fraction is the mainly responsible (Pierce et al., 2005). Given that SDPP is one of the most expensive protein sources commonly added in diets for weanling pigs, a novel swine nutritional supplement (**SNS**) completely derived from animal plasma has been developed. In this product, plasma goes through a patented chemical process in which the immunoglobulin components are activated by releasing them from their carrier protein (Hagen, 2010, *personal communication*). However, limited research has been conducted to determine the efficacy of replacing SDPP with a combination of SNS and less expensive protein sources.

Another important aspect of a successful nutritional program for weanling pigs is to formulate diets to closely meet the amino acids (**AA**) requirements without providing excess levels of crude protein (**CP**). Diets of early-weaned pigs contain high levels of CP to meet their high AA requirements. However, reducing CP levels in diets for weanling pigs may 1) improve overall utilization of N, 2) reduce N excretion, 3) reduce the buffering capacity of the diet, and 4) improve intestinal health and integrity. However, the effects of low CP-AA supplemented diets on growth performance of weanling pigs have been inconsistent. Additionally, in most of the previous research, low CP diets were supplemented with either Ile, Val, or both. At this particular period of time, the most cost effective approach to develop low CP diets for pigs is to maximize the use of supplemental L-Lys, DL-Met, L-Thr, and L-Trp before the next limiting AA (Ile, Val, or His) reduces growth performance.

Body weight at birth, at weaning, and at the end of the nursery period are critical for subsequent weight gain and age at slaughter. Therefore, developing a nutritional program aimed to maximize growth performance of pigs during the post-weaning period has the potential to improve overall pork production efficiency.

Therefore, the objectives of this research were 1) to evaluate novel carbohydrates sources (MCP and CO) as a replacement of DW or DWP on wk-1 feed intake and growth performance of weanling pigs, 2) to evaluate SNS as a replacement of SDPP on growth performance of weanling pigs, and 3) to maximize the use of commercially available supplemental AA (L-Lys, DL- Met, L-Thr, and L-Trp) in diets for 6- to12-kg and for 13- to 23-kg pigs.

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CHAPTER 2

REVIEW OF LITERATURE

INTRODUCTION

The average weaning age in most pork producing countries has been reduced to 18 to 24 d to potentially improve efficiency of production (King and Pluske, 2003).This practice has increased the number of pigs per sow per year and reduced the risk of disease transmission between sows and pigs. However, reducing weaning age also has increased the challenges for managing and feeding the early-weaned pig.

At weaning, pigs are separated from the sow, put into a new housing system, mixed with unfamiliar pigs, and offered a dry feed with carbohydrates instead of fat as the main source of energy (Spreeuwenberg et al., 2001). In contrast, sow milk contains 20% dry matter (**DM**) that is composed of 30% protein, 40% fat, and 25% lactose. These changes cause a post-weaning growth reduction, which is mainly driven by a reduced feed intake. The extent and duration of this reduction in growth may negatively affect growth during the subsequent dietary phases and possibly increase the number of days to reach market weight. Thus, one of the main goals for a successful post-weaning feeding program is to select ingredients that will maximize feed intake immediately after weaning.

UNDERSTANDING WEANING IN PIGS

Weaning under natural conditions is considered a "gradual process" that usually occurs at 9 to 22 wk of age (Brooks and Tsourgiannis, 2003, Bolhuis et al., 2009); whereas, weaning under commercial conditions is considered an "abrupt event" that usually occurs at 3 wk of age. Under natural conditions, weaning is a gradual transition from sow milk with approximately 20% DM to a solid diet containing 15 to 30% DM (forages). In contrast, pigs under commercial conditions are expected to make an instant transition from sow milk to a complex dry feed diet that usually contains 80 to 90% DM. However, to fully exploit the growth potential of weanling pigs, and thus, to maximize the efficiency of pork production, commercial weaning is necessary. Although in European countries, weaning before 21 d is not permitted. Furthermore, in other countries in which the use of antibiotic has been banned, weaning usually occurs from 35 to 42 d of age. Nevertheless, the primary objective at weaning is to ensure that the transition from sow milk to dry feed is as smooth as possible.

Before weaning, sow milk is the main source of energy, nutrients, and passive immunity for pigs. Intake of an adequate amount of colostrum during the first 24 to 36 h after parturition is essential for survival and subsequent growth performance (King and Pluske, 2003). Similarly, the immunoglobulins (mainly IgA) contained in sow milk provides continuous protection throughout the intestinal lumen against pathogenic stressors. The pig's own immune system begins to develop at approximately 3 wk of age, but is not fully active until 5 to 6 wk of age (Partridge and Gill, 2001). In addition, sow milk also contains bioactive peptides such as epidermal growth factor, insulin-like growth factors, and polyamines that contribute to the gastrointestinal tract development (Dunshea, 2003).

Despite the high biological value of sow milk and its high digestibility (Mavromichalis et al., 2001), pigs artificially reared achieved greater growth rate than sow-reared pigs (Le Dividich and Sève, 2001). The milk produced by the sow becomes a limiting factor at 7 to 10 d of lactation, as pigs have the capability to consume more milk. Additionally, milk composition may limit the growth potential of the suckling pig (Noblet and Etienne, 1987). Kim et al. (2004) reported that as lactation progresses, sow milk may become deficient in protein (or an essential amino acid, **AA**) and energy. This author, reported greater growth rate in milk-fed young pigs that were supplemented with Arg. It is evident that young pigs have a tremendous potential for growth and that there are great opportunities for improvements. The potential for growth of the young pig may be 2 or 3 times greater than those obtained under well managed commercial conditions (Williams, 2003).

At weaning, pigs encounter multiple environmental, social, and nutritional stressors that result in reduced feed intake and gastrointestinal alterations. Piè et al. (2004) reported that weaning, by itself, is associated with the upregulation of proinflammatory cytokines, especially during the first 2 d post-weaning. Cytokines are small peptide molecules that are important mediators in the regulation of the immune response. Weaning also has been associated with reductions in villous height and increase in crypt depth (Pluske et al., 1997). These alterations are more pronounced in pigs weaned at 14 d compared with those weaned at 21 d. From 5 to 8 d after weaning, intestinal structure begins to recover, but this response is highly associated with the level of feed intake.

There has been increased interest in maximizing feed intake during the first week post-weaning as gut structure and function may be maintained. Pluske et al. (1997) reported that the presence of feed in the intestinal lumen is one of the most potent stimuli for intestinal proliferation. Depravation of nutrients from the lumen of the small intestine results in reduced villous height and increased crypt depth. Reductions in villous height and increases in crypt depth have been associated with reduction in specific activity of brush border enzymes, which limits the digestive and absorptive capacity of pigs (Pluske et al., 1997). Because of these facts, it is logical to believe that an increase in feed intake in the immediate post-weaning period will maintain the integrity of the small intestine, the digestive and absorptive capacity, and therefore, will result in increased growth performance and health status.

In general, weaning in pigs may be summarized as follows:

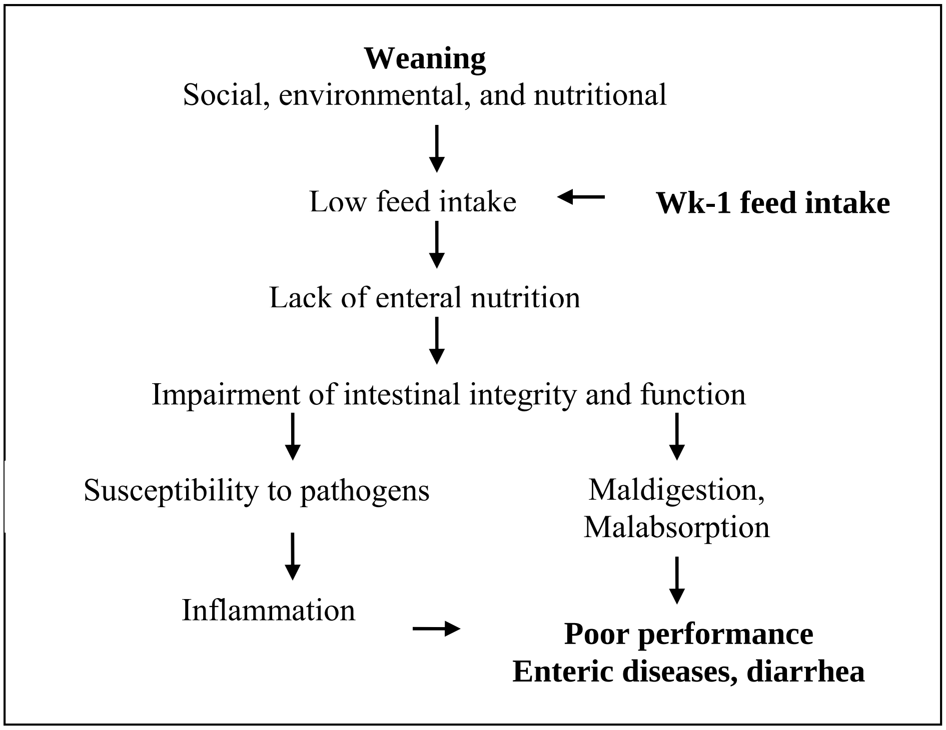

Figure 2.1. An integrated summary of some of the important aspects related to weaning of pigs (Adapted and modified from Vente-Spreewenber and Beynen, 2003).

CARBOHYDRATE SOURCES IN DIETS FOR WEANLING PIGS

The efficacy of milk products such as dried whey (**DW**), dried whey permeate (**DWP**), and deproteinized whey in improving feed intake and growth performance of weanling pigs is well documented (Mahan, 1993; Owen et al., 1993; Nessmith et al., 1997; Naranjo et al., 2010). Mahan (1992) evaluated the lactoalbumin and lactose component of DW and reported that lactose was mainly responsible for the enhanced growth performance.

Several studies have evaluated the effect of different levels of lactose in diets for weanling pigs. Nessmith et al. (1997) reported linear improvements in ADG and ADFI with increasing dietary lactose levels up to 40% in pigs weaned between 10 and 19 d of age. Mahan (1993) reported similar results in pigs weaned at 23 d of age and with lactose levels up to 25%. However, the dietary lactose level necessary to maximize growth performance of weanling pigs decreases as pigs become older and heavier. Mahan et al. (2004) reported that the lactose levels necessary to maximize growth performance of weanling pigs are: 25 to 30% from d 0 to 7; 15 to 20% from d 7 to 21; and 10 to15% from d 21 to 35. Based on pigs BW, Tokach et al. (2003) recommended lactose levels of: 18 to 25% for pigs weighing less than 5 kg, 15 to 20% for pigs weighing 5 to 7 kg, 6 to 8% for pigs weighing 7 to 11 kg, and no lactose for pigs weighing more than 11 kg.

Tokach et al. (2003) suggested that the changes in the pattern of digestive enzymes of the weanling pig must be considered in selecting the ingredients and levels used within each dietary phase. The specific activity of lactase, necessary to hydrolyze milk lactose, has been reported to be high at birth, peak at approximately 3 wk of age, and rapidly decline thereafter (Maxwell and Carter, 2001). Conversely, the activity of sucrase, maltase, and α-amylase necessary to hydrolyze the carbohydrates found in cereal grains, are low at birth and steadily increase with age, especially at approximately 4 wk of age (Corring et al., 1978). However, low levels of feed intake during the first week post-weaning negatively affect the intestinal structure of the small intestine, reducing the specific activity of the brush border enzymes lactase and sucrase (Pluske, 1997).

The fermentation of lactose to lactic acid in the digestive tract of weanling pig also may improve intestinal health. Although most dietary lactose may be hydrolyzed by mucosal lactase in the small intestine, a significant amount may be utilized by lactobacilli (Partridge and Gill, 2001). In addition, because intestinal lactase activity starts to decline at 3 wk of age, more dietary lactose will be available for lactobacillus fermentation. Increased formation of lactic acid in the intestinal tract will promote the colonization of lactobacillus bacteria over pathogenic bacteria. Similarly, more acidic conditions may stimulate proteolytic activity, improving the digestion of other dietary proteins.

Despite strong evidence that lactose improves growth performance and possibly, the health status of weanling pigs, recent research has focused on evaluating alternative but less expensive carbohydrate sources. The changes in milk supply and increased alternative markets for milk-by products have affected their availability and cost. Research has demonstrated that dextrose (Mahan and Newton, 1993; Richert et al., 1996), a high sucrose containing product (de Rodas et al., 1998; Naranjo et al., 2010), and sucrose (Mavromichalis et al., 2001) can effectively replace all or a portion of the lactose fraction in nursery diets. Similarly, Mavromichalis et al. (2001) reported that sucrose or molasses could be used to replace lactose in diets for nursery pigs with no negative effects on growth performance or nutrient digestibility. Naranjo et al. (2010) reported that DWP, which contains 80% lactose, can be effectively replaced with a novel carbohydrate product containing a blend of 40% lactose, 30% sucrose, and 10% glucose. Sullivan et al. (1992) reported that DW can be replaced with milk chocolate product at a dietary level of 12% without affecting growth performance of weanling pigs. Milk chocolate product contains 20% lactose and 60% total sugars. Therefore, it seems that alternative carbohydrate sources with different sugar profiles may be used as replacement of high lactose containing products. Novel carbohydrate sources should elicit a similar or greater growth performance than those obtained with benchmarking sources such as DW and DWP.

LOW CRUDE PROTEIN DIETS FOR WEANLING PIGS

Diets for weanling pigs are characterized by containing high levels of crude protein (**CP**). However, there has been increased interest in reducing the CP levels in diets for weanling pigs as it may 1) reduce N losses to the environment (Le Bellego and Noblet, 2002), 2) reduce the buffering capacity of the diet (Wellock et al., 2008), 3) improve gastrointestinal health (Nyachoti et al., 2006), and 4) reduce the incidence of post-weaning diarrhea (Heo et al., 2009). In addition, supplemental AA, mainly L-Lys, DL-Met, L-Thr, and L-Trp, have become increasingly available and at prices that often merit their inclusion in pig diets.

Weanling pigs are highly susceptible to pathogenic invasion that usually results in post-weaning diarrhea. Antibiotic growth promoters (**AGP**) have been widely used to reduce the incidence of post-weaning diarrhea and to enhance growth performance. However, there is a current interest in swine nutrition to eliminate the use of AGP as a response to controversial public concerns on the potential risk of inducing bacterial resistance in humans (Zhao et al., 2007). Low CP-AA supplemented diets have been suggested as an important nutritional strategy that may improve gastrointestinal health and thus, reduce the incidence of diarrhea.

Several researchers have reported that lowering the dietary CP of the diet reduced the incidence of post-weaning diarrhea and promoted intestinal health (Nyachoti et al., 2006; Opapeju et al., 2008). The undigested CP entering the large intestine may increase microbial fermentation and may provide more substrate for pathogen proliferation (Stein, 2007). Additionally, an increased metabolic demand for deaminating excess AA may compromise the immune system. Similarly, bacterial fermentation of undigested protein produces volatile fatty acids, ammonia, and amines that have been shown to negatively affect the intestinal structure of pigs (Gaskins, 2001).

Although reducing excess CP levels in diets for weanling pigs may improve intestinal health, the effects on growth performance have been inconsistent. In some experiments in which CP levels were reduced up to 17%, researchers suggested that the inclusion of either Ile, Val, or both are necessary to maintain growth performance (Le Bellego and Noblet, 2002; Htoo et al., 2007; Lordelo et al., 2008; Heo et al., 2009). However, in other experiments, growth performance was not maintained even with Ile supplementation (Opapeju et al., 2008).

Nevertheless, at this particular period of time, the inclusion of the next limiting AA in diets supplemented with Lys, Met, Thr, and Trp is not economical.

Essential AA for pigs can be divided into 2 groups according to their degree of limitation in common practical diets (Boisen, 2003). The primary limiting group includes Lys, Met, Thr, and Trp; while the secondary limiting group includes the branched-chain AA (**BCAA**) and possibly an aromatic AA. Thus, when the AA of the primary limiting group are increased, an AA of the secondary group may become limiting. To successfully develop low CP-AA supplemented diets for pigs, it is necessary to know 1) the Lys requirement, 2) the ratio of the required AA relative to Lys, 3) the response variable to use, and 4) force supplemental AA into the diet until a negative response is obtained (Southern et al., 2010).

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CHAPTER 3

EFFECT OF MILK CHOCOLATE PRODUCT ON WEEK-ONE FEED INTAKE AND GROWTH PERFORMANCE OF WEANLING PIGS[1]

INTRODUCTION

Weaning is recognized as a period of high stress for pigs. It is characterized by reduced feed intake, and therefore, a deficient supply of energy and nutrients. Increased feed intake during the first week post-weaning has been associated with enhanced growth performance and health status of weanling pigs. Highly palatable and digestible ingredients are used in diets of weanling pigs to promote feed intake, especially during the first week post-weaning.

Dried whey (**DW**), which contains 70% lactose, is widely used in diets for weanling pigs as it has been reported to increase feed intake and growth performance (Mahan, 1993; Cromwell et al., 2008). Milk chocolate product (**MCP**), which contains 20% lactose and 60% total sugars, is a by-product from the food and candy industries that contains approximately one third each of whole milk, sucrose, and cocoa (Sullivan et al., 1992; Yang et al., 1997). Several researchers (Sullivan et al., 1992; Yang et al., 1997) have shown that pigs preferred diets with MCP over diets with DW in feed preference trials. However, the effect of MCP on growth performance of weanling pigs has been inconsistent. Sullivan et al. (1992) reported that MCP can effectively replace DW at a dietary level of 12% without affecting growth performance of weanling pigs. In contrast, Yang et al. (1997) reported that ADG, ADFI, and G:F were linearly decreased with increasing levels of MCP as a replacement of DW.

More research is needed to elucidate the efficacy of MCP to stimulate feed intake during the first week post-weaning and on growth performance of weanling pigs. Milk chocolate product is less expensive than DW and may be an economical replacement in diets for weanling

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pigs. Therefore, the objectives of these experiments were to determine the effect of partial or total replacement of DW with MCP on daily collected feed intake during the first week post-weaning and subsequent growth performance of weanling pigs.

MATERIALS AND METHODS

All experimental protocols were approved by the Louisiana State University Agricultural Center Animal Care and Use Committee.

General

Pigs (Yorkshire, Yorkshire × Landrace, or Yorkshire × Landrace × Duroc) were obtained from the Louisiana State University Agricultural Center Swine Unit and housed in an environmentally controlled nursery building. Each pen (0.97 x 1.47 m in size) had hard plastic slotted flooring, 1 nipple waterer, and a 4-hole stainless steel self-feeder. Feed in meal form and water were provided for *ad libitum* intake.

In all experiments, weanling pigs were blocked by initial BW and allotted to dietary treatments in a randomized complete block design. Littermates were balanced across treatments and sex was equalized among pens within replicates. Pigs were fed in a 4-phase feeding program that lasted from d 0 to 7 for phase 1, d 7 to 14 for phase 2, d 14 to 21 for phase 3, and d 21 to 35 for phase 4. All pigs and feeders were weighed at the beginning and end of each growth phase for ADG, ADFI, and G:F determination. All feeders were weighed daily starting at 0700 during the first 7 d post-weaning to determine daily collected feed intake.

Dietary treatments were formulated based on the amino acid (**AA**) and nutrient concentrations provided by International Ingredient Corporation (St. Louis, MO) for DW and MCP. The nutrient values used for DW and MCP were: CP, 12.2 and 12.0%; crude fat, 1.0 and 6.0%; lactose, 70 and 20%; salt, 3.0 and 1.5%; Ca, 0.86 and 0.30%; P, 0.76 and 0.30%; Lys, 0.95 and 1.10%; Met, 0.21 and 0.22%; TSAA, 0.44 and 0.36%; Thr, 0.73 and 0.55%; Trp, 0.18 and

0.19%; and Ile, 0.64 and 0.56%, respectively. Nutrient values reported in the Aminodat 3.0 database by Evonik-Degussa (Hess et al., 2006) were used for all other ingredients. Diets were formulated to contain 1.60, 1.40, 1.40 and 1.20% total Lys for phases 1, 2, 3, and 4 respectively, and to meet or exceed the AA ratios suggested by Baker (1997) for 10- to 20-kg pigs. To keep dietary treatments isocaloric, fat levels were reduced with increasing levels of MCP as DW provides less ME (kcal/kg) than MCP. Because DW provides 2 times more salt than MCP (3.0 vs. 1.5% respectively), salt levels fluctuate among diets in order to keep the percentage of Na and Cl within an acceptable range. Dietary inclusion levels of nutrients and ingredients are expressed on an as-is basis.

Exp. 1 and 2

Experiments were conducted to determine the effect of partially replacing the dietary level of DW with MCP on wk-1 feed intake and growth performance of weanling pigs. In Exp. 1, 80 weanling pigs with an average initial BW of 6.5 ± 0.8 kg and weaned at an average age of 24 ± 2 d were used. Each treatment was replicated with 5 pens of 4 pigs per replicate pen. In Exp. 2, 120 weanling pigs with an average initial BW of 6.0 ± 0.9 kg and weaned at an average age of 19 ± 2 d were used. Each treatment was replicated with 6 pens of 5 pigs per replicate pen.

In Exp. 1 and 2, pigs were assigned to 4 dietary treatments that followed the same treatment arrangement during phases 1, 2, and 3 (Tables 3.1 to 3.3). Dietary treatments included 1) negative control diet (**NC**), no lactose added, 2) positive control diet (**PC**) with DW, 3) 25% replacement of DW used in the PC diet with MCP (**25MCP**), and 4) 50% replacement of DW used in the PC diet with MCP (**50MCP**). The inclusion levels of DW or the sum of DW and MCP in combination were 20, 10, and 5% for phases 1, 2, and 3 respectively. During phase 4, all pigs were fed the same corn-soybean meal diet with no lactose added (Table 3.3). Because the same dietary treatments were used in Exp. 1 and 2, data from both experiments were combined and analyzed together. Combined data from Exp. 1 and 2 resulted in a total of 200 weanling pigs with an average initial BW of 6.2 ± 0.9 kg and 21 ± 3 d of age. There were a total of 11 replicates with 4 or 5 pigs per replicate pen.

Exp. 3

This experiment was conducted to determine the effect of totally replacing the dietary level of DW with MCP on wk-1 feed intake and growth performance of weanling pigs. Eighty-four weanling pigs with an average initial BW of 6.3 ± 1.3 kg and weaned at an average age of 21 ± 2 d were allotted to 3 dietary treatments (Tables 3.1 to 3.3) 1) NC diet, 2) PC diet, and 3) 100% replacement of DW used in the PC diet with MCP (**100MCP**). Each treatment was replicated with 7 pens of 4 pigs per replicate pen. The NC, PC, and phase 4 diets were the same as in Exp. 1 and 2. Because Exp. 1, 2, and 3 included the same NC and PC diets, data were combined and analyzed together to determine the efficacy of DW to improve growth performance of weanling pigs compared with pigs fed diets with no lactose added.

Statistical Analysis

Data from all experiments were analyzed as randomized complete block designs using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Initial BW was used as the blocking factor and each pen of pigs served as the experimental unit. Combined data from Exp. 1 and 2, and combined data from Exp. 1, 2, and 3 (NC vs. PC) were analyzed using initial BW (block), dietary treatment, and experiment as sources of variation. The treatment × experiment interaction was not significant, and therefore, was removed from the model. In Exp. 3, data were analyzed using initial BW and dietary treatment as sources of variation. For all experiments, treatment means were separated using preplanned, pairwise comparisons (PDIFF option of SAS) with an α at 0.10.

Table 3.1. Composition of phase 1 experimental diets that were fed to weanling pigs in Exp. 1, 2, and 3 (as-fed basis)

	Exp. 1, 2, and 3		Exp. 1 and 2		Exp. 3
Item	NC[1,2]	PC[2,3]	25MCP[4]	50MCP[5]	100MCP[2,6]
Ingredient, %					
Corn	53.04	40.85	41.25	41.60	42.30
Soybean meal (48% CP)	25.98	20.44	20.15	19.86	19.28
Fishmeal menhaden	6.00	6.00	6.00	6.00	6.00
SDPP[7]	4.00	4.00	4.00	4.00	4.00
Dry fat[8]	4.76	3.57	3.28	3.02	2.50
Red blood cells	2.00	2.00	2.00	2.00	2.00
Dried whey (DW)	---	20.00	15.00	10.00	---
Milk chocolate product (MCP)	---	---	5.00	10.00	20.00
Monocalcium phosphate	1.02	0.64	0.75	0.87	1.10
Limestone	0.77	0.56	0.58	0.60	0.65
Sodium bentonite	0.50	0.50	0.50	0.50	0.50
Vitamin premix[9]	0.50	0.50	0.50	0.50	0.50
Zinc oxide	0.28	0.28	0.28	0.28	0.28
Salt	0.61	0.10	0.13	0.17	0.26
Trace mineral premix[10]	0.10	0.10	0.10	0.10	0.10
Antibiotic[11]	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05
DL-Met	0.14	0.17	0.17	0.18	0.19
L-Thr	---	---	0.003	0.016	0.04
Calculated composition					
ME, kcal/kg	3,534	3,534	3,534	3,534	3,534
Lys, %	1.60	1.60	1.60	1.60	1.60
TSAA, %	0.96	0.96	0.96	0.96	0.96
Thr, %	1.04	1.05	1.04	1.04	1.04
Trp, %	0.31	0.31	0.31	0.31	0.30
Ca, %	0.90	0.90	0.90	0.90	0.90
P, %	0.80	0.80	0.80	0.80	0.80
Na, %	0.42	0.43	0.42	0.43	0.44
Cl, %	0.53	0.50	0.49	0.49	0.49

[1]NC = negative control diet.
[2]Dietary treatments were used in Exp. 3.
[3]PC = positive control diet.
[4]25MCP = 25% replacement of DW used in the PC diet with MCP.
[5]50MCP = 50% replacement of DW used in the PC diet with MCP.
[6]100MCP = 100% replacement of DW used in the PC diet with MCP.
[7]SDPP = spray-dried plasma protein (AP-920) was obtained from American Protein Corp., Ames, IA.
[8]Fat Pak 100, Milk Specialties Co., Dundee, IL.
[9]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg;

pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 µg; biotin, 441 µg; vitamin C, 110 µg.

[10]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.

[11]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.

Table 3.2. Composition of phase 2 experimental diets that were fed to weanling pigs in used in Exp. 1, 2, and 3 (as-fed basis)

	Exp. 1, 2, and 3		Exp. 1 and 2		Exp. 3
Item	NC[1,2]	PC[2,3]	25MCP[4]	50MCP[5]	100MCP[2,6]
Ingredient, %					
Corn	55.81	49.68	49.87	50.04	50.40
Soybean meal (48% CP)	30.39	27.62	27.48	27.33	27.04
Dry fat[7]	3.62	3.03	2.90	2.77	2.50
Fishmeal menhaden	6.00	6.00	6.00	6.00	6.00
Dried whey (DW)	---	10.00	7.50	5.00	---
Milk chocolate product (MCP)	---	---	2.50	5.00	10.00
Monocalcium phosphate	1.20	1.01	1.07	1.12	1.24
Limestone	0.66	0.56	0.57	0.58	0.60
Sodium bentonite	0.50	0.50	0.50	0.50	0.50
Vitamin premix[8]	0.50	0.50	0.50	0.50	0.50
Zinc oxide	0.28	0.28	0.28	0.28	0.28
Salt	0.33	0.10	0.12	0.14	0.18
Trace mineral premix[9]	0.10	0.10	0.10	0.10	0.10
Antibiotic[10]	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05
L-Lys·HCl	0.15	0.15	0.15	0.15	0.15
DL-Met	0.12	0.13	0.14	0.14	0.15
L-Thr	0.04	0.04	0.05	0.05	0.07
Calculated composition					
ME, kcal/kg	3,446	3,446	3,446	3,446	3,446
Lys, %	1.40	1.40	1.40	1.40	1.40
TSAA, %	0.84	0.84	0.84	0.84	0.84
Thr, %	0.91	0.91	0.91	0.91	0.91
Trp, %	0.26	0.26	0.26	0.26	0.26
Ca, %	0.90	0.90	0.90	0.90	0.90
P, %	0.80	0.80	0.80	0.80	0.80
Na, %	0.18	0.19	0.18	0.20	0.20
Cl, %	0.28	0.28	0.27	0.27	0.27

[1]NC = negative control diet.
[2]Dietary treatments were used in Exp. 3.
[3]PC = positive control diet.
[4]25MCP = 25% replacement of DW used in the PC diet with MCP.
[5]50MCP = 50% replacement of DW used in the PC diet with MCP.
[6]100MCP = 100% replacement of DW used in the PC diet with MCP.
[7]Fat Pak 100, Milk Specialties Co., Dundee, IL.
[8]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[9]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.

[10]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.

Table 3.3. Composition of phases 3 and 4 experimental diets that were fed to weanling pigs in Exp. 1, 2, and 3 (as-fed basis)

	Phase 3					
	Experimental diets[1]					
Item	NC[2]	PC[3]	25MCP[4]	50MCP[5]	100MCP[6]	Phase 4
Ingredient, %						
Corn	54.80	51.70	51.83	51.92	52.21	60.50
Soybean meal (48% CP)	35.11	33.73	33.66	33.58	33.43	32.31
Dry fat[7]	3.16	2.88	2.80	2.73	2.50	2.50
Fishmeal menhaden	3.00	3.00	3.00	3.00	3.00	---
Dried whey (DW)	---	5.00	3.75	2.50	---	---
Milk chocolate product (MCP)	---	---	1.25	2.50	5.00	---
Monocalcium phosphate	1.01	0.92	0.95	0.98	1.03	1.46
Limestone	0.86	0.80	0.81	0.81	0.83	1.08
Sodium bentonite	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix[8]	0.50	0.50	0.50	0.50	0.50	0.50
Salt	0.35	0.25	0.24	0.25	0.27	0.50
Trace mineral premix[9]	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic[10]	0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05	0.05
L-Lys·HCl	0.15	0.15	0.15	0.15	0.15	0.15
DL-Met	0.13	0.13	0.14	0.14	0.14	0.09
L-Thr	0.03	0.03	0.03	0.04	0.04	0.01
Calculated composition						
ME, kcal/kg	3,432	3,432	3,432	3,432	3,432	3,376
Lys, %	1.40	1.40	1.40	1.40	1.40	1.20
TSAA, %	0.84	0.84	0.84	0.84	0.84	0.72
Thr, %	0.91	0.91	0.91	0.91	0.91	0.78
Trp, %	0.28	0.27	0.27	0.27	0.27	0.24
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80
P, %	0.70	0.70	0.70	0.70	0.70	0.70
Na, %	0.18	0.19	0.18	0.18	0.19	0.23
Cl, %	0.27	0.28	0.27	0.27	0.27	0.35

[1]NC and PC diets were used in Exp. 1, 2, and 3; 25MCP and 50MCP diets were used in Exp. 1 and 2; 100MCP diet was used in Exp. 3

[2]NC = negative control diet.

[3]PC = positive control diet.

[4]25MCP = 25% replacement of DW used in the PC diet with MCP.

[5]50MCP = 50% replacement of DW used in the PC diet with MCP.

[6]100MCP = 100% replacement of DW used in the PC diet with MCP.

[7]Fat Pak 100, Milk Specialties Co., Dundee, IL.

[8]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 µg; biotin, 441 µg; vitamin C, 110 µg.

[9]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[10]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.

RESULTS

Exp. 1 and 2

There were no treatment × experiment interactions ($P > 0.10$) in any of the growth variables of the combined data. Thus, results and discussion are based on the combined data of Exp. 1 and 2.

Wk-1 Feed Intake

Feed intake was increased ($P < 0.10$) from d 3 to 7 for pigs fed the PC diet, on d 2, 3, 4, and 7 for pigs fed the 25MCP diet, and from d 2 to 7 for pigs fed the 50MCP compared with pigs fed the NC diet (Table 3.4, Figure 3.1). There was no difference ($P > 0.10$) in feed intakes on any day among pigs fed the PC, 25MCP and 50MCP diets.

Table 3.4. Effect of dietary dried whey (DW) and its partial replacement with milk chocolate product (MCP) on feed intake (g/d) during the first 7 d post-weaning in the combined data from Exp. 1 and 2[1]

	Experimental diets					
Days post-weaning	NC[2]	PC[3]	25MCP[4]	50MCP[5]	SEM	*P*-value[6]
1	22	23	32	35	11	0.74
2	120^{b}	165^{ab}	187^{a}	203^{a}	22	0.06
3	200^{b}	265^{a}	253^{a}	261^{a}	17	0.04
4	235^{b}	286^{a}	288^{a}	306^{a}	21	0.10
5	266^{b}	336^{a}	300^{ab}	317^{a}	20	0.10
6	300^{b}	382^{a}	346^{ab}	388^{a}	24	0.05
7	313^{b}	399^{a}	381^{a}	398^{a}	23	0.03

[a,b]Treatment means with different superscripts on the same row are significantly different, $P < 0.10$.
[1]Data are means of 11 replicates with 4 and 5 pigs per replicate pen in Exp. 1 and 2, respectively.
[2]NC = negative control diet.
[3]PC = positive control diet.
[4]25MCP = 25% replacement of DW used in the PC diet with MCP.
[5]50MCP = 50% replacement of DW used in the PC diet with MCP.
[6]Overall treatment *P*-value.

Growth Performance

During phase 1, pigs fed the PC, 25MCP, and 50MCP diets had increased ($P < 0.10$) ADG and ADFI compared with pigs fed the NC diet, but G:F was not affected ($P > 0.10$; Table 3.5). There was no difference ($P > 0.10$) in ADG, ADFI, and G:F among pigs fed the PC diet and pigs fed the 25MCP and 50MCP diets.

Table 3.5. Effect of dietary dried whey (DW) and its partial replacement with milk chocolate product (MCP) on growth performance of weanling pigs in the combined data from Exp. 1 and 2[1]

	Experimental diets					
Item	NC[2]	PC[3]	25MCP[4]	50MCP[5]	SEM	*P*-value[6]
Initial BW, kg	6.4	6.4	6.4	6.4	0.04	0.61
Final BW, kg	21.3	21.9	21.6	22.0	0.31	0.33
Phase 1, d 0 to 7						
ADG, g	133[b]	165[a]	171[a]	181[a]	12	0.04
ADFI, g	211[b]	265[a]	255[a]	276[a]	14	0.02
G:F	0.62	0.63	0.67	0.66	0.03	0.56
Phase 2, d 7 to 14						
ADG, g	383[b]	418[a]	398[ab]	390[ab]	13	0.28
ADFI, g	553[b]	643[a]	603[a]	614[a]	18	0.01
G:F	0.69[a]	0.64[b]	0.65[ab]	0.63[b]	0.02	0.09
Phase 3, d 14 to 21						
ADG, g	520	551	520	550	16	0.29
ADFI, g	783[b]	877[a]	829[ab]	836[a]	21	0.03
G:F	0.67[a]	0.64[b]	0.63[b]	0.66[ab]	0.01	0.15
Phase 4, d 21 to 35						
ADG, g	567	561	561	575	14	0.88
ADFI, g	1,036	1,033	1,012	1,046	23	0.74
G:F	0.55	0.54	0.56	0.55	0.01	0.66
Overall, d 0 to 35						
ADG, g	433	450	441	452	9	0.43
ADFI, g	716[b]	762[a]	737[ab]	759[a]	16	0.15
G:F	0.60	0.60	0.60	0.60	0.01	0.5

[a,b]Treatment means with different superscripts on the same row are significantly different, $P < 0.10$.
[1]Data are means of 11 replicates with 4 and 5 pigs per replicate pen in Exp. 1 and 2, respectively.
[2]NC = negative control diet.
[3]PC = positive control diet.
[4]25MCP = 25% replacement of DW used in the PC diet with MCP.
[5]50MCP = 50% replacement of DW used in the PC diet with MCP.
[6]Overall treatment *P*-value.

During phase 2, pigs fed the PC, 25MCP, and 50MCP diets had increased ($P < 0.10$) ADFI compared with pigs fed the NC diet. Daily gain was increased ($P < 0.10$) for pigs fed the PC diet compared with pigs fed the NC diet. However, ADG was similar ($P > 0.10$) among pigs fed the 25MCP and 50MCP diets compared with pigs fed the PC diet. Gain:feed was not affected ($P > 0.10$) by dietary treatment. During phase 3, pigs fed the PC and 50MCP diets had increased ($P < 0.10$) ADFI compared with pigs fed the NC diet, but ADG was not affected ($P > 0.10$). Gain:feed was reduced ($P < 0.10$) for pigs fed the PC and 25MCP diets compared with pigs fed the NC diet. However, ADG, ADFI, and G:F were not different ($P > 0.10$) among pigs fed the PC, 25MCP, and 50MCP diets. During phase 4, when all pigs were fed the same diet, ADG, ADFI, and G:F were not affected ($P > 0.10$) by dietary treatment.

The combined overall data from Exp. 1 and 2 indicated that partial replacement of DW with MCP did not affect ($P > 0.10$) ADG, ADFI, or G:F of weanling pigs. There was no difference ($P > 0.10$) in ADG and G:F among pigs fed the NC diet and pigs fed the PC and MCP diets. Daily feed intake was increased ($P < 0.10$) for pigs fed the PC and 50MCP diets compared with pigs fed the NC diet, but similar to pigs fed the 25MCP diet. Final BW at the end of the 35 d nursery period was not affected ($P > 0.10$) by dietary treatment.

Exp. 3

Wk-1 Feed Intake

Daily feed intake was increased ($P < 0.10$) from d 2 to 5 for pigs fed the PC diet and on d 1 and 2 for pigs fed the 100MCP diet compared with pigs fed the NC diet (Table 3.6, Fig 3.1). However, there was no difference ($P > 0.10$) between pigs fed the PC and 100MCP diets.

Growth Performance

Total replacement of DW with MCP did not affect ($P > 0.10$) ADG, ADFI, or G:F during any growth phase of the experiment (Table 3.7). During phase 1, pigs fed the PC diet had increased ($P < 0.10$) ADG and ADFI compared with pigs fed the NC diet. Pigs fed the 100MCP diet had similar ($P > 0.10$) ADG and ADFI compared with pigs fed the PC diet.

Table 3.6. Effect of dietary dried whey (DW) and its total replacement with milk chocolate product (MCP) on feed intake (g/d) during the first 7 d post-weaning in Exp. 3[1]

	Experimental diets				
Days post-weaning	NC[2]	PC[3]	100MCP[4]	SEM	P-value[5]
1	14[b]	20[ab]	37[a]	9	0.21
2	146[b]	243[a]	274[a]	18	0.01
3	261[b]	337[a]	321[ab]	25	0.12
4	308[b]	379[a]	345[ab]	27	0.22
5	386[b]	486[a]	418[ab]	29	0.08
6	444	502	485	23	0.23
7	490	523	488	25	0.55

[a,b]Treatment means with different superscripts on the same row are significantly different, $P < 0.10$.
[1]Data are means of 7 replicates with 4 pigs per replicate pen.
[2]NC = negative control diet.
[3]PC = positive control diet.
[4]100MCP = 100% replacement of DW used in the PC diet with MCP.
[5]Overall treatment P-value.

Daily feed intake was increased ($P < 0.10$) for pigs fed the PC diet during phases 2 and 3 compared with pigs fed the NC diet, but pigs fed the 100MCP and PC diets had similar ADFI. Daily gain and G:F were not different ($P > 0.10$) among pigs fed the NC, PC, and 100MCP diets during phases 2, 3, 4, and overall. At the end of the 35-d nursery period, final BW was not affected ($P > 0.10$) by dietary treatment.

Effect of Dried Whey

Data from Exp. 1, 2, and 3 using the NC and PC diets were combined and analyzed to determine the efficacy of DW to increase growth performance of weanling pigs (Table 3.8). Daily gain and ADFI were increased ($P < 0.10$) for pigs fed the PC diet during phases 1, 2, 3, and overall. During phase 2, G:F was reduced ($P = 0.01$) for pigs fed the PC diet, but it was not affected ($P > 0.10$) in any other phase of the experiment. At the end of the 35-d nursery period, final BW was increased ($P < 0.10$) for pigs fed diets with DW.

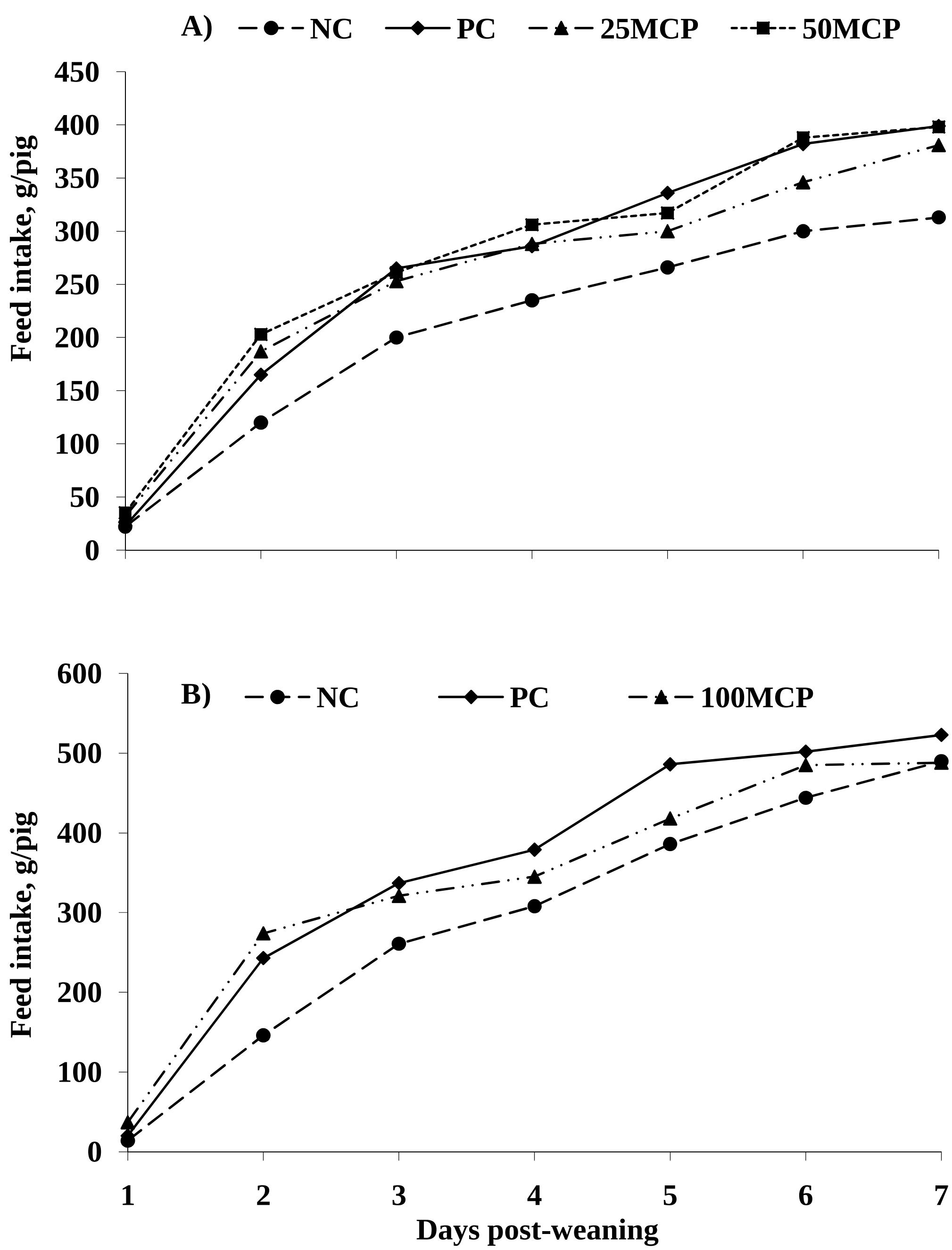

Figure 3.1. Daily feed intake (g/pig) of pigs fed diets with no lactose (NC), with 20% dried whey (PC), with 5% dried whey and 15% MCP (25MCP), and with 10% dried whey and 10% MCP (50MCP) in the combined data of Exp. 1 and 2 (Panel A; Table 3.4). Daily feed intake of pigs fed the NC, PC, and 20% MCP (100MCP) diets in Exp. 3 (Panel B; Table 3.6).

Table 3.7. Effect of dietary dried whey (DW) and its total replacement with milk chocolate product (MCP) on growth performance of weanling pigs in Exp. 3[1]

Item	NC[2]	PC[3]	100MCP[4]	SEM	P-value[5]
	Experimental diets				
Initial BW, kg	6.3	6.3	6.3	0.05	0.58
Final BW, kg	20.8	21.5	21.3	0.35	0.4
Phase 1, d 0 to 7					
ADG, g	183[b]	227[a]	211[ab]	12	0.07
ADFI, g	293[b]	355[a]	337[a]	17	0.06
G:F	0.62	0.64	0.63	0.02	0.77
Phase 2, d 7 to 14					
ADG, g	302	313	302	16	0.86
ADFI, g	496[b]	547[a]	517[ab]	12	0.03
G:F	0.61	0.57	0.58	0.03	0.54
Phase 3, d 14 to 21					
ADG, g	292	320	296	17	0.45
ADFI, g	602[b]	681[a]	651[ab]	20	0.04
G:F	0.49	0.47	0.46	0.02	0.69
Phase 4, d 21 to 35					
ADG, g	647	655	670	18	0.66
ADFI, g	1,160	1,186	1,177	26	0.77
G:F	0.56	0.55	0.57	0.01	0.43
Overall, d 0 to 35					
ADG, g	414	434	429	11	0.45
ADFI, g	742	785	761	17	0.25
G:F	0.56	0.55	0.56	0.01	0.78

[a,b]Treatment means with different superscripts on the same row are significantly different, $P <$ 0.10.
[1]Data are means of 7 replicates with 4 pigs per replicate pen.
[2]NC = negative control diet.
[3]PC = positive control diet.
[4]100MCP = 100% replacement of DW used in the PC diet with MCP.
[5]Overall treatment P-value.

DISCUSSION

Weaning represents a stressful event that commonly results in reduced feed intake and inadequate supply of energy and nutrients for the weanling pig. Bark et al. (1986) reported that the unfamiliar method of feed acquisition and the unfamiliar source of feed (liquid vs. dry feed) were the main causes for the reduced feed intake. Improving feed palatability with the use of sweeteners such as sucrose, whey, or artificial flavors may improve feed intake immediately after weaning. Research has shown that weanling pigs strongly preferred a diet with MCP over a diet with DW (Sullivan et al., 1992; Yang et al., 1997).

Table 3.8. Effect of dietary dried whey (DW) on growth performance of weanling pigs, combined data from Exp. 1, 2, and 3[1]

	Experimental diets			
Item	NC[2]	PC[3]	SEM	*P*-value
Initial BW, kg	6.6	6.6	0.03	0.73
Final BW, kg	21.5	22.1	0.22	0.03
Phase 1, d 0 to 7				
ADG, g	149	187	8	0.01
ADFI, g	237	294	10	0.01
G:F	0.63	0.64	0.02	0.58
Phase 2, d 7 to 14				
ADG, g	359	384	10	0.07
ADFI, g	537	612	11	0.01
G:F	0.66	0.62	0.02	0.01
Phase 3, d 14 to 21				
ADG, g	440	470	11	0.01
ADFI, g	720	809	14	0.01
G:F	0.60	0.58	0.01	0.15
Phase 4, d 21 to 35				
ADG, g	602	601	11	0.97
ADFI, g	1,093	1,101	17	0.72
G:F	0.55	0.55	0.01	0.45
Overall, d 0 to 35				
ADG, g	429	448	6	0.04
ADFI, g	731	776	10	0.01
G:F	0.59	0.58	0.01	0.20

[1]Data are means of 18 replicates with 4 or 5 pigs per replicate pen.
[2]NC = negative control diet.
[3]PC = positive control diet.

Results from our experiments indicated that weanling pigs had greater growth performance when fed diets with DW or MCP compared with pigs fed the NC diet. However, no further improvements were obtained with increasing levels of MCP as a replacement of DW on daily collected wk-1 feed intake post-weaning. The inclusion of DW or its partial replacement with 25 or 50% MCP improved feed intake during all days of wk-1 post-weaning compared with pigs fed a diet with no lactose added. These results are in agreement with published literature

(Mahan, 1993; Mahan and Newton, 1993) that have reported increased feed intake in pigs fed diets with lactose or other highly digestible carbohydrate sources compared with pigs fed diets with no sugars added.

Because no additional benefits or detrimental effects were obtained with partial replacements of DW with MCP in Exp. 1 and 2, a 100% replacement with MCP was conducted in Exp. 3. Feed intake was increased on more days (d 2 to 5) in pigs fed the PC diet than pigs fed the 100MCP diet (d 1 and 2) compared with pigs fed the NC diet. However, feed intake between pigs fed the PC and 100MCP diets were not different during any day of wk-1 post-weaning. Dried whey contains 70% lactose whereas MCP contains 20% lactose and 60% total sugars, mainly from lactose, sucrose, and glucose. Previous studies from our laboratory have shown that products containing a combination of lactose, sucrose, and glucose stimulate feed intake in a similar manner as a high-lactose product. The cocoa portion of MCP seems not to have an additional effect on increasing feed intake compared with DW. However, strong preference of weanling pigs for MCP over DW has been reported (Sullivan et al., 1992; Yang et al., 1997) using a single stimulus preference trial and free choice trials. However, in our experiments, pigs within each replicate pen were exposed to a single dietary treatment rather than allowing pigs to choose among 2 or more diets at the same time.

Our results indicated that partial or total replacement of DW with MCP did not affect growth performance of weanling pigs. Results from the combined data of Exp. 1 and 2, indicated no detrimental effects on ADG, ADFI, or G:F with increasing levels of MCP. Additionally, final BW at the end of the nursery period was not affected in any of the 3 experiments. Similarly, Sullivan et al. (1992) reported that MCP could totally replace DW at a dietary level of 12% with no detrimental effects on growth performance of weanling pigs.

In contrast, Yang et al. (1997) reported that increasing levels of MCP from 0 to 100% replacement of DW linearly decreased growth performance of weanling pigs. These authors recommended that MCP could replace DW at a dietary level no greater than 5% (5% MCP and 15% DW) without affecting growth performance. Greater replacement levels were associated with decreased growth performance. However, results from our Exp. 3 indicated that MCP could totally replace DW with no detrimental effects on growth performance. A possible explanation for the inconsistency of these results may be that in our experiments, supplemental Thr was added to the diets with increasing levels of MCP to meet the Thr:Lys recommended by Baker (1997) for 10- to 20-kg pigs, whereas, Yang et al. (1997) did not include any supplemental Thr. Yang et al. (1997) reported that their analyzed Thr:Lys ratio decreased with increasing levels of MCP and were lower than those recommended by Baker (1997). Therefore, the reduction in growth performance with increased levels of MCP may have been related to a deficiency in Thr. Additionally, our diets were fed in meal form whereas those used by Yang et al. (1997) were pelleted. However, no research has been published evaluating the effect of pelleting on the availability of nutrients in MCP. Also in our experiments, all pigs were offered a common diet with no lactose during the last 2 wk of the nursery period, whereas DW and MCP dietary treatments were fed until the end of the nursery period in Yang et al. (1997), either in 2 or 3 phase feeding programs.

Combined data from Exp. 1, 2, 3 using NC and PC diets demonstrated that the inclusion of DW in diets of weanling pigs improved growth performance and final BW at the end of the nursery period. These data are in agreement with the literature (Mahan, 1993; Tokach et al., 1995; Nessmith et al., 1997; Cromwell et al., 2008) that have reported enhanced growth performance of pigs fed diets with added lactose. Interestingly, this effect was not evident when analyzing each experiment independently, which suggest that increased numbers of replicates are required to elucidate the effects of lactose.

In conclusion, results indicate that partial or total replacement of DW with MCP does not affect overall growth performance of weanling pigs. The inclusion of DW, MCP, or the combination of both improved wk-1 feed intake compared with pigs fed a diet with no lactose added. Milk chocolate product could be considered as an alternative to DW.

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CHAPTER 4

EFFECT OF CANDY OATS ON WEEK-ONE FEED INTAKE AND GROWTH PERFORMANCE OF WEANLING PIGS

INTRODUCTION

Newly weaned pigs usually do not consume adequate amounts of feed to meet their energy requirement for protein deposition, particularly during the first week post-weaning. As a result, growth performance is reduced, intestinal functioning is impaired, and susceptibility to enteric diseases is increased. Additionally, the duration and extent of this undernutrition period may compromise subsequent growth performance and increase the number of days to reach slaughter weight (Le Dividich and Sève, 2001). Therefore, novel feed ingredients aimed to stimulate feed intake immediately after weaning are needed.

Candy oats (**CO**) is a novel carbohydrate source obtained from by-products of the food and candy industries. It contains approximately 60% total sugars and 25% cooked oat-based cereals. Although the exact sugar profile may vary among batches, CO contains more sucrose and glucose than fructose and lactose (Dean, 2010, *personal communication*). The cooked oat-based cereals component of CO, besides its nutritional properties, also improves the non-hygroscopic characteristic of the product and the flowability of the meal. However, limited research has been conducted evaluating the feeding value of CO in diets for weanling pigs.

Whey products such as dried whey and dried whey permeate (**DWP**) are widely used as energy sources in diets for weanling pigs. The efficacy of these products to stimulate feed intake and growth performance of weanling pigs is well documented (Mahan, 1992; Mahan et al., 2004; Naranjo et al., 2010). However, alternative markets for whey products affect their availability and cost. Candy oats is less expensive than whey products and may also be considered an economical source of cooked oats. Therefore, the objective of this research was to determine the effect of partial or total replacements of DWP with CO on wk-1 feed intake and growth performance of weanling pigs.

MATERIALS AND METHODS

The experimental protocol used in this research was approved by the Louisiana State University Agricultural Center Animal Care and Use Committee.

General

Weanling pigs (Yorkshire, Yorkshire × Landrace, or Yorkshire × Landrace × Duroc) were obtained from the Louisiana State University Agricultural Center Swine Unit and housed in an environmentally controlled nursery building. Each pen (0.97 × 1.47 m in size) had hard plastic slotted flooring, 1 nipple waterer, and a 4-hole stainless steel self-feeder. Pigs were fed in a 4-phase feeding program with a duration of 7 d each for phases 1 to 3 and 14 d for phase 4. All pigs and feeders were weighed at the beginning and end of each growth phase for ADG, ADFI, and G:F determination. During the first 7 d post-weaning, all feeders were weighed starting at 0700 for daily collected feed intake determination. Feed in meal form and water were provided for *ad libitum* intake.

Dietary treatments were formulated based on the amino acid (**AA**) and nutrient concentrations provided by International Ingredient Corporation (St. Louis, MO) for DWP and CO. Nutrient values for steam rolled oats (**SRO**) were obtained from the average of 2 analyzed batches previously used by our lab (Table 4.1). Nutrient values reported in the Aminodat 3.0 database by Evonik-Degussa (Hess et al., 2006) were used for all other ingredients. Diets were formulated to contain 1.60, 1.40, 1.40, and 1.20% total Lys for phases 1, 2, 3, and 4 respectively, and to meet or exceed the AA ratios suggested by Baker (1997) for 10- to 20-kg pigs. Soybean meal was held constant among treatments within each phase. Salt and fat levels varied among treatments to maintain the percentage of Na and Cl within an acceptable range and to keep diets isocaloric, respectively. Because CO contains 25% cooked oats, SRO varied among diets to maintain equal levels of total oats among diets within each phase, except for the positive control diet.

One hundred twenty weanling pigs with an average initial BW of 6.4 ± 0.8 kg and weaned at an average age of 21 ± 2 d were allotted to 5 dietary treatments. Each treatment was replicated with 6 pens of 4 pigs per replicate pen. During phases 1 to 3, dietary treatments followed the same design and included 1) positive control diet (**PC**), with total sugars provided by DWP and without SRO, 2) negative control diet (**NC**), without additional sugars and with SRO, 3) NC diet with total sugars provided by DWP (**100DWP**), 4) 50% replacement of the total sugars provided by DWP in the 100DWP diet with CO (**50CO**), and 5) 100% replacement of the total sugars provided by DWP in the 100DWP diet with CO (**100CO;** Tables 4.2 to 4.4). During phase 4, all pigs were fed the same corn and soybean meal diet with no additional sugars added. The levels of total sugars used in all diets, except in the NC diet, were 16, 8, and 3% for phases 1, 2, and 3, respectively. The levels of total oats used in all diets, except in the PC diet, were 7.5, 5, and 2.5% for phases 1, 2, and 3, respectively.

Statistical Analysis

Data were analyzed as a randomized complete block design using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Initial BW was used as the blocking factor and each pen of pigs served as the experimental unit. Treatment means were separated using the PDIFF option of SAS at an α level of $P < 0.10$.

Table 4.1. Nutrient composition of dried whey permeate (DWP), steam rolled oats (SRO), and candy oats (CO) used in diet formulation

Item	DWP[1]	SRO[2]	CO[1]
ME, kcal/kg	3,439	3,465	3,703
Amino acids, %			
Arg	0.07	0.79	0.12
Cys	0.03	0.39	0.06
Gly	---	0.61	---
His	0.03	0.28	0.08
Ile	0.07	0.46	0.09
Leu	0.11	0.90	0.32
Lys	0.08	0.53	0.08
Met	0.01	0.23	0.05
Phe	0.06	0.62	0.13
Ser	---	0.55	---
Thr	0.05	0.41	0.09
Trp	0.02	0.13	0.01
Tyr	0.04	0.37	0.08
Val	0.07	0.64	0.13
Proximate analysis, %			
CP	3.5	11.84	2.5
Fat	0.5	5.53	1.0
Fiber	0.0	2.69	0.5
Ash	10.0	1.78	3.0
Moisture	4.5	12.21	5.0
Total sugars	80.0	0.74	60.0
Minerals, %			
Ca	0.50	0.04	0.04
P	0.84	0.39	0.08
Na	1.05	0.05	---
Cl	1.62	0.09	---

[1]Typical nutrient analysis provided by International Ingredient Corporation (St. Louis, MO).
[2]Average of 2 analyzed batches of SRO used in previous experiments by our lab.

Table 4.2. Composition of phase 1 experimental diets that were fed to weanling pigs (as-fed basis)

Item	Experimental diets				
	PC[1]	NC[2]	100DWP[3]	50CO[4]	100CO[5]
Ingredient, %					
Corn	39.54	50.61	32.23	31.85	31.45
Soybean meal (48% CP)	20.79	20.79	20.79	20.79	20.79
Dried whey permeate (DWP)	20.00	---	20.00	10.00	---
Candy oats (CO)	---	---	---	13.33	26.67
Steam rolled oats	---	7.50	7.50	4.17	0.83
Fishmeal menhaden	7.00	7.00	7.00	7.00	7.00
SDPP[6]	4.00	4.00	4.00	4.00	4.00
Blood cells	2.00	2.00	2.00	2.00	2.00
Dry fat	3.08	3.75	3.00	2.72	2.45
Monocalcium phosphate	0.42	0.94	0.38	0.80	1.21
Limestone	0.71	0.71	0.73	0.65	0.58
Sodium bentonite	0.50	0.50	0.50	0.50	0.50
Vitamin premix[7]	0.50	0.50	0.50	0.50	0.50
Zinc oxide	0.28	0.28	0.28	0.28	0.28
Salt	0.10	0.62	0.10	0.37	0.64
Trace mineral premix[8]	0.10	0.10	0.10	0.10	0.10
Antibiotic[9]	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05
Biolys[10]	0.24	0.14	0.20	0.23	0.26
DL-Met	0.23	0.15	0.20	0.21	0.23
L-Thr	0.10	0.05	0.09	0.10	0.10
L-Ile	0.12	0.07	0.10	0.11	0.12
Calculated composition					
ME, kcal/kg	3,494	3,494	3,494	3,494	3,494
Lys, %	1.60	1.60	1.60	1.60	1.60
Total sulfur AA, %	0.96	0.96	0.96	0.96	0.96
Thr, %	1.04	1.04	1.04	1.04	1.04
Trp, %	0.28	0.30	0.29	0.28	0.28
Ca, %	0.90	0.90	0.90	0.90	0.90
P, %	0.80	0.80	0.80	0.80	0.80
Na, %	0.43	0.43	0.43	0.43	0.43
Cl, %	0.54	0.54	0.55	0.54	0.54
Total sugars, %	16.00	0.00	16.00	16.00	16.00
Total oats, %	0.00	7.50	7.50	7.50	7.50

[1]PC = positive control diet.
[2]NC = negative control diet.
[3]100DWP = NC diet with total sugars provided by DWP.
[4]50CO = 50% replacement of the total sugars provided by DWP in the 100DWP diet with CO.
[5]100CO = 100% replacement of the total sugars provided by DWP in the 100DWP diet with CO.
[6]SDPP = spray-dried plasma protein (AP-920) was obtained from American Protein Corp., Ames, IA.

[7]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[8]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[9]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.
[10]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).

Table 4.3. Composition of phase 2 experimental diets that were fed to weanling pigs (as-fed basis)

Item	Experimental diets				
	PC[1]	NC[2]	100DWP[3]	50CO[4]	100CO[5]
Ingredient, %					
Corn	46.10	50.40	41.25	41.04	40.84
Soybean meal (48% CP)	31.04	31.04	31.04	31.04	31.04
Dried whey permeate (DWP)	10.00	---	10.00	5.00	---
Candy oats (CO)	---	---	---	6.67	13.33
Steam rolled oats	---	5.00	5.00	3.33	1.67
Fishmeal menhaden	6.00	6.00	6.00	6.00	6.00
Dry fat	3.07	3.38	3.00	2.87	2.74
Monocalcium phosphate	0.90	1.15	0.88	1.08	1.29
Limestone	0.67	0.68	0.68	0.65	0.61
Sodium bentonite	0.50	0.50	0.50	0.50	0.50
Vitamin premix[6]	0.50	0.50	0.50	0.50	0.50
Zinc oxide	0.28	0.28	0.28	0.28	0.28
Salt	0.12	0.38	0.10	0.25	0.39
Trace mineral premix[7]	0.10	0.10	0.10	0.10	0.10
Antibiotic[8]	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05
Biolys[9]	0.23	0.17	0.20	0.22	0.23
DL-Met	0.14	0.10	0.13	0.13	0.14
L-Thr	0.05	0.03	0.05	0.05	0.05
Calculated composition					
ME, kcal/kg	3,438	3,438	3,438	3,438	3,438
Lys, %	1.40	1.40	1.40	1.40	1.40
Total sulfur AA, %	0.84	0.84	0.84	0.84	0.84
Thr, %	0.91	0.91	0.91	0.91	0.91
Trp, %	0.27	0.27	0.27	0.27	0.26
Ca, %	0.90	0.90	0.90	0.90	0.90
P, %	0.80	0.80	0.80	0.80	0.80
Na, %	0.20	0.20	0.20	0.20	0.20
Cl, %	0.31	0.31	0.30	0.30	0.30
Total sugars, %	8.00	0.00	8.00	8.00	8.00
Total oats, %	0.00	5.00	5.00	5.00	5.00

[1]PC = positive control diet.
[2]NC = negative control diet.
[3]100DWP = NC diet with total sugars provided by DWP.
[4]50CO = 50% replacement of the total sugars provided by DWP in the 100DWP diet with CO.
[5]100CO = 100% replacement of the total sugars provided by DWP in the 100DWP diet with CO.
[6]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.

[7]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[8]Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.
[9]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).

Table 4.4 Composition of phases 3 and 4 experimental diets that were fed to weanling pigs (as-fed basis)

	Phase 3					
Item	PC[1]	NC[2]	100DWP[3]	50CO[4]	100CO[5]	Phase 4
Ingredient, %						
Corn	50.89	51.90	48.47	48.38	48.31	59.84
Soybean meal (48% CP)	35.68	35.68	35.68	35.68	35.68	32.95
Dried whey permeate (DWP)	3.75	---	3.75	1.88	---	---
Candy oats (CO)	---	---	---	2.50	5.00	---
Steam rolled oats	---	2.50	2.50	1.88	1.25	---
Fishmeal menhaden	3.00	3.00	3.00	3.00	3.00	---
Dry fat	3.04	3.15	3.00	2.95	2.90	2.50
Monocalcium phosphate	0.90	0.99	0.88	0.96	1.04	1.45
Limestone	0.86	0.86	0.87	0.85	0.84	1.08
Sodium bentonite	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix[6]	0.50	0.50	0.50	0.50	0.50	0.50
Salt	0.11	0.20	0.10	0.16	0.21	0.50
Trace mineral premix[7]	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic[8]	0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05	0.05
Biolys[9]	0.21	0.19	0.20	0.21	0.21	0.20
DL-Met	0.13	0.11	0.12	0.13	0.13	0.09
L-Thr	0.03	0.02	0.03	0.03	0.03	0.002
Calculated composition						
ME, kcal/kg	3,440	3,440	3,440	3,440	3,440	3,378
Lys, %	1.40	1.40	1.40	1.40	1.40	1.20
Total sulfur AA, %	0.84	0.84	0.84	0.84	0.84	0.72
Thr, %	0.91	0.91	0.91	0.91	0.91	0.78
Trp, %	0.28	0.28	0.28	0.28	0.28	0.25
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80
P, %	0.70	0.70	0.70	0.70	0.70	0.70
Na, %	0.12	0.12	0.12	0.12	0.12	0.23
Cl, %	0.19	0.19	0.18	0.19	0.19	0.35
Total sugars, %	3.00	0.00	3.00	3.00	3.00	0.00
Total oats, %	0.00	2.50	2.50	2.50	2.50	0.00

[1]PC = positive control diet.
[2]NC = negative control diet.
[3]100DWP = NC diet with total sugars provided by DWP.
[4]50CO = 50% replacement of the total sugars provided by DWP in the 100DWP diet with CO.
[5]100CO = 100% replacement of the total sugars provided by DWP in the 100DWP diet with CO.
[6]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[7]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.

[8] Neo-terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.
[9] Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).

RESULTS

Wk-1 Feed Intake

Daily collected feed intake was increased ($P < 0.01$) more frequently (d 2 to 7) for pigs fed the PC and 50CO diets than for pigs fed the 100DWP (d 4) and 100CO (d 2 to 4) diets compared with pigs fed the NC diet (Table 4.5). Additionally, pigs fed the 50CO diet had increased feed intake ($P < 0.10$) from d 1 to 7 compared with pigs fed the 100DWP and 100CO diets, and from d 1 to 3 compared with pigs fed the PC diet. During the first 7 d post-weaning, pigs fed the 50CO diet had the greatest feed intake while pigs fed the NC diet had the lowest (Table 4.5, Figure 4.1).

Growth Performance

During phase 1, pigs fed the 50CO diet had increased ($P < 0.10$) ADG and ADFI compared with pigs fed the NC or all the other diets (Table 4.6). Pigs fed the PC, 100DWP, and 100CO diets had increased ($P < 0.10$) ADG compared with pigs fed the NC diet. Feed intake was increased ($P < 0.10$) for pigs fed the PC and 100CO diets compared with pigs fed the NC diet, but G:F was not affected among pigs fed these diets ($P > 0.10$).

During phase 2, pigs fed 50CO diet had increased ($P < 0.10$) ADG compared with pigs fed the NC diet but similar ($P > 0.10$) to that of pigs fed all the other diets. Feed intake was increased ($P < 0.10$) for pigs fed the 50CO and 100DWP diets compared with pigs fed the NC diet, but similar ($P > 0.10$) to pigs fed the PC diet. Feed efficiency was not affected ($P > 0.10$) by dietary treatment.

During phase 3, pigs fed the 50CO diet had increased ($P < 0.10$) ADG compared with pigs fed the NC, PC, and 100DWP diets, but similar ($P > 0.10$) to pigs fed the 100CO diet. Feed intake was increased ($P < 0.10$) for pigs fed 50CO diet compared with pigs fed all the other diets. Gain:feed was not affected ($P > 0.10$) by dietary treatment.

Table 4.5. Effect of dietary dried whey permeate (DWP) and its partial or total replacement with candy oats (CO) on feed intake (g/d) during the first 7 d post-weaning[1]

	Experimental diet						
d post-weaning	PC[2]	NC[3]	100DWP[4]	50CO[5]	100CO[6]	SEM	*P*-value[7]
1	40[b]	59[ab]	47[b]	83[a]	55[b]	11	0.09
2	289[b]	194[c]	250[bc]	373[a]	282[b]	26	< 0.01
3	339[b]	271[c]	299[bc]	407[a]	339[b]	24	< 0.01
4	471[ab]	322[d]	386[c]	499[a]	424[bc]	21	< 0.01
5	494[ab]	397[c]	420[bc]	558[a]	443[bc]	31	0.01
6	436[ab]	320[c]	333[c]	465[a]	371[bc]	28	< 0.01
7	414[ab]	310[c]	348[bc]	452[a]	352[bc]	31	0.03

[a,b]Treatment means with different superscripts on the same row are significantly different, $P < 0.10$.
[1]Data are means of 6 reps with 4 pigs per replicate pen.
[2]PC = positive control diet, with DWP, but with no steam rolled oats.
[3]NC = negative control diet, no DWP but with steam rolled oats.
[4]100DWP = NC diet with total sugars provided by DWP.
[5]50CO = 50% replacement of the total sugars provided by DWP in the 100DWP diet with CO.
[6]100CO = 100% replacement of the total sugars provided by DWP in the 100DWP diet with CO.
[7]Overall treatment *P*-value.

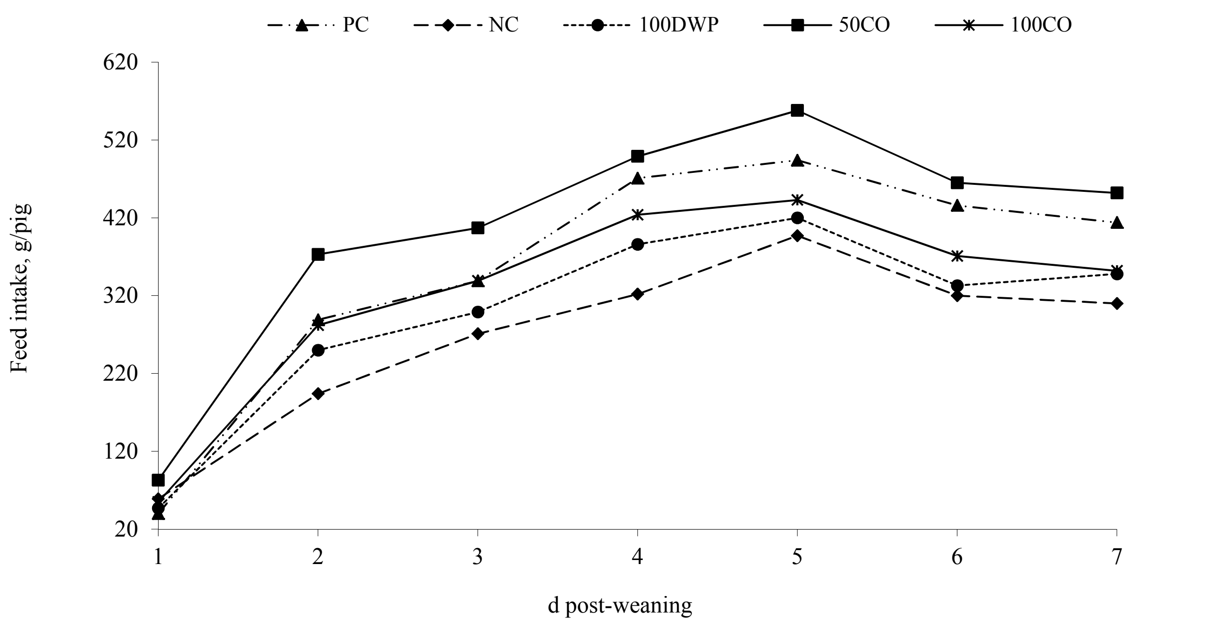

Figure 4.1. Daily feed intake (g/d) of pigs fed 1) positive control diet (PC) with dried whey permeate (DWP) but with no steam rolled oats, 2) negative control diet (NC) with no DWP but with steam rolled oats, 3) NC with DWP (100DWP), 4) 50% replacement of the total sugars provided by DWP in the 100DWP diet with CO (50CO), and 5) 100% replacement of the total sugars provided by DWP in the 100DWP diet with CO (100CO; Table 4.5).

During phase 4, when all pigs were fed the same diet for 14 d, pigs previously fed the 50CO diet had increased ($P < 0.10$) ADG compared with pigs that had consumed the NC diet, but similar ($P > 0.10$) to pigs that had consumed all the other diets. Feed intake and G:F were not affected ($P > 0.10$) by dietary treatment.

In the overall data, pigs fed the 50CO diet had increased ($P < 0.10$) ADG and ADFI compared with pigs fed all the other diets, but G:F was not affected ($P > 0.10$) by diet. At the end of the nursery period, pigs fed the 50CO diet had increased ($P < 0.10$) final BW compared with pigs fed all the other diets.

DISCUSSION

An important goal for a successful feeding program for weanling pigs is to stimulate feed intake immediately after weaning (Tokach et al., 2003). In our experiment, feed intake was effectively stimulated during all 7 d post-weaning with a combination of DWP and CO, each providing 50% of the total sugar level. Pigs fed the NC diet, with no additional sugar, had the lowest feed intake from d 2 to 7. Our results support previous research showing increased feed intake during the first weeks post-weaning with the inclusion of highly digestible carbohydrates (Mahan and Newton, 1993; Mavromichalis et al., 2001; Mahan et al., 2004; Naranjo et al., 2010). Both DWP and CO contain disaccharides and monosaccharides that increase diet palatability and digestibility (Glaser et al., 2000; Cromwell et al., 2008). Dried whey permeate contains 80% lactose, while CO contains a combination of sucrose, glucose, fructose, and lactose to give 60% total sugars. Although the exact sugar profile of CO may vary among batches, it consistently contains greater proportions of sucrose (40 – 60%) and glucose (10 – 30%) and lower levels of fructose (3 – 7.5%) and lactose (0 – 10%; Dean, 2010, *personal communication*).

Table 4.6. Effect of dietary dried whey permeate (DWP) and its partial or total replacement with candy oats (CO) on growth performance of weanling pigs[1]

	Experimental diet						
Item	PC[2]	NC[3]	100DWP[4]	50CO[5]	100CO[6]	SEM	*P*-value[7]
Phase 1, d 0 to 7							
ADG, g	200[b]	166[c]	194[b]	234[a]	199[b]	11	< 0.01
ADFI, g	355[b]	268[d]	297[cd]	405[a]	323[bc]	19	< 0.01
G:F	0.57[b]	0.62[ab]	0.65[a]	0.58[b]	0.62[ab]	0.03	0.29
Phase 2, d 7 to 13							
ADG, g	401[ab]	363[b]	403[ab]	405[a]	389[ab]	17	0.40
ADFI, g	612[ab]	553[b]	628[a]	626[a]	547[b]	27	0.11
G:F	0.66	0.67	0.65	0.65	0.72	0.03	0.56
Phase 3, d 13 to 21							
ADG, g	432[b]	437[b]	417[b]	481[a]	456[ab]	16	0.09
ADFI, g	727[b]	717[b]	726[b]	817[a]	731[b]	24	0.05
G:F	0.60	0.61	0.57	0.59	0.63	0.02	0.53
Phase 4, d 21 to 35							
ADG, g	595[ab]	588[b]	589[ab]	637[a]	607[ab]	20	0.42
ADFI, g	1,124	1,109	1,111	1,190	1,129	42	0.64
G:F	0.53	0.53	0.53	0.54	0.54	0.01	0.98
Overall, d 0 to 35							
ADG, g	444[b]	430[b]	438[b]	481[a]	452[b]	10	0.02
ADFI, g	792[b]	751[b]	777[b]	851[a]	765[b]	19	0.01
G:F	0.56	0.57	0.56	0.57	0.59	0.01	0.51
Final BW, kg	21.9[b]	21.4[b]	21.7[b]	23.2[a]	22.2[b]	0.35	0.02

[a,b]Treatment means with different superscripts on the same row are significantly different, $P < 0.10$.
[1]Data are means of 6 reps with 4 pigs per replicate pen. Pigs had an average initial BW of 6.4 ± 0.8 kg and weaned at an average age of 21 ± 2 d.
[2]PC = positive control diet with DWP, but with no steam rolled oats.
[3]NC = negative control diet, no DWP but with steam rolled oats.
[4]100DWP = NC diet with total sugars provided by DWP.
[5]50CO = 50% replacement of the total sugars provided by DWP in the 100DWP diet with CO.
[6]100CO = 100% replacement of the total sugars provided by DWP in the 100DWP diet with CO.
[7]Overall treatment *P*-value.

Previous studies from our laboratory have consistently shown that carbohydrate products containing a blend of lactose, sucrose, and glucose effectively stimulated feed intake and growth performance of weanling pigs compared with high-lactose sources (Naranjo et al., 2010). In addition, products containing some level of sucrose were more effective in stimulating feed intake than high-lactose sources during the first week post-weaning. Similarly, Glaser et al.

(2000) reported that weanling pigs have a stronger preference for sucrose than for other sugars. In this experiment, pigs fed the 50CO diet consumed 108 and 77% more feed compared with pigs fed the PC and 100DWP diets on d 1 post-weaning, respectively. Feed presence in the intestinal lumen immediately after weaning is essential for maintaining the intestinal structure and function and thus, lactase and sucrase activities (Pluske et al., 1997). Some level of sucrose in combination with lactose, sucrose, and glucose seems to be more beneficial in stimulating feed intake than providing lactose as the only sugar source. However, linear increments in feed intake have been reported during the first 7 d post-weaning with increased levels of lactose ranging from 10 to 35% (Mahan and Newton, 1993). Furthermore, the total replacement of DWP with CO was not as effective in stimulating feed intake, suggesting that some greater level of lactose may be needed to elicit this response.

Another important characteristic of CO is that it also provides 25% cooked oats, which may reduce the level of corn in the diet. Because the newly weaned pig (3 wk of age) has a limited ability to digest the starch and protein from corn, reducing its level of inclusion may be beneficial. Candy oats provided 16% more kcal/kg of ME than DWP, thus reducing the level of corn in the diet. Although diet digestibility was not determined in our experiment, Thacker (1999) reported that small differences in diet digestibility have a strong effect on voluntary feed intake during the first week post-weaning. Similarly, Cromwell et al. (1999) reported that weanling pigs have a strong feed preference for diets containing 10% of a carbohydrate product that contained a blend of sugars and cooked cereals compared with a control diet with 10% dried whey. However, the benefits of replacing corn with further processed carbohydrate sources remains highly controversial. Furthermore, Mahan and Newton (1993) reported that replacing corn with oat groats reduced feed intake from d 0 to 14 post-weaning, but ADG was not affected.

The growth potential of the weanling pig is mostly driven by the level of feed intake. In our experiment, pigs fed the 50CO diet had the greatest feed intake during phases 1 to 3 and in the overall data compared with pigs fed the NC diet. As a result, ADG was increased during all these phases and also during phase 4 when all pigs were fed the same diet for 14 d. At the end of the nursery period, pigs fed the 50CO diet had 6 and 8% greater final BW compared with pigs fed the PC and NC diets, respectively. Conversely, pigs fed the PC diet only had increased ADG and ADFI during phase 1, with no effect in the subsequent phases. However, Cromwell et al. (2008) reported that weanling pigs respond to dietary lactose levels even during the mid to latter phases of the nursery period. Mahan et al. (2004) reported that the lactose levels necessary to maximize growth performance of weanling pigs are: 25 to 30% (d 0 to 7); 15 to 20% (d 7 to 21); and 10 to15% (d 21 to 35). In our experiment, diets were formulated to contain lower levels of total sugars, which may have limited the degree of the response in the DWP diets.

In conclusion, a combination of DWP and CO, each providing 50% of the total sugar level of the diet, effectively stimulated feed intake immediately after weaning resulting in increased growth performance and final BW at the end of the nursery period. Additionally, given that the total replacement of DWP with CO did not negatively affect growth performance of weanling pigs, CO can be considered an alternative carbohydrate source to DWP. Further research is needed to better understand the interactive effects of DWP and CO to stimulate feed intake and growth performance of weanling pigs.

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CHAPTER 5

EFFECT OF SPRAY-DRIED PLASMA PROTEIN AND A NOVEL SWINE NUTRITIONAL SUPPLEMENT ON GROWTH PERFORMANCE OF WEANLING PIGS

INTRODUCTION

The efficacy of spray-dried plasma protein (**SDPP**) to stimulate feed intake and growth performance of pigs during the first 2 wk post-weaning is well documented (Maxwell and Carter, 2001; van Dijk et al., 2001; Torrallardona, 2010). These beneficial effects have been consistent even in experiments in which high quality protein sources with similar or better nutritional value to that of SDPP were used in the control diet (van Dijk et al., 2001; Torrallardona, 2010). Inclusion levels from 4 to 8% SDPP have been recommended to maximize growth performance during the first 2 wk post-weaning (van Dijk et al., 2001; Torrallardona, 2010). Given that SDPP is one of the most expensive protein sources commonly used in diets for weanling pigs, alternative feed ingredients are needed.

Recently, it has become evident that the immunoglobulin fraction (mainly IgG) of SDPP is the main ingredient responsible for the enhanced growth performance of weanling pigs. Pierce et al. (2005) reported that pigs fed diets with SDPP had similar growth performance compared with pigs fed diets supplemented with the IgG-rich fraction of plasma. Similarly, improved intestinal health and reduced expression of proinflammatory cytokines have been reported with the inclusion of both SDPP or the IgG-rich fraction of plasma (Gatnau et al., 1995; Bosi et al., 2004; Pierce et al., 2005; Moretó and Pérez-Bosque, 2009). Because the bioactive components present in SDPP are more concentrated in the isolated IgG-rich fraction of plasma, lower levels of this fraction in combination with less expensive protein sources may elicit a similar growth performance to that obtained with greater levels of SDPP.

Different technological processes have been developed to obtain SDPP and to separate plasma into its different components (Torrallardona, 2010). The efficacy of these products may be affected by the technological process used and the concentration of bioactive immunoglobulins present in the product. Swine nutritional supplement (**SNS**) is a novel feed additive derived completely from animal plasma that goes through a patented chemical process. In this process, the immunoglobulin components are activated by releasing them from their carrier proteins (Hagen, 2010, *personal communication*). Previous experiments have shown that 4% SDPP can be effectively replaced with liquid SNS. However, limited research has been conducted with the powder form of SNS.

Therefore, the objective of this research was to determine the effect of replacing SDPP with a combination of protein sources with SNS supplementation on growth performance of weanling pigs.

MATERIALS AND METHODS

All experimental protocols were approved by the Louisiana State University Agricultural Center Animal Care and Use Committee.

General

Two experiments were conducted to determine the effect of SDPP and SNS on growth performance of weanling pigs. Pigs (Yorkshire, Yorkshire × Landrace, or Yorkshire × Landrace × Duroc) were obtained from the Louisiana State University Agricultural Center Swine Unit and housed in an environmentally controlled nursery building. Each pen (0.97 × 1.47 m in size) had hard plastic slotted flooring, 1 nipple waterer, and a 4-hole stainless steel self-feeder. At weaning, pigs were blocked by initial BW in a randomized complete block design; littermates and sex were balanced across treatments. Pigs were fed in a 3-phase feeding program that lasted from d 0 to 7 for phase 1, d 7 to 21 for phase 2, and d 21 to 35 for phase 3. All pigs and feeders were weighed at the beginning and end of each growth phase to determine ADG, ADFI, and G:F. Feed in meal form and water were provided for *ad libitum* intake.

Table 5.1. Nutrient composition of spray-dried plasma protein (SDPP) and swine nutritional supplement (SNS)

Item	SDPP[1]	SNS[2]
ME, kcal/kg	---	2,502
Amino acids, %		
Arg	4.55	4.50
Cys	2.63	2.54
His	2.55	2.48
Ile	2.71	2.91
Leu	7.61	7.66
Lys	6.84	7.04
Met	0.75	0.68
Phe	4.42	4.44
Thr	4.72	4.42
Trp	1.36	1.33
Tyr	3.53	---
Val	4.94	5.03
Proximate analysis, %		
Fat	2.0	1.92
Moisture	8.0	6.26
Ash	---	23.52
CP	78.0	60.87
Minerals		
Ca, %	0.15	0.11
P, %	1.71	1.09
Na, %	3.02	2.75
Cl, %	1.50	5.89
Cu, ppm	---	12.23
Fe, ppm	55.00	54.46
Zn, ppm	---	14.87

[1]Values reported in NRC (1998).
[2]Analyzed values provided by the supplier of the ingredient.

In both experiments, dietary treatments were formulated to contain 1.38, 1.29, and 1.10% SID Lys for phases 1, 2, and 3, respectively, and to meet or exceed the AA ratios reported by NRC (1998). The same batch of SDPP and SNS was used in Exp. 1 and 2 (Table 5.1). Salt and fat levels varied among treatments to maintain the percentage of Na and Cl within an acceptable range and to keep diets isocaloric, respectively. Diets fed during phases 1 and 2 contained (as-fed basis): dried whey, 22.5 and 12.5%; fishmeal 7 and 4%; zinc oxide, 0.28%; and copper sulfate, 0.07%, respectively, but no antibiotics. The diet fed during phase 3 contained antibiotics, but no zinc oxide or copper sulfate.

Exp. 1

This experiment was conducted to determine the effect of SNS (0.80% phase 1; 0.50% phase 2) as a replacement of SDPP on growth performance of weanling pigs. One hundred-twelve weanling pigs with an average initial BW of 5.8 ± 1.4 kg and weaned at an average age of 19 ± 3 d were allotted to 4 dietary treatments. Each treatment was replicated with 7 pens of 4 pigs per replicate pen. Dietary treatments (Tables 5.2 and 5.3) followed the same design in phases 1 and 2 and included 1) negative control diet (**NC**) with no SDPP or SNS; 2) positive control diet (**PC**) with SDPP; 3) SDPP replacement with SNS supplementation (**SNS**); soy protein concentrate, and red blood cells in phase 1 or red blood cells in phase 2 were used as protein sources to complete the replacement of SDPP; and 4) protein replacement diet (**PR**), which was diet 3, but with no SNS supplementation. In diets 2 to 4, soybean meal (**SBM**) levels were maintained constant across treatments within each phase, whereas the NC diet had slightly more SBM. During phase 3, all pigs were fed the same corn-SBM diet.

Exp. 2

This experiment was conducted to determine the effect of lower levels of SNS (0.27% phase 1; 0.17% phase 2) as a replacement of SDPP on growth performance of weanling pigs. One hundred-sixty weanling pigs with an average initial BW of 5.5 ± 1 kg and weaned at an average age of 19 ± 2 d were allotted to 5 dietary treatments. Each treatment was replicated with 6 pens of 5 or 6 pigs per replicate pen. Dietary treatments used in Exp. 2 followed the same design as those of Exp. 1. The NC and PC diets were the same as those used in Exp. 1. Diet 3 and 4 contained slightly more soy protein concentrate in phase 1 and more red blood cells in phase 2 to compensate for the reduced levels of SNS within each phase compared with Exp. 1. Similar to Exp. 1 in diets 2 to 4, SBM levels were maintained constant across treatments within each phase, but the NC diet had more SBM. Additionally, a fifth diet was included by supplementing the NC diet with SNS at the same level used in diet 3 (**NC+SNS**). Similar to Exp. 1, all pigs were fed the same corn-SBM diet during phase 3 (Tables 5.4 and 5.5).

Statistical Analysis

Data were analyzed as a randomized complete block design using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Initial BW was used as the blocking factor and each pen of pigs served as the experimental unit. Treatment means were separated using the PDIFF option of SAS at an α level of $P < 0.10$.

RESULTS

Exp. 1

During phase 1, pigs fed the PC diet had increased ($P < 0.10$) ADG and G:F compared with pigs fed the NC diet, but similar ($P > 0.10$) to pigs fed the SNS and PR diets (Table 5.6). Feed intake was similar ($P > 0.10$) among pigs fed the PC, NC, and PR diets. However, pigs fed the SNS diet had reduced ($P < 0.10$) ADFI compared with pigs fed PC diet, but similar ($P > 0.10$) to pigs fed the other diets. Pigs fed the PC and SNS diets had increased ($P < 0.10$) G:F compared with pigs fed the NC diet, but similar ($P > 0.10$) to pigs fed the PR diet.

During phase 2, pigs fed the PC diet had similar ($P > 0.10$) ADG compared with pigs fed the NC diet, but reduced ADG ($P < 0.10$) compared with pigs fed the SNS and PR diets. Feed intake was reduced ($P < 0.10$) for pigs fed the PC diet compared with pigs fed the NC and PR diets, but similar to pigs fed the SNS diet. Pigs fed the PC and SNS diets had increased ($P < 0.10$) G:F compared with pigs fed the NC diet but similar ($P > 0.10$) to pigs fed the PR diet.

Table 5.2. Composition of phase 1 experimental diets that were fed to weanling pigs in Exp. 1 (as-fed basis)

			SDPP replacement	
Item	NC[1]	PC[2]	SNS	PR[3]
Ingredient, %				
Corn	40.60	43.95	42.90	43.60
Soybean meal, 46%	23.30	17.50	17.50	17.50
Dried whey[4]	22.50	22.50	22.50	22.50
Fishmeal menhaden	7.00	7.00	7.00	7.00
SDPP[5]	---	4.00	---	---
Soy protein concentrate	---	---	1.95	1.95
Red blood cells[6]	---	---	1.30	1.30
Swine nutritional supplement (SNS)	---	---	0.80	---
Dry fat[7]	3.80	2.85	3.55	3.45
Monocalcium phosphate	0.40	0.20	0.35	0.40
Limestone	0.30	0.38	0.30	0.30
Salt	0.52	0.30	0.45	0.51
Vitamin premix[8]	0.50	0.50	0.50	0.50
Trace mineral premix[9]	0.10	0.10	0.10	0.10
Copper sulfate	0.07	0.07	0.07	0.07
Zinc oxide	0.28	0.28	0.28	0.28
Choline chloride	0.05	0.05	0.05	0.05
Biolys[10]	0.36	0.20	0.20	0.27
DL-Met	0.13	0.09	0.13	0.14
L-Thr	0.11	0.04	0.08	0.10
Calculated composition				
ME, kcal/kg	3,373	3,373	3,373	3,373
SID[11] Lys, %	1.38	1.38	1.38	1.38
SID TSAA, %	0.77	0.77	0.77	0.77
SID Thr, %	0.87	0.85	0.86	0.85
SID Trp, %	0.23	0.24	0.26	0.23
SID Ile, %	0.83	0.82	0.80	0.79
SID Ile:Lys	0.60	0.59	0.58	0.57
Ca %	0.82	0.80	0.82	0.81
P, %	0.75	0.72	0.75	0.73

[1]NC = negative control diet.
[2]PC = positive control diet.
[3]PR = protein replacement diet, with the same levels of protein sources used as replacement of SDPP in the SNS diet, but with no SNS supplementation.
[4]Dried whey was obtained from International Ingredient Corporation (St. Louis, MO).
[5]SDPP = spray-dried plasma protein provided by Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[6]Innomax Porcine red blood cells, provided by Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[7]Fat Pak 100, Milk Specialties Co., Dundee, IL.

[8]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 µg; biotin, 441 µg; vitamin C, 110 µg.
[9]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[10]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).
[11]SID = standardized ileal digestible.

Table 5.3. Composition of phases 2 and 3 experimental diets that were fed to weanling pigs in Exp. 1 (as-fed basis)

	Phase 2				
			SDPP replacement		
Item	NC[1]	PC[2]	SNS	PR[3]	Phase 3
Ingredient, %					
Corn	51.95	53.52	53.45	53.96	57.86
Soybean meal, 46%	24.90	21.80	21.80	21.80	33.67
Dried whey[4]	12.50	12.50	12.50	12.50	---
Fishmeal menhaden	4.00	4.00	4.00	4.00	---
SDPP[5]	---	2.50	---	---	---
Red blood cells[6]	---	---	1.35	1.35	---
Swine nutritional supplement (SNS)	---	---	0.50	---	---
Dry fat[7]	2.85	2.30	2.75	2.65	4.00
Monocalcium phosphate	1.10	1.00	1.10	1.13	1.45
Limestone	0.63	0.68	0.65	0.63	1.07
Salt	0.38	0.21	0.33	0.36	0.25
Vitamin premix[8]	0.50	0.50	0.50	0.50	0.50
Trace mineral premix[9]	0.10	0.10	0.10	0.10	0.10
Copper sulfate	0.07	0.07	0.07	0.07	---
Zinc oxide	0.28	0.28	0.28	0.28	---
Choline chloride	0.05	0.05	0.05	0.05	0.05
Biolys[10]	0.48	0.35	0.35	0.39	0.20
DL-Met	0.12	0.09	0.13	0.14	0.10
L-Thr	0.11	0.06	0.09	0.11	0.01
Antibiotic[11]	---	---	---	---	0.25
Calculated composition					
ME, kcal/kg	3,318	3,318	3,318	3,318	3,443
SID[12] Lys, %	1.30	1.29	1.29	1.29	1.08
SID TSAA, %	0.73	0.72	0.72	0.72	0.65
SID Thr, %	0.79	0.79	0.79	0.79	0.68
SID Trp, %	0.24	0.22	0.21	0.21	0.21
SID Ile, %	0.76	0.77	0.72	0.72	0.76
SID Ile:Lys	0.59	0.60	0.56	0.55	0.71
Ca %	0.84	0.84	0.84	0.84	0.80
P, %	0.77	0.76	0.76	0.76	0.70

[1]NC = negative control diet.
[2]PC = positive control diet.
[3]PR = protein replacement diet, with the same levels of protein sources used as replacement of SDPP in the SNS diet, but with no SNS supplementation.
[4]Dried whey was obtained from International Ingredient Corporation (St. Louis, MO).
[5]SDPP = spray-dried plasma protein provided by Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[6]Innomax Porcine red blood cells, provided by Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[7]Fat Pak 100, Milk Specialties Co., Dundee, IL.

[8]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[9]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[10]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).
[11]Neo-Terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.
[12]SID = standardized ileal digestible.

Table 5.4. Composition of phase 1 experimental diets that were fed to weanling pigs in Exp. 2 (as-fed basis)

			SDPP replacement,		
Item	NC[1]	PC[2]	SNS	PR[3]	NC+SNS
Ingredient, %					
Corn	40.60	43.95	42.93	43.16	40.82
Soybean meal, 46%	23.30	17.50	17.50	17.50	22.85
Dried whey[4]	22.50	22.50	22.50	22.50	22.50
Fishmeal menhaden	7.00	7.00	7.00	7.00	7.00
SDPP[5]	---	4.00	---	---	---
Soy protein concentrate	---	---	2.50	2.50	---
Red blood cells[6]	---	---	1.30	1.30	---
Swine nutritional supplement	---	---	0.27	---	0.27
Dry fat[7]	3.80	2.85	3.45	3.40	3.80
Monocalcium phosphate	0.40	0.20	0.38	0.40	0.38
Limestone	0.30	0.38	0.30	0.30	0.30
Salt	0.52	0.30	0.49	0.51	0.51
Vitamin premix[8]	0.50	0.50	0.50	0.50	0.50
Trace mineral premix[9]	0.10	0.10	0.10	0.10	0.10
Copper sulfate	0.07	0.07	0.07	0.07	0.07
Zinc oxide	0.28	0.28	0.28	0.28	0.28
Choline chloride	0.05	0.05	0.05	0.05	0.05
Biolys[10]	0.36	0.20	0.20	0.23	0.36
DL-Met	0.13	0.09	0.13	0.13	0.13
L-Thr	0.11	0.04	0.08	0.08	0.10
Calculated composition					
Modified ME, kcal/kg	3,373	3,373	3,373	3,373	3,373
SID[11] Lys, %	1.38	1.38	1.38	1.38	1.38
SID Total sulfur AA, %	0.77	0.77	0.77	0.77	0.77
SID Thr, %	0.86	0.85	0.86	0.86	0.86
SID Trp, %	0.23	0.24	0.23	0.23	0.23
SID Ile, %	0.83	0.82	0.81	0.80	0.82
SID Ile:Lys	0.60	0.59	0.59	0.58	0.60
Ca %	0.82	0.80	0.80	0.81	0.82
P, %	0.75	0.72	0.73	0.73	0.74

[1]NC = negative control diet.
[2]PC = positive control diet.
[3]PR = protein replacement diet, with the same levels of protein sources used as replacement of SDPP in the SNS diet, but with no SNS supplementation.
[4]Dried whey was obtained from International Ingredient Corporation (St. Louis, MO).
[5]SDPP = spray-dried plasma protein provided by Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[6]Innomax porcine red blood cells, provided by Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[7]Fat Pak 100, Milk Specialties Co., Dundee, IL.

[8]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[9]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[10]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% $Lys{\cdot}SO_4$).
[11]SID = standardized ileal digestible.

Table 5.5. Composition of phases 2 and 3 experimental diets that were fed to weanling pigs in Exp. 2 (as-fed basis)

	Phase 2					
			SDPP replacement			
Item	NC[1]	PC[2]	SNS	PR[3]	NC+SNS	Phase 3
Ingredient, %						
Corn	51.95	53.52	53.74	53.85	52.44	57.86
Soybean meal, 46%	24.90	21.80	21.80	21.80	24.20	33.67
Dried whey[4]	12.50	12.50	12.50	12.50	12.50	---
Fishmeal menhaden	4.00	4.00	4.00	4.00	4.00	---
SDPP[5]	---	2.50	---	---	---	---
Red blood cells[6]	---	---	1.50	1.50	---	---
Swine nutritional supplement (SNS)	---	---	0.17	---	0.17	---
Dry fat[7]	2.85	2.30	2.65	2.65	2.85	4.00
Monocalcium phosphate	1.10	1.00	1.10	1.13	1.10	1.45
Limestone	0.63	0.68	0.63	0.63	0.65	1.07
Salt	0.38	0.21	0.35	0.36	0.37	0.25
Vitamin premix[8]	0.50	0.50	0.50	0.50	0.50	0.50
Trace mineral premix[9]	0.10	0.10	0.10	0.10	0.10	0.10
Copper sulfate	0.07	0.07	0.07	0.07	0.07	---
Zinc oxide	0.28	0.28	0.28	0.28	0.28	---
Choline chloride	0.05	0.05	0.05	0.05	0.05	0.05
Biolys[10]	0.48	0.35	0.35	0.37	0.50	0.20
DL-met	0.12	0.09	0.14	0.14	0.13	0.10
L-Thr	0.11	0.06	0.10	0.10	0.11	0.01
Antibiotic[11]	---	---	---	---	---	0.25
Calculated composition						
Modified ME, kcal/kg	3,318	3,318	3,318	3,318	3,318	3,443
SID[12] Lys, %	1.30	1.29	1.29	1.29	1.30	1.08
SID Total sulfur AA, %	0.72	0.72	0.73	0.73	0.73	0.65
SID Thr, %	0.79	0.79	0.79	0.79	0.79	0.68
SID Trp, %	0.21	0.22	0.21	0.21	0.21	0.21
SID Ile, %	0.76	0.77	0.72	0.72	0.76	0.76
SID Ile:Lys	0.59	0.60	0.56	0.55	0.58	0.71
Ca %	0.84	0.84	0.83	0.84	0.84	0.80
P, %	0.77	0.76	0.76	0.76	0.77	0.70

[1]NC = negative control diet.
[2]PC = positive control diet.
[3]PR = protein replacement diet, with the same levels of protein sources used as replacement of SDPP in the SNS diet, but with no SNS supplementation.
[4]Dried whey was obtained from International Ingredient Corporation (St. Louis, MO).
[5]SDPP = spray-dried plasma protein provided by Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[6]Innomax porcine red blood cells, provided by Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[7]Fat Pak 100, Milk Specialties Co., Dundee, IL.

[8]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[9]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[10]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).
[11]Neo-Terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.
[12]SID = standardized ileal digestible.

Dietary treatments were only fed during phases 1 and 2; thus, overall growth performance from these 2 phases was also evaluated. In the overall data from d 0 to 21 post-weaning, ADG, and ADFI were not affected ($P > 0.10$) by dietary treatment. Feed efficiency was greater ($P < 0.10$) for pigs fed the PC and SNS diets compared with pigs fed the NC diet, but similar ($P > 0.10$) to pigs fed the PR diet.

During phase 3, when all pigs were fed the same corn-SBM meal diet for 14 d, and in the overall data from d 0 to 35 post-weaning, ADG, ADFI, or G:F were not affected ($P > 0.10$) by dietary treatments. Final BW at the end of the nursery period was similar ($P > 0.10$) among dietary treatments.

Exp. 2

In this experiment, the inclusion levels of SNS were reduced within each phase compared with Exp. 1 and a fifth dietary treatment was included by supplementing the NC diet with SNS but no other proteins. During phase 1, pigs fed the PC diet had similar ($P > 0.10$) ADG compared with pigs fed the NC and SNS diets (Table 5.7). Pigs fed the PR and NC+SNS diets had reduced ($P < 0.10$) ADG compared with pigs fed the PC diet, but similar to pigs fed the other diets. Pigs fed the PC diet had increased ($P < 0.10$) ADFI compared with pigs fed the NC, PR, and NC+SNS diets, but similar ($P > 0.10$) to pigs fed the SNS diet. Feed efficiency was not affected ($P > 0.10$) by dietary treatment.

During phase 2, ADG and G:F were not affected ($P > 0.10$) by dietary treatment. Pigs fed the SNS diet had increased ($P < 0.10$) ADFI compared with pigs fed the PR diet, but similar ($P > 0.10$) to pigs fed the other diets. These same responses were maintained in the overall data from d 0 to 21 post-weaning.

Table 5.6. Effect of swine nutritional supplement (SNS) as a replacement of spray-dried plasma protein (SDPP) on growth performance of weanling pigs in Exp. 1[1]

			SDPP replacement			
Item	NC[2]	PC[3]	SNS	PR[4]	SEM	*P*-value[5]
Initial BW, kg	5.8	5.7	5.8	5.7	0.04	0.39
Final BW, kg	20.6	20.3	21.0	21.0	0.32	0.41
Phase 1, d 0 to 7						
ADG, g	145[b]	173[a]	149[ab]	159[ab]	11	0.27
ADFI, g	306[ab]	317[a]	275[b]	298[ab]	13	0.18
G:F	0.48[b]	0.55[a]	0.56[a]	0.54[ab]	0.03	0.16
Phase 2, d 7 to 21						
ADG, g	422[bc]	416[c]	452[a]	446[ab]	11	0.09
ADFI, g	752[a]	698[b]	728[ab]	755[a]	19	0.16
G:F	0.56[b]	0.60[a]	0.62[a]	0.59[ab]	0.01	0.05
Overall, d 0 to 21						
ADG, g	330	335	351	350	10	0.30
ADFI, g	603	571	577	598	17	0.45
G:F	0.55[b]	0.59[a]	0.61[a]	0.59[a]	0.01	0.03
Phase 3, d 21 to 35						
ADG, g	565	542	561	567	14	0.59
ADFI, g	966	972	992	1,005	20	0.54
G:F	0.59	0.56	0.57	0.56	0.01	0.22
Overall, d 0 to 35						
ADG, g	424	418	435	439	9	0.37
ADFI, g	749	731	743	769	15	0.42
G:F	0.57	0.57	0.59	0.57	0.01	0.49

[a,b]Treatment means with different superscripts on the same row are significantly different, $P < 0.10$.
[1]Data are means of 7 replicates with 4 pigs per replicate pen.
[2]NC = negative control diet.
[3]PC = positive control diet.
[3]PR = protein replacement diet, with the same levels of protein sources used as replacement of SDPP in the SNS diet, but with no SNS supplementation.
[5]Overall treatment *P*-value.

During phase 3, when all pigs were fed the same corn-SBM diet for 14 d, ADG and ADFI were not affected ($P > 0.10$) by dietary treatment. Pigs fed the PC and SNS diets had reduced ($P < 0.10$) G:F compared with pigs fed the NC diet but similar ($P > 0.10$) to pigs fed the PR and NC+SNS diets.

In the overall data from d 0 to 35 post-weaning, ADG was not affected ($P > 0.10$) among pigs fed the NC, PC, SNS, or NC+SNS diets. Pigs fed the PR diet had reduced ($P < 0.10$) ADG compared with pigs fed the NC diet but similar ($P > 0.10$) to pigs fed all other diets. Feed intake was not affected ($P > 0.10$) by dietary treatment. Feed efficiency was reduced ($P < 0.10$) for pigs fed the PC and SNS diet compared with pigs fed the NC and NC+SNS diets but similar ($P > 0.10$) to pigs fed the PR diet. Similar to Exp. 1, final BW at the end of the nursery period was not affected ($P > 0.10$) by dietary treatment.

Table 5.7. Effect of swine nutritional supplement (SNS) as a replacement of spray-dried plasma protein (SDPP) on growth performance of weanling pigs in Exp. 2[1]

			SDPP replacement				
Item	NC[2]	PC[3]	SNS	PR[4]	NC+SNS	SEM	*P*-value[5]
Initial BW, kg	5.6	5.6	5.6	5.6	5.6	0.03	0.47
Final BW, kg	18.0	17.5	17.8	17.2	17.9	0.40	0.57
Phase 1, d 0 to 7							
ADG, g	122[ab]	146[a]	127[ab]	110[b]	120[b]	11	0.23
ADFI, g	255[b]	294[a]	261[ab]	239[b]	255[b]	14	0.14
G:F	0.48	0.50	0.49	0.47	0.47	0.03	0.94
Phase 2, d 7 to 21							
ADG, g	397	380	400	376	405	14	0.47
ADFI, g	636[ab]	637[ab]	678[a]	616[b]	640[ab]	23	0.46
G:F	0.63	0.60	0.59	0.62	0.64	0.02	0.55
Overall, d 0 to 21							
ADG, g	307	300	309	288	312	11	0.56
ADFI, g	504[ab]	518[ab]	534[a]	485[b]	503[ab]	19	0.47
G:F	0.61	0.58	0.58	0.60	0.62	0.02	0.39
Phase 3, d 21 to 33							
ADG, g	503	479	474	462	474	18	0.59
ADFI, g	884	897	890	844	852	34	0.74
G:F	0.57[a]	0.53[b]	0.53[b]	0.55[ab]	0.56[ab]	0.01	0.16
Overall, d 0 to 33							
ADG, g	378[a]	362[ab]	369[ab]	351[b]	371[ab]	11	0.50
ADFI, g	640	654	661	614	627	23	0.59
G:F	0.59[a]	0.56[b]	0.56[b]	0.58[ab]	0.59[a]	0.01	0.12

[a,b]Treatment means with different superscripts on the same row are significantly different, $P < 0.10$.
[1]Data are means of 6 replicates with 5 or 6 pigs per replicate pen.
[2]NC = negative control diet.
[3]PC = positive control diet.
[3]PR = protein replacement diet, with the same levels of protein sources used as replacement of SDPP in the SNS diet, but with no SNS supplementation.
[5]Overall treatment *P*-value.

DISCUSSION

Spray-dried plasma protein is commonly added in diets for weanling pigs to stimulate feed intake and ADG during the first 2 wk post-weaning. Recent reviews indicated that inclusion levels between 4 and 8% SDPP are necessary to effectively elicit these responses (van Dijk et al., 2001; Torrallardona, 2010). Given that SDPP is one of the most expensive protein sources commonly added in diets for weanling pigs, there has been increased interest in understanding its mode of action. Although improvements in diet palatability have been suggested (Ermer et al., 1994), the specific bioactive component of SDPP may be the main ingredient responsible for the enhanced growth performance (Pierce et al., 2005, Torrallardona, 2010). Thus SNS, which is derived completely from animal plasma and contains a concentrated immunoglobulin component, was developed to be used in combination with less expensive protein sources as a replacement of SDPP. The levels of SNS supplementation used in Exp. 1 and 2 were those that maximized the growth performance of weanling pigs in a previous titration experiment using liquid SNS as a replacement of 4% SDPP (data not shown).

Results from our Exp. 1 indicate that during the first 7 d post-weaning, pigs fed the PC diet had increased ADG and G:F compared with pigs fed the NC diet but similar to pigs fed the PR and SNS diets. Feed intake was reduced in pigs fed the SNS diet compared with pigs fed the PC diet but similar to the other diets. The inclusion of either SDPP or SNS during the first 21 d post-weaning did not affect ADG or ADFI during the subsequent dietary phases compared with pigs fed the NC diet. Final BW at the end of the nursery period was not affected by dietary treatment. These results are in agreement with recent reviews that reported that the SDPP effect is more evident during the first 14 d post-weaning, especially during the first 7 d. Similarly, limited carry-over effects in the subsequent dietary phases have been reported (van Dijk et al., 2001). Additionally, the responses to SDPP may be more pronounced in younger pigs, with low health status, and housed under nonsanitary conditions (Coffey and Cromwell, 1995). Because our experiments were conducted under highly sanitary conditions with high health status pigs, the efficacy of SDPP or SNS may have been less evident.

In Exp. 2, the levels of SNS supplementation were reduced compared with those used in Exp. 1 and a fifth diet was included by supplementing the NC diet with SNS. During the first 7 d post-weaning, pigs fed the PC diet had increased ADFI compared with pigs fed the NC diet, but similar to pigs fed the SNS diet. Daily gain was increased by 20% and 4% in pigs fed the PC and SNS diets, respectively, compared with pigs fed the NC diet. Similar to Exp. 1, these improvements were not maintained during the subsequent dietary phases, and in the overall data from d 0 to 35, pigs fed the PC and SNS diets had reduced G:F compared with pigs fed the NC diet. Similar to Exp. 1, final BW at d 35 post-weaning was not affected by dietary treatment.

The first week post-weaning is well recognized as a period of reduced feed intake, growth rate, and upregulation of expression of inflammatory cytokines in the intestine of weanling pigs (Piè et al., 2004). Spray-dried plasma protein or its immunoglobulin component has been shown to reduce the production of mucosal proinflammatory cytokines and thus, reduce the overstimulation of the immune response of weanling pigs (Moretó and Pérez-Bosque, 2009). Increased cytokine production may act in the brain to reduce feed intake and growth of animals. Thus, responses to SDPP or to SNS may be more evident when evaluated under greater disease or management challenging conditions. Given that SDPP is an expensive protein source, and limited carry-over effects were confirmed in our experiments, its inclusion has to be highly evaluated. Under conditions in which pigs are managed properly and reared under high sanitary conditions, the inclusion of SDPP may not be essential. Thus, less expensive high quality proteins may be used such as those used in our PR diet.

Despite some improvements in G:F and ADFI during phase 2 of Exp. 1, the inclusion of SNS did not elicit greater growth performance to that of the other diets. These results are not in agreement with a previous experiment (unpublished data) in which linear improvements in ADG and ADFI during phase 1 and in the overall data with increased levels of SNS were reported. However, in the previous experiment, a liquid form of SNS was used; whereas in our experiment a powder form of SNS was used. Thus, it seems that the process that was used to dry the SNS product, negatively affects its bioactive compounds. Nevertheless, more research is needed to better elucidate the effects of SNS on growth performance of weanling pigs.

In conclusion, these results indicate that the inclusion of SDPP or SNS did not affect growth performance of weanling pigs compared with pigs fed a NC diet. These responses were obtained in high health status pigs housed under high sanitary conditions.

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CHAPTER 6

MAXIMIZING THE USE OF SUPPLEMENTAL AMINO ACIDS IN DIETS FOR WEANLING PIGS: I. SIX- TO TWELVE-KILOGRAM PIGS

INTRODUCTION

Supplemental amino acids (**AA**), mainly L-Lys, DL-Met, L-Thr, and L-Trp, have become increasingly available and at competitive prices for use in swine diets. These AA have been identified as the first 4 limiting AA in corn-soybean meal (**SBM**) diets for growing pigs, and their inclusion may reduce diet cost and N losses to the environment (Southern et al., 2010). However, when these supplemental AA are increased to replace an intact protein source, diets become deficient in other AA, possibly a branched-chain AA (**BCAA**) or His (Boisen, 2003). At this particular period of time, the inclusion of the next limiting AA in diets supplemented with Lys, Met, Thr, and Trp, is not economical. Therefore, it is worthwhile to determine the maximum level of these 4 AA that can be added before the next limiting AA reduces growth performance.

This approach has been previously used in developing practical low crude protein (**CP**)-AA supplemented diets for growing and finishing pigs (Figueroa et al., 2002; Southern et al., 2010), but very limited in diets for weanling pigs. Additionally, reducing CP levels in diets for weanling pigs may improve HCl production in the stomach (Wellock et al., 2008), improve gastrointestinal health, and reduce the incidence of post-weaning diarrhea (Heo et al., 2009). However, the effects on growth performance have been inconsistent. Some suggested that the inclusion of either Ile, Val, or both is necessary to maintain growth performance (Le Bellego and Noblet, 2002; Htoo et al., 2007; Heo et al., 2008; Lordelo et al., 2008), but not others (Opapeju et al., 2008). Nevertheless, these diets may not be economically practical and more research is needed to better understand the precise requirement of the next limiting AA and its interaction with the type of diet used.

Therefore, the objective of this research was to determine the maximum level of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp that can be added in diets for 6- to 12-kg pigs without negatively affecting growth performance. A following paper will be based on the subsequent dietary phase for 13- to 23-kg pigs.

MATERIALS AND METHODS

All experimental protocols were approved by the Louisiana State University Agricultural Center Animal Care and Use Committee.

General

Four experiments were conducted to determine the maximum level of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp that can be added in diets for 6- to 12-kg pigs with no negative effects on growth performance. Yorkshire, Yorkshire × Landrace, or Yorkshire × Landrace × Duroc weanling pigs were obtained from the Louisiana State University Agricultural Center Swine Unit and housed in an environmentally controlled nursery building. Each pen (0.97 × 1.47 m in size) had hard plastic slotted flooring, 1 nipple waterer, and a 4-hole stainless steel self-feeder. Pigs and their environment were monitored at least twice daily.

Experiment 1 was conducted from d 0 to 7 post-weaning; whereas, Exp. 2 to 4 were conducted from d 7 to 21 post-weaning. Pigs were blocked by initial BW (weaning weight in Exp. 1; final BW at d 7 post-weaning in Exp. 2 to 4) and allotted to dietary treatments in a randomized complete block design. Littermates were balanced across treatments and barrows and gilts were equalized among pens within replicates. Pigs and feeders were weighed at the beginning and end of each experimental period for ADG, ADFI, and G:F determination. Feed in meal form and water were supplied for *ad libitum* intake. In Exp. 3 and 4, blood samples were collected from all pigs at the end of the experiment via the anterior vena cava. Blood from each pig was placed into 10-mL tubes (BD Vacutainer; Franklin Lakes, NJ) and placed on ice until all pigs had been bled. Immediately after blood collection, plasma was collected after centrifugation at 3,000 × g at 4°C for 20 min, and samples were frozen until plasma urea nitrogen (**PUN**) analysis (Mathies, 1964) using commercial reagent kits (Pointe Scientific, Canton, MI).

Dietary treatments were formulated based on the analyzed AA values for peanut meal (**PM**) and SBM. The same batch of PM was used in Exp. 1 and 2, and the same batch of SBM was used in Exp. 1 to 4. Nutrient values reported in the Aminodat 3.0 database by Evonik-Degussa (Hess et al., 2006) were used for all other ingredients. All diets were formulated on a standardized ileal digestible (**SID**) basis. In Exp. 1 and 2, diets were formulated to meet or exceed the following SID AA ratios to Lys: 0.60 TSAA, 0.63 Thr, 0.18 Trp (Hess et al., 2006); 0.60 Ile, 0.68 Val, 0.32 His, 0.42 Arg, and 1.0 Leu (Baker, 1997); whereas, in Exp. 3 and 4 the ratios other than those for Met, Thr, and Trp were allowed to float with increasing levels of supplemental L-Lys. In Exp. 1, the basal diet contained the following specialty ingredients (as-fed basis): 15% dried whey, 5% fishmeal, 4% spray-dried plasma protein, 2% red blood cells, and 3% dry fat. In Exp. 2 to 4, the basal diet contained the following specialty ingredients (as-fed basis): 5% dried whey, 2% red blood cells, and 3% dry fat. In all experiments, diets contained antibiotics and were calculated to contain 0.90% Ca, 0.80% P, and 2,000 ppm Zn.

Exp. 1

The purpose of this experiment was to validate PM as a low Lys source that when supplemented with supplemental L-Lys would result in similar growth performance to that of a positive control (**PC**) diet. Therefore, PM could be validated as a low Lys source that could be used in the subsequent Lys requirement study. A total of 120 weanling pigs weaned at an average age of 22 ± 1 d were allotted to 3 dietary treatments. Dietary treatments were fed from d

0 to 7 post-weaning (initial BW = 6.4 ± 0.7 kg) and included 1) PC diet, Lys-adequate (1.40% SID Lys), 2) Lys-deficient PM diet (0.95% SID Lys), and 3) Lys-adequate PM diet (1.40% SID Lys; Table 6.1). Each treatment was replicated with 7 pens of 6 pigs per replicate pen. Soybean meal was chosen as the protein source to be replaced.

Exp. 2

The purpose of this experiment was to estimate the SID Lys requirement of our 6- to 12-kg pigs to prevent overestimating the amount of supplemental L-Lys that can be added in the subsequent experiments. A total of 114 weanling pigs weaned at an average age of 19 ± 2 d were allotted to 6 dietary treatments. During the first 7 d post-weaning, all pigs were fed the same PC diet used in Exp. 1. Dietary treatments were fed from d 7 to 21 post-weaning (initial BW = 7.4 ± 1.2 kg) and included 1 to 5) SID Lys levels from 0.754 to 1.254% at 0.125% increments, and 6) PC diet, formulated to contain 1.254% SID Lys with no PM (Table 6.2). Each treatment was replicated with 5 pens of 3 or 4 pigs per replicate pen. In diets 1 to 5, the amounts of SBM and PM were held constant across treatments, and the incremental levels of SID Lys were provided by Lys·SO_4 additions. Supplemental DL-Met, L-Trp, L-Thr, L-Ile, and L-Val were added to diets when appropriate to meet or exceed the AA ratios previously described.

Exp. 3

The purpose of this experiment was to determine the level of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp, that could be added without negatively affecting growth performance of 6-to 12-kg pigs. A total of 120 weanling pigs weaned at an average age of 17 ± 2 d were allotted to 6 dietary treatments. Similar to Exp. 2, all pigs were fed the same diet during the first 7 d post-weaning. Dietary treatments were fed from d 7 to 21 post-weaning (initial BW = 6.3 ± 0.8 kg) and included 1) control diet with no supplemental L-Lys, and 2 to 6) control diet with 0.049, 0.099, 0.149, 0.198 and 0.248% supplemental L-Lys (Table 6.3). Each treatment was replicated with 5 pens of 4 pigs per replicate pen. In diets 2 to 6, the levels of supplemental L-Lys were provided by 0.098, 0.195, 0.293, 0.391, and 0.489% Lys·SO_4 additions replacing the Lys provided by SBM, respectively. All diets were formulated to contain 1.221% SID Lys. Diet 3, which contained 0.099% supplemental L-Lys, was calculated to exactly meet the 0.60 SID Ile:Lys requirement (Baker, 1997). Diets 4 to 6 were calculated to be deficient in Ile with SID Ile:Lys ratios from 0.57 to 0.52. From diets 1 to 6, CP levels were reduced from 22.95 to 19.49%.

Exp. 4

This experiment had the same objective as Exp. 3. However, greater levels of supplemental L-Lys along with DL-Met, L-Thr, and L-Trp were evaluated until a negative effect on growth performance was obtained. A total of 100 weanling pigs weaned at an average age of 21 ± 2 d were allotted to 5 dietary treatments. Similar to Exp. 2 and 3, pigs were fed the same diet during the first 7 d post-weaning. Dietary treatments were fed from d 7 to 21 post-weaning (initial BW = 6.9 ± 1 kg) and included 1 to 2) the greatest 2 levels of supplemental L-Lys used in Exp 3 (0.198 and 0.248%), and 3 to 5) control diet with 0.298, 0.347, and 0.397% supplemental L-Lys (Table 6.4). Each treatment was replicated with 5 pens of 4 pigs per replicate pen. In diets 1 to 5, the levels of supplemental L-Lys were provided by 0.391, 0.489, 0.587, 0.685, and 0.783% Lys·SO_4 additions replacing the Lys provided by SBM, respectively. All diets were formulated to contain 1.221% SID Lys. All diets calculated to contain less than 0.60 SID Ile:Lys ratio. Diet 3, which contained 0.298% supplemental L-Lys, was calculated to exactly meet the 0.68 SID Val:Lys ratio requirement (Baker, 1997). Diets 4 and 5 were calculated to be deficient in both Ile and Val. From diets 1 to 5, CP levels were reduced from 20.19 to 17.43% CP.

Table 6.1. Composition of experimental diets that were fed to weanling pigs in Exp. 1 (as-fed basis)

	PC[1]	Peanut meal	
	SID[2] Lys, %	SID Lys, %	
Item	1.40	0.95	1.40
Ingredient, %			
Corn	44.45	59.48	57.65
Soybean meal (48% CP)	22.85	---	---
Dried whey[3]	15.00	15.00	15.00
Fishmeal menhaden	5.00	5.00	5.00
SDPP[4]	4.00	4.00	4.00
Red blood cells[5]	2.00	2.00	2.00
Dry fat[6]	3.00	3.00	3.00
Peanut meal	---	7.63	7.63
Monocalcium phosphate	0.86	1.17	1.19
Limestone	0.72	0.72	0.72
Sodium bentonite	0.50	0.50	0.50
Vitamin premix[7]	0.50	0.50	0.50
Zinc oxide	0.28	0.28	0.28
Salt	0.25	0.25	0.25
Trace mineral premix[8]	0.10	0.10	0.10
Antibiotic[9]	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05
Biolys[10]	---	---	0.89
DL-Met	0.17	0.07	0.33
L-Thr	0.01	---	0.25
L-Trp	---	---	0.08
L-Ile	---	---	0.24
Calculated composition			
ME, kcal/kg	3,479	3,468	3,475
Total Lys, %	1.59	1.10	1.55
SID Lys, %	1.40	0.95	1.40
SID Trp, %	0.26	0.18	0.25
SID Thr, %	0.88	0.64	0.88
SID Met, %	0.49	0.31	0.57
SID TSAA, %	0.84	0.58	0.84
SID Val, %	1.14	0.87	0.95
SID His, %	0.68	0.52	0.52
Ca, %	0.90	0.90	0.90
P, %	0.80	0.80	0.80
Na, %	0.42	0.42	0.42
Cl, %	0.53	0.53	0.53

[1]PC = positive control diet.
[2]SID = standardized ileal digestible.
[3]Dried whey, granular obtained from International Ingredient Corporation, Fenton, MO.

[4]SDPP = spray-dried plasma protein (AP-920) was obtained from American Protein Corp., Ames, IA.
[5]Innomax Porcine RBC, Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[6]Fat Pak 100, Milk Specialties Co., Dundee, IL.
[7]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 µg; biotin, 441 µg; vitamin C, 110 µg.
[8]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[9]Neo-Terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.
[10]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).

Table 6.2. Composition of experimental diets that were fed to weanling pigs in Exp. 2 (as-fed basis)

	SID[1] Lys, %					
Item	0.754	0.879	1.004	1.129	1.254	PC[2]
Ingredient, %						
Corn	61.43	61.09	60.60	60.09	59.52	51.93
Peanut meal	15.10	15.10	15.10	15.10	15.10	---
Soybean meal (48% CP)	8.41	8.41	8.41	8.41	8.41	32.79
Dried whey[3]	5.00	5.00	5.00	5.00	5.00	5.00
Red blood cells[4]	2.00	2.00	2.00	2.00	2.00	2.00
Dry fat[5]	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium phosphate	2.04	2.04	2.04	2.05	2.06	1.83
Limestone	1.09	1.09	1.09	1.09	1.09	1.07
Sodium bentonite	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix[6]	0.50	0.50	0.50	0.50	0.50	0.50
Salt	0.25	0.25	0.25	0.25	0.25	0.25
Zinc oxide	0.28	0.28	0.28	0.28	0.28	0.28
Trace mineral premix[7]	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic[8]	0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05	0.05
Biolys[9]	---	0.25	0.50	0.75	0.99	0.20
DL-Met	---	0.08	0.15	0.23	0.31	0.18
L-Thr	---	0.02	0.10	0.19	0.27	0.07
L-Ile	---	---	0.07	0.15	0.23	---
L-Trp	---	---	0.009	0.03	0.06	---
L-Val	---	---	---	---	0.06	---
Calculated composition						
ME, kcal/kg	3,391	3,390	3,388	3,387	3,386	3,409
Total Lys, %	0.87	1.00	1.12	1.25	1.37	1.41
SID Lys, %	0.754	0.879	1.004	1.129	1.254	1.254
SID Met, %	0.23	0.30	0.38	0.45	0.53	0.44
SID TSAA, %	0.45	0.53	0.60	0.68	0.75	0.75
SID Thr, %	0.53	0.55	0.63	0.71	0.79	0.79
SID Trp, %	0.17	0.17	0.18	0.20	0.23	0.26
SID Val, %	0.80	0.80	0.80	0.80	0.85	1.06
SID His, %	0.51	0.51	0.51	0.50	0.50	0.66
Ca, %	0.90	0.90	0.90	0.90	0.90	0.90
P, %	0.80	0.80	0.80	0.80	0.80	0.80
Na, %	0.18	0.18	0.18	0.18	0.18	0.18
Cl, %	0.30	0.30	0.30	0.30	0.30	0.30

[1]SID = standardized ileal digestible.
[2]PC = positive control diet.
[3]Dried whey, granular obtained from International Ingredient Corporation, Fenton, MO.
[4]Innomax Porcine RBC, Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[5]Fat Pak 100, Milk Specialties Co., Dundee, IL.

[6]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[7]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[8]Neo-Terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.
[9]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).

Table 6.3. Composition of experimental diets that were fed to weanling pig in Exp. 3 (as-fed basis)

	Supplemental L-Lys, %					
Item	0.000[1]	0.049	0.099[2]	0.149[3]	0.198[3]	0.248[3]
Ingredient, %						
Corn	49.40	51.31	53.21	55.12	57.03	58.93
Soybean meal (48% CP)	35.70	33.60	31.52	29.42	27.32	25.22
Dried whey[4]	5.00	5.00	5.00	5.00	5.00	5.00
Red blood cells[5]	2.00	2.00	2.00	2.00	2.00	2.00
Dry fat[6]	3.00	3.00	3.00	3.00	3.00	3.00
Monocalcium phosphate	1.76	1.80	1.85	1.89	1.93	1.98
Limestone	1.06	1.06	1.06	1.05	1.05	1.05
Sodium bentonite	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix[7]	0.50	0.50	0.50	0.50	0.50	0.50
Salt	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[8]	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic[9]	0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05	0.05
Zinc oxide	0.28	0.28	0.28	0.28	0.28	0.28
Biolys[10]	---	0.098	0.195	0.293	0.391	0.489
DL-Met	0.139	0.158	0.177	0.196	0.215	0.234
L-Thr	0.011	0.039	0.067	0.002	0.124	0.152
L-Trp	---	---	---	---	---	0.023
Calculated composition						
ME, kcal/kg	3,409	3,408	3,406	3,405	3,404	3,403
Total Lys, %	1.37	1.36	1.36	1.35	1.35	1.34
SID[11] Lys, %	1.22	1.22	1.22	1.22	1.22	1.22
SID Met, %	0.43	0.44	0.45	0.46	0.47	0.48
SID TSAA, %	0.73	0.73	0.73	0.73	0.73	0.73
SID Thr, %	0.77	0.77	0.77	0.77	0.77	0.77
SID Trp, %	0.25	0.24	0.23	0.22	0.22	0.22
SID Val, %	1.04	1.00	0.97	0.94	0.90	0.87
SID His, %	0.65	0.63	0.61	0.59	0.57	0.55
SID Ile:Lys	0.66	0.63	0.60	0.57	0.54	0.52
SID Val:Lys	0.85	0.82	0.80	0.77	0.74	0.71
Ca, %	0.90	0.90	0.90	0.90	0.90	0.90
P, %	0.80	0.80	0.80	0.80	0.80	0.80
Na, %	0.18	0.18	0.18	0.18	0.18	0.18
Cl, %	0.29	0.29	0.29	0.29	0.29	0.29
CP, %	22.95	22.25	21.56	20.87	20.18	19.49

[1]Control diet with no supplemental L-Lys.
[2]This diet exactly met the recommended SID Ile:Lys ratio of 0.60.
[3]These diets were calculated to be deficient in Ile.
[4]Dried whey, granular obtained from International Ingredient Corporation, Fenton, MO.
[5]Innomax Porcine RBC, Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.

[6]Fat Pak 100, Milk Specialties Co., Dundee, IL.
[7]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[8]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[9]Neo-Terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.
[10]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).
[11]SID = standardized ileal digestible.

Table 6.4. Composition of experimental diets that were fed to weanling pigs in Exp. 4 (as-fed basis)

	Supplemental L-Lys, %				
Ingredient, %	0.198[1]	0.248[1]	0.298[2]	0.347[3]	0.397[3]
Corn	57.10	59.00	60.91	62.82	64.72
Soybean meal (48% CP)	27.23	25.13	23.03	20.92	18.82
Dried whey[4]	5.00	5.00	5.00	5.00	5.00
Red blood cells[5]	2.00	2.00	2.00	2.00	2.00
Dry fat[6]	3.00	3.00	3.00	3.00	3.00
Monocalcium phosphate	1.94	1.98	2.03	2.07	2.11
Limestone	1.06	1.06	1.06	1.05	1.05
Sodium bentonite	0.50	0.50	0.50	0.50	0.50
Vitamin premix[7]	0.50	0.50	0.50	0.50	0.50
Salt	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[8]	0.10	0.10	0.10	0.10	0.10
Antibiotic[9]	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05
Zinc oxide	0.28	0.28	0.28	0.28	0.28
Biolys[10]	0.391	0.489	0.587	0.685	0.783
DL-Met	0.213	0.232	0.252	0.271	0.290
L-Thr	0.122	0.151	0.179	0.207	0.235
L-Trp	0.012	0.022	0.033	0.044	0.054
Calculated composition					
ME, kcal/kg	3,406	3,405	3,404	3,403	3,402
Total Lys, %	1.35	1.34	1.34	1.33	1.33
SID[11] Lys, %	1.22	1.22	1.22	1.22	1.22
SID Met, %	0.47	0.48	0.49	0.50	0.51
SID TSAA, %	0.73	0.73	0.73	0.73	0.73
SID Thr, %	0.77	0.77	0.77	0.77	0.77
SID Trp, %	0.22	0.22	0.22	0.22	0.22
SID Val, %	0.90	0.87	0.84	0.80	0.77
SID Ile, %	0.67	0.63	0.60	0.57	0.53
SID His, %	0.57	0.55	0.53	0.51	0.49
SID Ile:Lys	0.55	0.52	0.49	0.46	0.44
SID Val:Lys	0.74	0.71	0.68	0.66	0.63
Ca, %	0.90	0.90	0.90	0.90	0.90
P, %	0.80	0.80	0.80	0.80	0.80
Na, %	0.18	0.18	0.18	0.18	0.18
Cl, %	0.29	0.29	0.29	0.29	0.29
CP, %	20.19	19.49	18.81	18.12	17.43

[1]These diets were the 2 greatest levels of supplemental L-Lys evaluated in Exp. 3 and were calculated to be deficient in Ile compared with the recommended SID Ile:Lys ratio of 0.60.
[2]This diet was deficient in Ile and exactly met the recommended SID Val:Lys ratio of 0.68.
[3]These diets were calculated to be deficient in Ile and Val.
[4]Dried whey, granular obtained from International Ingredient Corporation, Fenton, MO.

[5]Innomax Porcine RBC, Innovative Proteins: A division of PMI Nutrition International LLC, Brentwood, MO.
[6]Fat Pak 100, Milk Specialties Co., Dundee, IL.
[7]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 µg; biotin, 441 µg; vitamin C, 110 µg.
[8]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[9]Neo-Terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.
[10]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% $Lys{\cdot}SO_4$).
[11]SID = standardized ileal digestible.

Statistical Analysis

Data from all experiments were analyzed as randomized complete block designs using the GLM procedure (SAS Inst. Inc., Cary, NC). Initial BW was used as the blocking factor and each pen of pigs served as the experimental unit. In Exp. 1, 3, and 4, treatment means were separated using the PDIFF option of SAS with an α at 0.10. In Exp. 2, 3, and 4, orthogonal contrast statements were used to determine linear and quadratic effects of graded levels of either SID Lys or supplemental L-Lys. In Exp.2, ADG data were fitted to a single slope model using PROC NLIN to estimate the SID Lys requirement.

RESULTS

Exp. 1

There were no differences ($P > 0.10$) in ADG and ADFI among pigs fed the PC diet and pigs fed the PM-deficient or PM-adequate diets (Table 6.5). However, pigs fed the PM-deficient diet had reduced ($P < 0.10$) G:F compared with pigs fed the PC diet. Gain:feed was restored ($P > 0.10$) to the same level of pigs fed the PC diet in pigs fed the PM-adequate diet. Based on the G:F data, PM was validated as a low Lys source that when supplemented with supplemental L-Lys results in similar growth performance to that of a PC diet. Therefore, PM was used in the subsequent Lys requirement study.

Exp. 2

Increasing SID Lys levels from 0.754 to 1.254% linearly increased ($P < 0.01$) ADG, ADFI, G:F, and final BW (Table 6.6). There were no quadratic effects ($P > 0.10$) in any of these variables. However, based on ADG data, the single slope broken-line model yielded a SID Lys requirement of 1.221% ($P = 0.02$). There were no differences between pigs fed the PM diet formulated to contain 1.254% SID Lys and pigs fed the PC diets formulated to contain the same SID Lys level, but with no PM.

Table 6.5. Effect of supplementing a Lys deficient peanut meal diet with supplemental L-Lys on growth performance of weanling pigs from d 0 to 7 post-weaning in Exp. 1[1]

	PC[2]	Peanut meal			
	SID[3] Lys, %	SID Lys, %			
Item	1.40	0.95	1.40	SEM	*P*-value[3]
ADG, g	243	219	227	12	0.36
ADFI, g	305	306	282	12	0.31
G:F	0.80[a]	0.72[b]	0.80[a]	0.02	0.01
Final BW, kg	8.03	7.89	7.87	0.09	0.35

[a,b]Treatment means with different superscripts on the same row are significantly different, $P < 0.10$.
[1]Data are means of 7 replicates with 6 pigs per replicate pen. Pigs were weaned at average age of 22 ± 1 d and had an average initial BW of 6.4 ± 0.7 kg.
[2]PC = positive control diet.
[3]SID = standardized ileal digestible.
[3]Overall treatment *P*-value.

Table 6.6. Effect of graded levels of standardized ileal digestible (SID) Lys on growth performance of weanling pigs from d 7 to 21 post-weaning in Exp. 2[1]

	SID Lys, %							
Item	0.754	0.879	1.004	1.129	1.254	PC[2]	SEM	*P*-value[3]
ADG,[4,5] g	257	329	364	399	440	449	17	0.01
ADFI,[4] g	620	781	700	737	804	782	29	0.01
G:F[4]	0.42	0.42	0.52	0.54	0.55	0.57	0.01	0.01
Final BW,[4] kg	11.11	11.99	12.49	13.08	13.70	13.71	0.26	0.01

[1]Data are means of 5 replicates with 3 or 4 pigs per pen. Pigs were weaned at an average age of 19 ± 2 d. The average initial BW at d 7 post-weaning was 7.4 ± 1.2 kg.
[2]PC= positive control diet formulated to contain 1.254% SID Lys.
[3]Overall treatment *P*-value.
[4]SID Lys linear effect, $P < 0.01$, excluding the PC diet.
[5]The single slope broken-line model yielded an estimated requirement of 1.221% SID Lys for ADG ($P = 0.02$).

Exp. 3

To prevent overestimating the amount of supplemental L-Lys along with DL-Met, L-Thr, and L-Trp that can be added in diets for 6- to12 -kg pigs, diets were formulated to contain 1.221% SID Lys. There were no linear or quadratic effects ($P > 0.10$) in ADG, ADFI, or G:F with supplemental L-Lys levels from 0 to 0.248% (Table 6.7). Similarly, final BW at d 21 post-weaning was not affected ($P > 0.10$) by dietary treatment. However, PUN was linearly decreased ($P < 0.01$) with the increasing levels of supplemental L-Lys.

Table 6.7. Effect of graded levels of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp on growth performance of weanling pigs from d 7 to 21 post-weaning in Exp. 3[1]

	Supplemental L-Lys, %							
Item	0.000	0.049	0.099	0.149	0.198	0.248	SEM	*P*-value[2]
ADG, g	358	362	386	358	351	356	14	0.38
ADFI, g	861	787	857	822	819	893	45	0.61
G:F	0.42	0.47	0.46	0.44	0.43	0.41	0.03	0.83
Final BW, kg	11.3	11.3	11.8	11.3	11.3	11.3	0.21	0.60
PUN,[3] mg/dL	11.93	10.08	8.97	6.69	4.62	4.03	0.48	0.01

[1]Data are means of 5 replicates with 4 pigs per replicate pen. Pigs were weaned at an average age of 17 ± 2 d. The average initial BW at d 7 post-weaning was 6.3 ± 0.8 kg.
[2]Overall treatment *P*-value
[3]Supplemental L-Lys linear effect, $P < 0.01$.

Exp. 4

Because growth performance was not affected with supplemental L-Lys levels up to 0.248% in Exp. 3, greater inclusion levels were evaluated in Exp. 4. The 2 highest levels of inclusion from Exp. 3 were used as the starting point in this experiment. Increasing supplemental L-Lys from 0.198 to 0.397% linearly decreased ($P < 0.05$) ADG, G:F, final BW, and PUN (Table 6.8). There were no linear or quadratic effects ($P > 0.10$) in ADFI. Pigs fed diets with supplemental L-Lys levels of 0.198, 0.248, and 0.298% had similar ($P > 0.10$) ADG, but G:F started to decrease in pigs fed diets with 0.248% supplemental L-Lys compared with pigs fed diets with 0.198% supplemental L-Lys. Final BW was not affected ($P > 0.10$) in pigs fed diets with supplemental L-Lys levels from 0.198 to 0.397%.

DISCUSSION

To successfully develop low CP-AA supplemented diets for pigs, it is necessary to know 1) the Lys requirement, 2) the ratio of the required AA relative to Lys, 3) the response variable to use, and 4) force supplemental AA into the diet until a negative response is obtained (Southern et al., 2010). This basic approach was used in our research to estimate the maximum level of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp that can be added in diets for 6- to 12-kg pigs.

Table 6.8. Effect of graded levels of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp on growth performance of weanling pigs from d 7 to 21 post-weaning in Exp. 4[1]

	Supplemental L-Lys, %						
Item	0.198[2]	0.248[2]	0.298	0.347	0.397	SEM	*P*-value[3]
ADG,[4] g	376[ab]	384[a]	379[ab]	351[bc]	344[c]	12	0.13
ADFI, g	615[b]	718[a]	682[ab]	675[ab]	696[a]	30	0.20
G:F[4]	0.62[a]	0.54[bc]	0.56[b]	0.52[bc]	0.50[c]	0.02	0.003
Final BW,[4] kg	12.22[a]	12.20[a]	12.16[ab]	11.81[ab]	11.72[b]	0.19	0.32
PUN,[4] mg/dL	5.87[a]	4.51[b]	3.77[c]	3.07[d]	3.02[d]	0.24	0.01

[a,b]Treatment means with different superscripts on the same row are significantly different, *P* < 0.10.
[1]Data are means of 5 replicates with 4 pigs per replicate pen. Pigs were weaned at an average age of 21 ± 2 d. The average initial BW at d 7 post-weaning was 6.9 ± 1 kg.
[2]These diets were the greatest level of supplemental L-Lys used in Exp. 3.
[3]Overall treatment *P*-value.
[4]Supplemental L-Lys linear effect, *P* ≤ 0.03.

To estimate the Lys requirement of our pigs, we first validated PM as a low Lys source that when supplemented with supplemental L-Lys would result in similar growth performance to that of a PC diet. Soybean meal was chosen as the protein source to be replaced as some specialty proteins may not only serve as a source of highly digestible AA, but also may improve diet palatability and provide immunocompetence to pigs (Tokach et al., 2003). Additionally, high inclusion levels of SBM may lead to intestinal hypersensitivity reactions and decreased growth performance (Li et al., 1990). Supplementing the PM deficient diet with supplemental L-Lys resulted in similar G:F compared with pigs fed the PC diet. Thus, PM was validated as low Lys source that could be used in subsequent Lys requirement studies. Similarly, Liu et al. (2007) successfully used PM to reduce the total Lys level of a basal diet to compare the bioefficacy of Lys from L-Lys·SO_4 and L-Lys·HCl in diets for 10- to 20-kg pigs. Peanut meal supplies a good balance of all essential AA with the exception of Lys. In a previous experiment (data not shown) we were unable to validate sunflower meal or PM as low Lys sources, as the deficient diets were formulated to contain 1.15% SID Lys, Thus, in Exp. 1, the SID Lys level used in the deficient diet was 0.95%.

In Exp. 2, SID Lys levels from 0.754 to 1.254% were used. The SID Lys requirement for our 6-to 12-kg pigs was estimated at 1.221% using the single slope broke-line model. However, in a previous experiment from our lab, Dean et al. (2007) reported that the SID Lys requirement of 6- to12-kg pigs was 1.40% using diets with corn gluten meal and with different concentrations of specialty proteins than those used in our experiment. Nevertheless, in our experiment there were no differences among pigs fed diets with SID Lys levels of 1.129 and 1.254% and pigs fed the PC diet. Therefore, the estimated SID Lys requirement does not exceed the Lys requirement of our current genotype pig and prevents overestimating the levels of supplemental AA that can be added in the subsequent experiments. Recent published estimates of the SID Lys requirements for pigs less than 20 kg are highly variable (Dean et al., 2007; Kendall et al., 2008), but consistently greater than those in the NRC (1998).

Once the Lys requirement was estimated, Exp. 3 and 4 were conducted to determine the maximum level of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp that can be added without negatively affecting growth performance of 6- to 12-kg pigs. In Exp. 3, supplemental L-Lys levels from 0 to 0.248% did not negatively affect ADG, ADFI, G:F, or final BW. However, the diets with 0.149 to 0.248% supplemental L-Lys calculated to contain SID Ile:Lys ratios lower than 0.60, which was previously recommended for 10- to 20-kg pigs (Baker, 1997). Furthermore, PUN was linearly decreased as dietary protein was reduced, indicating a more efficient utilization of N. Because a negative response in growth performance was not obtained in Exp. 3, greater levels of supplemental L-Lys were used in Exp. 4. The diets with 0.198 and 0.248% supplemental L-Lys were used as control diets for Exp. 4.

In Exp. 4, supplemental L-Lys levels from 0.198 to 0.387% linearly decreased ADG, G:F, final BW, and PUN. Daily gain was similar among pigs fed diets with supplemental L-Lys levels from 0.198 to 0.298%, but it was reduced at greater levels of supplemental L-Lys. The 0.298% supplemental L-Lys diet calculated to contain a SID Ile:Lys ratio of 0.49 and a SID Val:Lys ratio of 0.68. Based on G:F data, supplemental L-Lys levels greater than 0.198% reduced G:F. The 0.198% supplemental Lys diet calculated to contain a SID Ile:Lys ratio of 0.55. These results suggest that a SID Ile:Lys ratio of 0.60 may be too high, and a ratio less than 0.55 may negatively affect feed efficiency, but not ADG. Similar to Exp. 3, PUN was linearly decreased as dietary protein was reduced, indicating a more efficient utilization of N. Final BW was similar among pigs fed diets with supplemental L-Lys levels from 0.198 to 0.347% supplemental L-Lys. Therefore, the maximum levels of supplemental AA that can be added in diets vary depending on the response variable used.

Previous experiments evaluating low CP-AA supplemented diets have suggested that supplementation with Ile or Val, or both is necessary to maintain growth performance of weanling pigs (Le Bellego and Noblet, 2002, Htoo et al., 2007; Heo et al., 2008). However, estimates on the optimum SID Ile:Lys ratio for weanling pigs have been inconsistent. Kerr et al. (2004) estimated a digestible Ile:Lys ratio of 0.61 for 7- to11-kg pigs based on the average of some performance variables using diets containing red blood cells. Some researchers suggested that Ile requirements estimates obtained using red blood cell-based diets may be overestimated as an excess of one BCAA may affect the utilization of other BCAA (Dean et al., 2005; Barea et al., 2009). Conversely, Barea et al. (2009) estimated that the SID Ile:Lys ratio was not greater than 0.50 for 11- to 23-kg pigs fed corn-soybean meal based diets with a moderate BCAA content.

These researchers were not able to confirm that the Ile requirement was affected by the BCAA content of the diet. Conversely, Wiltafsky et al. (2009) reported that the optimal SID Ile:Lys ratio depends on diet composition and is increased in diets with excess Leu. These researchers reported that the SID Ile:Lys ratio for 8- to 25-kg pigs was 0.59 using diets with 7.5% spray-dried blood cells, and 0.54% using a corn gluten meal based diet. In our Exp. 2 to 4, only 2% red blood cells were included in the basal diet. Pigs at this BW range (6 to12 kg) have a more mature digestive system and the inclusion of specialty products can be minimized to reduce cost and to shift pigs to simple corn-SBM diets in the subsequent phases (Tokach et al., 2003). It seems that the inclusion of 2% red blood cells does not increase the Ile requirement, and thus an optimum SID Ile:Lys for maintaining ADG, may not be greater than 0.50. This hypothesis is consistent with previous SID Ile:Lys estimates using diets with moderate BCAA (Barea et al., 2009).

In conclusion, supplemental L-Lys levels up to 0.298 (0.59% Lys·$SO_{4;}$ 0.38% Lys·HCl) or 0.198% (0.39% Lys·$SO_{4;}$ 0.25% Lys·HCl), along with DL-Met, L-Thr, and L-Trp can be added in diets for 6- to 12-kg pigs without negatively affecting ADG or G:F, respectively. Additionally, the optimum SID Ile:Lys ratio may not be greater than 0.55 in diets containing low levels of red blood cells.

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CHAPTER 7

MAXIMIZING THE USE OF SUPPLEMENTAL AMINO ACIDS IN DIETS FOR WEANLING PIGS: II. THIRTEEN- TO TWENTY-THREE KILOGRAM PIGS

INTRODUCTION

Supplemental amino acids (**AA**), mainly L-Lys, DL-Met, L-Thr, and L-Trp, have become increasingly available and at prices that often merit their inclusion in pig diets. Several experiments have been conducted to optimize the use of these 4 supplemental AA in corn-soybean meal (**SBM**) diets for growing pigs (Figueroa et al., 2002; Southern et al., 2010), but not extensively in diets for weanling pigs. However, there has been increased interest in reducing excess N in diets for weanling pigs as it may not only reduce N losses to the environment, but may also improve gastrointestinal health (Htoo et al., 2007) and reduce the incidence of diarrhea (Heo et al., 2009).

At this particular period of time, the most cost effective approach to develop low crude protein (**CP**) diets for pigs is to maximize the use of supplemental L-Lys, DL-Met, L-Thr, and L-Trp before the next limiting AA (Ile, Val, or His) reduces growth performance; especially if diets are fed for extended periods of time. Previously we have determined the maximum level of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp that can be added in diets for 6- to 12-kg pigs using corn-SBM diets with 5% dried whey and 2% red blood cells. After this dietary phase, weanling pigs usually at 11 kg, are typically switched to a less expensive corn-SBM diet until a nursery exit weight of 23 kg. Because this diet is consumed in the greatest quantities, it usually accounts for over 50% of the total feed cost from weaning to 23 kg (Tokach et al., 2003). Therefore, optimizing the use of supplemental AA in this dietary phase may be cost effective.

The objective of this research was to determine the maximum level of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp that can be added in diets for13- to 23-kg pigs without negatively affecting growth performance.

MATERIALS AND METHODS

All experimental protocols were approved by the Louisiana State University Agricultural Center Animal Care and Use Committee.

General

Four experiments were conducted to determine the maximum level of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp that can be added in diets for 13- to 23-kg pigs without negatively affecting growth performance. Pigs (Yorkshire, Yorkshire × Landrace, or Yorkshire × Landrace × Duroc) were obtained from the Louisiana State University Agricultural Center Swine Unit and housed in an environmentally controlled nursery building. Each pen (0.97 × 1.47 m in size) had hard plastic slotted flooring, 1 nipple waterer, and a 4-hole stainless steel self-feeder. Pigs and their environment were monitored at least twice daily. Average weaning age among experiments ranged from 17 to 21 d.

From d 7 to 21 post-weaning, all pigs were fed the same semi-complex diet formulated to meet or exceed the nutrient requirements for 5- to 10-kg pigs (NRC, 1998). Experiments started on d 21 post-weaning and were either 7 (Exp. 1 and 2) or 14 (Exp. 3 and Exp. 4) d in duration. Pigs were weighed and allotted to their respective pens based on BW, sex, and ancestry 3 or 4 d before the initiation of each experiment; thus, social hierarchies within each pen could be established. Pigs and feeders were weighed at the beginning (appropriate blocking was checked) and end of each experimental period for ADG, ADFI, and G:F determination. Feed in meal form and water were supplied for *ad libitum* intake. In Exp. 3, blood samples were collected from all pigs at the end of the experiment via the anterior vena cava. Blood from each pig was placed into

10-mL tubes (BD Vacutainer; Franklin Lakes, NJ) and placed on ice until all pigs had been bled. Immediately after blood collection, plasma was collected after centrifugation at 3,000 × g at 4°C for 20 min, and samples were frozen until plasma urea nitrogen (**PUN**) analysis (Mathies, 1964) using commercial reagent kits (Pointe Scientific, Canton, MI).

Dietary treatments were formulated based on the analyzed AA values for peanut meal (**PM**) in Exp. 1, and soybean meal (**SBM**) in Exp. 1 to 4. The same batch of SBM was used in all experiments. Nutrient values reported in the Aminodat 3.0 database by Evonik-Degussa (Hess et al., 2006) were used for all other ingredients. All diets were formulated on a standardized ileal digestible (**SID**) basis. In Exp. 1, diets were formulated to meet or exceed the following SID AA ratios to Lys: 0.60 TSAA, 0.63 Thr, 0.18 Trp (Hess et al., 2006); 0.60 Ile, 0.68 Val, 0.32 His, 0.42 Arg, and 1.0 Leu (Baker, 1997). In Exp. 2 to 4, supplemental DL-Met, L-Thr, and L-Trp were increased as levels of supplemental L-Lys were increased to meet the ratios previously described for these AA. However, AA ratios for the other essential AA were allowed to float with increasing levels of supplemental L-Lys. All diets contained antibiotics and were calculated to contain 0.80% Ca and 0.70% P.

Exp. 1

The purpose of this experiment was to estimate the SID Lys requirement of our 13-kg pigs to prevent overestimating the amount of supplemental L-Lys that can be added in the subsequent experiments. A total of 150 weanling pigs with an average initial BW of 13.6 ± 2 kg were allotted to 6 dietary treatments 1 to 5) SID Lys levels from 0.700 to 1.200% at 0.125% increments using corn-SBM-PM-based diets, and 6) positive control diet (**PC**) formulated to contain 1.200% SID Lys without PM (Table 7.1). Each treatment was replicated with 5 pens of 5 pigs per replicate pen. In a previous experiment from our lab, PM was validated as a low Lys source that when supplemented with supplemental L-Lys results in similar growth performance to that of a positive control diet. Thus, PM could be used in Lys requirement studies. In diets 1 to 5, equal amounts of SBM and PM were used across treatments and the incremental levels of SID Lys were provided by Lys·SO_4 additions. Supplemental DL-Met, L-Trp, L-Thr, L-Ile, and L-Val were added when appropriate to meet or exceed the AA ratios previously described.

Exp. 2

The purpose of this experiment was to determine the level of supplemental L-Lys along with DL-Met, L-Thr, and L-Trp, that could be added without negatively affecting growth performance of 13-kg pigs. A total of 80 weanling pigs with an average initial BW of 13.3 ± 2 kg were allotted to 5 dietary treatments calculated to contain 1 to 5) 0.100 (**control**), 0.146, 0.192, 0.238, and 0.284% supplemental L-Lys, respectively (Table 7.2). In diets 1 to 5, the levels of supplemental L-Lys were provided by 0.197, 0.288, 0.379, 0.470, and 0.561% Lys·SO_4 additions replacing the Lys provided by SBM, respectively. Each treatment was replicated with 4 pens of 4 pigs per replicate pen. All diets were formulated to contain 1.075% SID Lys. Diet 4, which contained 0.238% supplemental L-Lys, was calculated to be slightly above the recommended 0.60 SID Ile:Lys ratio and to exactly meet the recommended 0.68 SID Val:Lys ratio (Baker, 1997). Diet 5 which contained 0.284% supplemental L-Lys, was calculated to be deficient in Ile and Val. From diets 1 to 6, CP levels were reduced from 21.01 to 18.34%.

Exp. 3

This experiment had the same objective as Exp. 2, but greater levels of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp were used. A total of 100 weanling pigs with an average initial BW of 13.3 ± 1.7 kg were allotted to 5 dietary treatments 1) control diet used in Exp. 2; 2 to 3) the 2 greatest levels of supplemental L-Lys used in Exp. 2 (0.238 and 0.284%); and 4 to 5) 0.331 and 0.377% supplemental L-Lys, respectively (Table 7.2). In diets 1 to 6, the levels of supplemental L-Lys were provided by 0.197, 0.470, 0.561, 0.652, and 0.743% Lys·SO_4

additions replacing the Lys provided by SBM, respectively. Each treatment was replicated with 5 pens of 4 pigs per replicate pen. All diets were formulated to contain 1.075% SID Lys. In Diets 3 to 5, the calculated SID Ile:Lys and SID Val:Lys ratios ranged from 0.59 to 0.53 and 0.65 to 0.60, respectively. From diets 2 to 5, CP levels were reduced from 19.00 to 17.01%.

Exp. 4

This experiment had the same objective as Exp. 2 and 3, but greater levels of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp, were evaluated. A total of 120 weanling pigs with an average initial BW of 14.7 ± 2 kg were allotted to 5 dietary treatments 1) control diet used in Exp. 2 and 3; 2 to 3) the 2 greatest levels of supplemental L-Lys used in Exp 3 (0.331 and 0.377%); and 4 to 5) 0.423 and 0.469% supplemental L-Lys, respectively (Table 7.2). In diets 1 to 5, the levels of supplemental L-Lys were provided by 0.197, 0.652, 0.743, 0.834, and 0.925% Lys·SO_4 additions replacing the Lys provided by SBM, respectively. Each treatment was replicated with 6 pens of 4 pigs per replicate pen. All diets were formulated to contain 1.075% SID Lys. In diets 2 to 5, the calculated SID Ile:Lys and SID Val:Lys ratios ranged from 0.56 to 0.47 and 0.62 to 0.53, respectively. Diet 5, which contained 0.469% supplemental L-Lys, was calculated to be slightly below the recommended 0.32 SID His:Lys ratio. From diets 2 to 5, CP levels were reduced from 17.68 to 15.69 % CP.

Statistical Analysis

Data from all experiments were analyzed as randomized complete block designs using the GLM procedure (SAS Inst. Inc., Cary, NC). Initial BW was used as the blocking factor and each pen of pigs served as the experimental unit. Littermates were balanced across treatments and sex was equalized among pens within replicate. In Exp. 1 to 4, orthogonal contrast statements were used to determine linear and quadratic effects of graded levels of either SID Lys or supplemental L-Lys. Treatment means were separated using the PDIFF option of SAS with an α at 0.10.

Table 7.1. Composition of experimental diets that were fed to weanling pigs in Exp. 1 (as-fed basis)

	SID[1] Lys, %					
Item	0.700	0.825	0.950	1.075	1.200	PC[2]
Ingredient, %						
Corn	66.71	66.41	66.00	65.48	64.89	48.83
Soybean meal (48% CP)	20.00	20.00	20.00	20.00	20.00	43.08
Peanut meal	4.94	4.94	4.94	4.94	4.94	---
Dry fat[3]	4.00	4.00	4.00	4.00	4.00	4.00
Monocalcium phosphate	1.63	1.64	1.64	1.64	1.65	1.27
Limestone	1.07	1.07	1.07	1.07	1.07	1.08
Sodium bentonite	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix[4]	0.50	0.50	0.50	0.50	0.50	0.50
Salt	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[5]	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic[6]	0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05	0.05
Biolys[7]	---	0.25	0.50	0.74	0.99	---
DL-Met	0.005	0.05	0.12	0.20	0.27	0.09
L-Thr	---	0.002	0.08	0.16	0.24	---
L-Trp	---	---	0.01	0.03	0.06	---
L-Val	---	---	---	0.07	0.16	---
L-Ile	---	---	---	0.01	0.08	---
Calculated composition						
ME, kcal/kg	3,436	3,436	3,433	3,431	3,431	3,444
Total Lys, %	0.816	0.941	1.066	1.191	1.315	1.363
SID Lys, %	0.700	0.825	0.950	1.075	1.200	1.200
SID Met, %	0.23	0.27	0.34	0.42	0.49	0.41
SIDSAA, %	0.46	0.50	0.57	0.65	0.72	0.72
SID Thr, %	0.52	0.52	0.60	0.68	0.76	0.80
SID Trp, %	0.16	0.16	0.17	0.19	0.22	0.26
SID Val, %	0.66	0.66	0.66	0.73	0.82	0.98
SID His, %	0.39	0.39	0.39	0.39	0.39	0.58
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80
P, %	0.70	0.70	0.70	0.70	0.70	0.70
Na, %	0.13	0.13	0.13	0.13	0.13	0.13
Cl, %	0.20	0.20	0.20	0.20	0.20	0.20

[1]SID = standardized ileal digestible.
[2]PC = positive control diet formulated to contain 1.20% SID Lys
[3]Fat Pak 100, Milk Specialties Co., Dundee, IL.
[4]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg;

pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 μg; biotin, 441 μg; vitamin C, 110 μg.
[5]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[6]Neo-Terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.
[7]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% $Lys \cdot SO_4$).

Table 7.2. Composition of experimental diets that were fed to weanling pigs in Exp. 2 to 4 (as-fed basis)

	Exp. 2 to 4	Exp. 2		Exp. 2 and 3		Exp. 3 and 4		Exp. 4	
	Supplemental L-Lys, %								
Item	0.100[1]	0.146	0.192	0.238[2]	0.284[3]	0.331[3]	0.377[3]	0.423[3]	0.469[4]
Ingredient, %									
Corn	57.86	59.61	61.36	63.11	64.85	66.59	68.33	70.08	71.82
Soybean meal (48% CP)	33.67	31.74	29.82	27.89	25.97	24.04	22.12	20.20	18.27
Dry fat[5]	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Monocalcium phosphate	1.45	1.49	1.53	1.57	1.61	1.65	1.69	1.73	1.77
Limestone	1.07	1.07	1.06	1.06	1.06	1.06	1.05	1.05	1.05
Sodium bentonite	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin premix[6]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Salt	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Trace mineral premix[7]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotic[8]	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Choline chloride	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Biolys[9]	0.20	0.29	0.38	0.47	0.56	0.65	0.74	0.83	0.93
DL-Met	0.10	0.12	0.14	0.15	0.17	0.19	0.20	0.22	0.24
L-Thr	0.009	0.036	0.063	0.09	0.12	0.14	0.17	0.18	0.22
L-Trp	---	---	---	0.01	0.02	0.03	0.04	0.05	0.06
Calculated composition									
ME, kcal/kg	3,443	3,442	3,441	3,439	3,438	3,437	3,436	3,452	3,451
Total Lys, %	1.21	1.21	1.20	1.20	1.20	1.19	1.19	1.18	1.18
SID[10] Lys, %	1.075	1.075	1.075	1.075	1.075	1.075	1.075	1.075	1.075
SID Met, %	0.37	0.38	0.39	0.40	0.41	0.42	0.42	0.43	0.44
SID TSAA, %	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
SID Thr, %	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
SID Trp, %	0.21	0.20	0.20	0.19	0.19	0.19	0.19	0.19	0.19
SID Val, %	0.83	0.79	0.76	0.73	0.70	0.67	0.64	0.61	0.57
SID Ile, %	0.76	0.72	0.69	0.66	0.63	0.60	0.57	0.54	0.50
SID His, %	0.49	0.47	0.45	0.43	0.42	0.40	0.38	0.36	0.34
SID Ile:Lys	0.71	0.70	0.64	0.61	0.59	0.56	0.53	0.50	0.47

SID Val:Lys	0.77	0.73	0.71	0.68	0.65	0.62	0.60	0.57	0.53
Ca, %	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
P, %	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Na, %	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Cl, %	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
CP, %	21.01	20.34	19.68	19.00	18.34	17.68	17.01	16.35	15.69

[1]This diet with 0.10% supplemental L-Lys was used as the control diet in Exp. 2 to 4.
[2]This diet is slightly above the recommended SID Ile:Lys ratio of 0.60 and exactly met the recommended SID Val:Lys ratio of 0.68.
[3]These diets were calculated to be deficient in Ile and Val.
[4]This diet is calculated to be deficient in Ile, Val, and His.
[5]Fat Pak 100, Milk Specialties Co., Dundee, IL.
[6]Provided the following per kilogram of diet: vitamin A, 11,023 IU; vitamin D_3 3,307 IU; vitamin E, 88 IU; niacin, 88 g; pantothenic acid, 50 mg; riboflavin, 13 mg; menadione, 8 mg; pyridoxine, 4 mg; thiamin, 4 mg; folic acid, 3 mg; vitamin B_{12}, 61 µg; biotin, 441 µg; vitamin C, 110 µg.
[7]Provided the following per kilogram of diet: Fe, 127 mg; Zn, 127 mg; Cu, 12.7 mg; Mn, 20 mg; I, 0.80 mg; and Se, 0.30 mg.
[8]Neo-Terra 10/10 from Nutra Blend LLC, Neosho, MO. Provided 165 mg oxytetracycline and 116 mg neomycin per kilogram of diet.
[9]Evonik-Degussa Feed Additives, Kennesaw, GA (Biolys contains 50.7% Lys·SO_4).
[10]SID = standardized ileal digestible.

RESULTS

Exp. 1

Increasing SID Lys levels from 0.700 to 1.200%, linearly increased ($P \leq 0.01$) ADG and G:F, but ADFI was not affected ($P > 0.10$; Table 7.3). There were no ($P > 0.10$) quadratic effects in any of these variables. Daily gain and final BW were reduced ($P < 0.10$) among pigs fed diets with SID Lys levels from 0.700 to 0.950% compared with pigs fed the PC diet. However, ADG, G:F, and final BW were similar ($P > 0.10$) among pigs fed diets with 1.075 or 1.200% SID Lys compared with pigs fed the PC diet. Thus, the SID Lys requirement for our 13-kg pigs was estimated to be at least 1.075% SID Lys.

Table 7.3. Effect of graded levels of standardized ileal digestible (SID) Lys on growth performance of weanling pigs from d 21 to 28 post-weaning in Exp. 1[1]

	SID Lys, %							
Item	0.700	0.825	0.950	1.075	1.200	PC[2]	SEM	*P*-value[3]
ADG, [4]g	452[b]	479[b]	465[b]	551[a]	567[a]	588[a]	17	0.01
ADFI, g	977	1,038	960	1,062	1,053	1,007	57	0.79
G:F[4]	0.46[b]	0.46[b]	0.49[ab]	0.53[a]	0.54[a]	0.59[a]	0.02	0.01
Final BW, kg	16.99[bc]	16.47[c]	16.69[bc]	17.88[ab]	17.46[abc]	18.36[a]	0.46	0.10

[a,b]Treatment means with different superscripts on the same row are significantly different, $P < 0.10$.
[1]Data are means of 5 replicates with 5 pigs per replicate pen. Pigs The average initial BW at d 21 post-weaning was 13.6 ± 2 kg.
[2]PC = positive control diet.
[3]Overall treatment *P*-value.
[4]SID Lys linear effect, $P \leq 0.01$.

Exp. 2

To prevent overestimating the amount of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp that can be added in diets for 13-kg pigs, diets were formulated to contain 1.075% SID Lys. There were no linear or quadratic effects ($P > 0.10$) in ADG, ADFI, G:F, or final BW at d 28 post-weaning with supplemental L-Lys levels ranging from 0.100 to 0.284% (Table 7.4).

Table 7.4. Effect of graded levels of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp on growth performance of weanling pigs from d 21 to 28 post-weaning in Exp. 2[1]

	Supplemental L-Lys, %						
Item	0.100[2]	0.146	0.192	0.238	0.284	SEM	P-value[3]
ADG, g	598	580	569	624	597	29	0.73
ADFI, g	1,067	1,091	1,083	1,109	1,080	46	0.98
G:F	0.56[a]	0.53[b]	0.53[b]	0.55[ab]	0.55[ab]	0.01	0.18
Final BW, kg	17.29	17.52	17.17	18.02	17.30	0.33	0.42

[a,b]Treatment means with different superscripts on the same row are significantly different, $P <$ 0.10.
[1]Data are means of 4 replicates with 4 pigs per replicate pen. The average initial BW at d 21 post-weaning was 13.3 ± 2 kg.
[2]This diet with 0.10% supplemental L-Lys was used as the control diet.
[3]Overall treatment P-value.

Exp. 3

Because supplemental L-Lys levels up to 0.284% did not negatively affect growth performance of pigs in Exp. 2, greater levels of inclusion were used in this experiment. The control diet and the 2 greatest levels of supplemental L-Lys from Exp. 2 were used as the starting point in this experiment. Supplemental L-Lys levels from 0.238 to 0.377%, did not affect ($P >$ 0.10) ADG, ADFI or G:F (Table 7.5). Final BW at d 35 post-weaning was not affected by dietary treatments. However, PUN was linearly decreased ($P < 0.05$) with the increasing levels of supplemental L-Lys.

Table 7.5. Effect of graded levels of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp on growth performance of weanling pigs from d 21 to 35 post-weaning in Exp. 3[1]

	Supplemental L-Lys, %						
Item	0.100[2]	0.238	0.284	0.331	0.377	SEM	P-value[3]
ADG, g	539	561	545	580	539	16	0.34
ADFI, g	900	976	926	1,005	964	37	0.21
G:F	0.60	0.58	0.60	0.58	0.56	0.02	0.69
Final BW, kg	21.05	21.25	21.17	21.54	21.19	0.33	0.87
PUN, mg/dL	11.88[a]	7.27[b]	5.66[c]	4.66[cd]	3.66[d]	0.65	<.001

[a,b]Treatment means with different superscripts on the same row are significantly different, $P <$ 0.10.
[1]Data are means of 5 replicates with 4 pigs per replicate pen. The average initial BW at d 21 post-weaning was 13.3 ± 2 kg.
[2]This diet with 0.10% supplemental L-Lys was used as the control diet.

[3]Overall treatment *P*-value.

Exp. 4

Because supplemental L-Lys levels up to 0.377% did not affect growth performance of pigs in Exp. 3, greater levels of inclusion were used in this experiment. The control diet and the 2 greatest levels of supplemental L-Lys from Exp. 3 were used as the starting points in this experiment. Supplemental L-Lys levels from 0.331 to 0.469% linearly decreased ($P \leq 0.06$) ADG and G:F, but ADFI was linearly increased ($P = 0.05$; Table 7.6). Pigs fed diets with supplemental L-Lys levels up to 0.423% had similar ($P > 0.10$) ADG compared with pigs fed the control diet. However, G:F was reduced ($P < 0.10$) in pigs fed diets with a supplemental L-Lys level of 0.377% compared with pigs fed the control diet. Thus, supplemental L-Lys levels up to 0.423 or 0.331% can be added along with DL-Met, L-Thr, and L-Trp without affecting ADG or G:F, respectively of 13- to 23-kg pigs. However, final BW at d 35 post-weaning was not affected ($P > 0.10$) by dietary treatment.

Table 7.6. Effect of graded levels of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp on growth performance of weanling pigs from d 21 to 35 post-weaning in Exp. 4[1]

	Supplemental L-Lys, %						
Item	0.100[2]	0.331	0.377	0.423	0.469	SEM	*P*-value[3]
ADG, [4] g	636.2[a]	607.0[ab]	593.1[ab]	591.7[ab]	569.6[b]	23.22	0.37
ADFI, [4] g	1141.7[b]	1118.6[b]	1160.8[ab]	1189.1[ab]	1234.6[a]	38.1	0.27
G:F[4]	0.56[a]	0.54[ab]	0.51[bc]	0.50[c]	0.46[d]	0.01	0.001
Final BW, kg	23.49	23.10	22.98	23.10	22.86	0.38	0.81

[a,b]Treatment means with different superscripts on the same row are significantly different, $P < 0.10$.
[1]Data are means of 6 replicates with 4 pigs per replicate pen. The average initial BW at d 21 post-weaning was 14.7 ± 2 kg.
[2]This diet with 0.10% supplemental L-Lys was used as the control diet.
[3]Overall treatment *P*-value.
[4]Supplemental L-Lys effect, $P \leq 0.06$.

DISCUSSION

Essential AA for pigs can be divided into 2 groups according to their degree of limitation in common practical diets (Boisen, 2003). The primary limiting group includes Lys, Met, Thr, and Trp while the secondary limiting group includes branched-chain AA (**BCAA**) and possibly aromatic AA. At this particular period of time, the primary group of AA are commercially available and at competitive prices for inclusion in diets for pigs, whereas AA in the secondary limiting group may greatly increase diet cost (Boisen, 2003; Heo et al., 2008). Therefore, the most cost effective approach to develop practical low CP-AA supplemented diet for pigs is to maximize the use of supplemental AA in the primary limiting group, before an AA of the secondary limiting group reduces growth performance. Therefore, this research aimed to determine the maximum level of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp that can be added in corn-SBM diets for 13-kg pigs without negatively affecting growth performance.

To prevent overestimating the amount of supplemental AA that can be added in corn-SBM diets for 13-kg pigs, Exp. 1 was conducted to estimate the SID Lys requirement. Previous experiments from our lab validated PM as a low Lys source that can be used in Lys requirement studies. Therefore, diets in Exp. 1 were corn-PM-SBM-based with the exception of the PC diet. Peanut meal was also validated in this experiment as growth performance was similar between pigs fed the 1.200% SID Lys PM diet and pigs fed the PC diet formulated to contain the same SID Lys level. Increasing SID Lys levels from 0.700 to 1.200%, linearly increased ADG and G:F, but ADFI was not affected. Daily gain or G:F data did not fit any regression model commonly used to estimate nutrient requirements (Robbins et al., 2006). However, results from treatment mean separations indicated that diets with SID Lys levels from 0.700 to 0.950% had reduced ADG compared with pigs fed the PC diet. Pigs fed diets with SID Lys levels of 1.075 and 1.200% had similar ADG to that of pigs fed the PC diet. Therefore, based on ADG data, the

SID Lys requirement of our 13-kg pigs is at least 1.075%. An additional data point above 1.200% SID Lys may have been needed to successfully fit a quadratic regression model. Nevertheless, in close agreement with our results, James et al. (2002) reported that the SID Lys requirement of 12- to 20-kg pigs was at least 1.1% for ADG and 1.3% for G:F. Similarly, the NRC (1998) reported a SID Lys requirement of 1.01% for 10- to 20-kg pigs. However, there is increased evidence suggesting that the SID Lys requirement for the current high-lean growth potential pigs may be greater than those reported in the NRC (Tokach et al., 2003; Dean et al., 2007; Kendall et al., 2008). Thus, our SID Lys estimate is close to the requirement of our pigs, and is certainly not overestimated.

The next step in developing low CP-AA supplemented diets for pigs is to force supplemental AA in the diet until a negative effect on growth performance is obtained (Southern et al., 2010). In Exp. 2 and 3, growth performance was not affected with increasing levels of supplemental L-Lys. However, in Exp. 3, PUN was linearly decreased as dietary protein was reduced, indicating a more efficient utilization of N. It was not until Exp. 4 that growth performance was negatively affected. In Exp. 4, supplemental L-Lys levels from 0.331 to 0.469% linearly decreased ADG and G:F, while ADFI was linearly increased. It seems that as supplemental L-Lys levels were increased, pigs attempted to increase feed intake to compensate for some AA deficiency. Similarly, ADFI was numerically increased in our previous experiment in 6- to 12-kg pigs when supplemental L-Lys levels increased between the range that linearly reduced ADG and G:F. Furthermore, Le Bellego and Noblet (2002) suggested that limiting protein content while balancing dietary AA may maximize feed intake in weanling pigs. Because in our experiments, feed intake was increased, it seems that diets may have been deficient in an AA, rather than having an AA imbalance.

Supplemental L-Lys level up to 0.423 or 0.331% did not affect ADG or G:F, respectively compared with pigs fed the control diet. The diet with 0.423% supplemental L-Lys calculated to contain 0.50 SID Ile:Lys and 0.57 SID Val: Lys, whereas the diet with 0.331% supplemental L-Lys calculated to contain 0.56 SID Ile:Lys and 0.62 SID Val:Lys. These diets were thought to be deficient in Ile and Val based on previous recommended SID Ile:Lys and Val:Lys ratios of 0.60 and 0.68, respectively for 10- to 20-kg pigs (Baker, 1997). However, our results coupled with recent published estimates suggest that those ratios are too high (Barea et al., 2009; Wiltafsky et al., 2009). Furthermore, these results are consistent with previous research that have reported that Ile or Val may be among the next limiting AA in low CP diets for pigs, after Lys, Met, Thr, or Trp (Brudevold and Southern, 1994; Figueroa et al., 2002; Wiltafsky et al., 2009).

In our experiment, corn-SBM diets were used to be consistent with commercial nursery feeding programs. Pigs at approximately 11 kg are typically switched to a simple lower cost corn-SBM diet to prevent overfeeding expensive specialty ingredients (Tokach et al., 2003). Based on our results, it seems that SID Ile:Lys and SID Val:Lys ratios of at least 0.50 and 0.57, respectively may not affect ADG, but will reduce feed efficiency. However, SID Ile:Lys and Val:Lys ratios of at least 0.56 and 0.62 may be necessary to maintain feed efficiency. Similarly Barea et al. (2009) reported that the optimum SID Ile:Lys in 11- to 23-kg pigs is not greater than 0.50, and this requirement was not affected by BCAA content of the diet. Similarly, Lordelo et al. (2008) did not obtain an improvement in growth by supplementing a low CP cereal-SBM diet that contained 0.50 SID Ile:Lys. However, Wiltafasky et al. (2009) suggested a SID Ile:Lys ratio of 0.54 using diets without excess Leu in 8- to 25-kg pigs. However, these same authors reported that in diets with excess Leu, or with 7.5% red blood cells, the optimum SID Ile:Lys ratio for ADG is 0.59. Contradictory results have also been reported regarding the optimal SID Val:Lys ratio. The NRC (1998) recommended a SID Val:Lys of 0.68, which is similar to that recommended by Baker (1997). Conversely, James et al. (2001), reported that 0.58 or 0.64 SID Val:Lys are optimal for ADG and feed efficiency, respectively. Recently, Wiltafsky et al. (2009) estimated the optimal SID Val:Lys ratios of 0.66, 0.67 and 0.65 for ADG, ADFI, and N retention, respectively. Conversely, Barea et al. (2009) recommended a SID Val:Lys ratio of at least 0.70 for 12- to 25-kg pigs to optimize growth performance. It is evident that great variation exists among the recommended ratios of BCAA relative to Lys, Further research is needed to better elucidate the interactions of these AA and how these affect their requirement.

In conclusion, supplemental L-Lys levels up to 0.423 (0.83% Lys·$SO_{4;}$ 0.54% Lys·HCl) or 0.331% (0.65% Lys·$SO_{4;}$ 0.42% Lys·HCl) along with DL-Met, L-Thr, and L-Trp can be added in corn-SBM diets for 13- to 23-kg pigs without negatively affecting ADG or G:F, respectively. Additionally, previous recommendations (Baker, 1997) of 0.60 and 0.68 for SID Ile:Lys and Val:Lys ratios, respectively are too high. It seems that ratios of 0.56 or 0.62 for SID Ile:Lys and Val:Lys respectively may not affect growth performance of 13-kg pigs fed corn-SBM diets.

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CHAPTER 8

SUMMARY AND CONCLUSIONS

The weaning period is considered the most stressful event in the pork production cycle. It is characterized by reduced feed intake, poor growth performance, and increased susceptibility to enteric diseases. A period of anorexia or low feed intake during the first week post-weaning has been identified as the main cause for poor growth performance and also for the negative alterations in intestinal structure and function. Consequently, a mixture of highly digestible and palatable ingredients, such as dried whey (**DW**), dried whey permeate (**DWP**), and spray-dried plasma protein (**SDPP**), have been used to stimulate feed intake and to reduce the growth lag after weaning. However, the cost of these standard ingredients is usually high and in some instances, their availability is limited. Thus, novel feed ingredients capable to support similar or greater performance are needed.

Similarly, there is increased interest in reducing excess N in diets for weanling pigs as it may reduce N losses to the environment, improve gastrointestinal health, and reduce the incidence of diarrhea. Additionally, supplemental amino acids (**AA**) mainly L-Lys, DL-Met, L-Thr, and L-Trp have become increasingly available and at prices that often merit their inclusion in pig diets. Therefore, it is worthwhile to determine the maximum level of these 4 AA that can be added before the next limiting AA reduces growth performance.

Three experiments were conducted to compare the feeding value of milk chocolate product (**MCP**; 20% lactose and 60% sugars) and DW (70% lactose) in diets for weanling pigs. Results from these experiments indicate that partial or total replacement of DW with MCP did not affect wk-1 feed intake or growth performance of weanling pigs. Thus, MCP could be considered as a formulation alternative to DW. The efficacy of DW to stimulate growth performance was confirmed in these experiments. A similar experiment was conducted to compare the feeding value of candy oats (**CO**; 60% total sugars and 25% cooked oat-based cereals) and DWP (80% lactose). Results from this experiment indicate that a combination of DWP and CO, each providing 50% of the total sugar level of the diet, effectively stimulated wk-1 feed intake and growth performance of weanling pigs. Because total replacement of DWP with CO did not affect growth performance, CO can be considered as a formulation alternative to DWP.

Two experiments were conducted to determine the effect of replacing SDPP with a novel swine nutritional supplement (**SNS**; concentrated plasma fraction) on growth performance of weanling pigs. Results from these experiments indicate that the inclusion of SDPP or SNS did not affect growth performance of pigs compared with those fed a negative control diet housed under high sanitary conditions.

A total of 8 experiments were conducted to determine the maximum level of supplemental L-Lys, along with DL-Met, L-Thr, and L-Trp that can be added in diets for 6- to 12-kg and 13- to 23-kg pigs without negatively affecting growth performance. Results from these experiments indicated that supplemental L-Lys levels up to 0.298 (0.59% Lys·SO_4; 0.38% Lys·HCl) or 0.198% (0.39% Lys·SO_4; 0.25% Lys·HCl) can be added in diets for 6- to 12-kg pigs without negatively affecting ADG or G:F, respectively. The optimum SID Ile:Lys ratio may not be greater than 0.55 in diets containing low levels of red blood cells. In diets for 13- to 23-kg pigs, supplemental L-Lys levels up to 0.423 (0.83% Lys·SO_4; 0.54% Lys·HCl) or 0.331% (0.65% Lys·SO_4; 0.42% Lys·HCl) can be added in corn-soybean meal (**SBM**) diets without negatively affecting ADG or G:F, respectively. It seems that ratios of 0.56 or 0.62 for SID Ile:Lys and Val:Lys respectively, may be adequate for 13-kg pigs fed corn-SBM diets.

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VITA

Victor D. Naranjo Haro was born on February 24, 1984 on the beautiful coast of Ecuador; specifically, in Guayaquil, the city known as the "Pearl of the Pacific". Victor, son of Victor Naranjo and Diana Haro, grew until the age of 17 with his parents and his 2 sisters, Sandra and Diana. In December of 2001, Victor finished his high school education at the American School of Guayaquil and went to Honduras to attend the Pan-American School of Agriculture Zamorano. After 4 years of education, Victor completed his Bachelor of Science degree in Agricultural Sciences and Production with a major in Animal Sciences in December of 2005. During the summer of 2006, Victor worked in an internship program with Dr. Lee Southern at Louisiana State University and was admitted to start graduate school in the spring of 2007. In December of 2009, Victor completed his Master of Science degree in Animal, Dairy, and Poultry Sciences evaluating novel dietary feed additives for nursery and growing-finishing pigs. Victor continued with his graduate education at LSU evaluating different feed additives and maximizing the use of supplemental amino acids in diets for weanling pigs. Victor is currently a doctoral candidate in Interdepartmental Program in Animal and Dairy Sciences.