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Nursery Pig Growth Response To Feed Ingredients and Feed Additives: I). Spray-Dried Blood Plasma vs. Spray-Dried Egg Effect on Nursery Pig Growth Performance Ii). Effect of **A**-galactosidase and Citric Acid on Nursery Pig Growth Performance When Added to a Corn-soybean Meal Diet

Elizabeth Kaye Pegg
Illinois State University, elpegg29@gmail.com

NURSERY PIG GROWTH RESPONSE TO FEED INGREDIENTS AND FEED ADDITIVES: I). SPRAY-DRIED BLOOD PLASMA VS. SPRAY-DRIED EGG EFFECT ON NURSERY PIG GROWTH PERFORMANCE II). EFFECT OF α-GALACTOSIDASE AND CITRIC ACID ON NURSERY PIG GROWTH PERFORMANCE WHEN ADDED TO A CORN-SOYBEAN MEAL DIET

Elizabeth K. Pegg

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Nursery pigs are defined as newly weaned pigs adjusting to a solid-plant based diet after being weaned from a milk-based diet. Weaning has nutritional, environmental, social, and physiological impacts on the nursery pig. Nutrition is modified to accommodate changing needs of the nursery pig. The nursery pig diet is developed by adding highly digestible animal proteins to the standard corn-soybean meal swine diet. Development of the nursery diet improves pig performance but animal-based proteins can be expensive and do not address undigestible components of the plant-based ingredients. Addition of lower-cost animal proteins, addition of enzymes, and addition of acidifiers have the capability to improve nutrient utilization of corn-soybean meal diets by nursery pigs at a lower cost. This thesis consists of four chapters. Chapter one consists of a literature review examining nursery pig management and nutrition in the United

Statesswine industry. Chapter two examines the effectiveness of independent addition of spray-dried blood plasma or spray-dried egg to improve nursery pig growth performance when added to the standard nursery diet. Chapter three examines the effectiveness of the independent and joint addition of α-galactosidase and citric acid to improve nursery pig growth performance when added to a corn-soybean meal diet. Chapter four summarizes the findings of Chapter two and three and the implications of these findings for the swine industry.

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ELIZABETH K. PEGG

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ELIZABETH K. PEGG

COMMITTEE MEMBERS:

Peter J. Lammers, Chair

Leslie A. Lekatz

Kerry W. Tudor

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CONTENTS

TABLES

INTRODUCTION

In the swine industry, nursery pigs are weaned at an early age before they are biologically mature and independent of the sow. Weaning involves changes to a pig's nutrition, environment, social structure and physiological development. These changes stress the pig which leads to slow or negative growth, inappetence, scours, illness and, in some cases, death. Diet is the one factor that is easily modified to improve the pig's performance during the weaning period. Nursing piglets are accustomed to sow's milk which is composed of highly digestible proteins and fat. At weaning, abrupt change to a low moisture plant based diet is incompatible with the pig's gastrointestinal tract. An appropriate diet can minimize the negative effects of weaning and may more effectively transistion the pig from a milk based diet to a plant based diet.

Spray-dried plasma (SDP) is a highly digestible animal protein shown to improve growth performance in pigs and the glycoproteins (Grinstead et al., 2000) and immunoglobulins present in SDP may inhibit pathogen adhesion to the gut wall thereby decreasing challenges to the immune system (Bosi et al., 2004; Campbell et al., 2010). Commonly used in starter diets, the highly digestible, highly palatable SDP stimulates feed intake and decreases the growth lag occurring in newly weaned piglets (Pierce et al., 2005). Spray-dried egg protein (SDE), like SDP is thought to have immunological effect on the nursery pig gastrointestinal tract. This feed additive is also more cost effective because it is sourced from unusable eggs. Spray-dried egg may be the most viable animal based protein due to high digestibility, low cost, neutral public perception, potential intestinal barrier function, and nutrient balance.

Although nursery diets can be designed to allow the nursery pig to overcome the postweaning lag, inclusion of highly digestible proteins makes the nursery diets very expensive. Use of soybean meal is a potential alternative to animal based protein products due to the low cost and high protein content. In two studies, feed additives were included in standard nursery pig diets to evaluate the effect on nursery pig growth performance. In the first study, a control corn soybean meal diet containing low levels of SDP was compared to two experimental diets: one containing higher concentration of SDP and one containing SDE to evaluate the effect of SDP and SDE on nursery pig growth performance. In the second study, a corn-soybean meal diet was supplemented with independent and joint addition of α-galactosidase and citric acid to evaluate the additives ability to improve growth performance by improving nutrient utilization. Nursery pig growth performance was evaluated in terms of average daily gain (ADG), average daily feed intake (ADFI), and (gain to feed) G:F.

CHAPTER I

LITERATURE REVIEW

Introduction

Nursery pigs require a palatable, highly digestible, nutrient dense diet to support healthy, rapid growth. With diets composed largely of plant based materials the animal may benefit from feed ingredients and feed additives that increase consumption rates and enhance digestibility. At weaning the nursery pig is susceptible to illness due to the stressful changes including change in environment, diet, social interaction, and physiological changes. An appropriate diet can minimize the negative effects of weaning and more effectively transition the pig from a milk based diet to a plant based diet.

Spray-dried egg protein (SDE) is an excellent feed ingredient due to its high digestibility and immunological activity. This feed ingredient is considered a replacement to the more common spray-dried plasma protein (SDP), which is also a highly digestible feed ingredient with immunological activity. Historically, SDP has been a very expensive protein due to the high demand and limited supply. Spray-dried egg is examined as an alternative to SDP due to its lower cost. Currently porcine derived SDP is $6.82/kg and SDE is $2.49/kg (Kuerth).

Use of feed additives like enzymes and dietary acids can improve the diet by increasing its digestibility. The enzyme α-galactosidase increases nutrient utilization of the diet by hydrolyzing bonds that are unbreakable by endogenous enzymes of the nursery pig gastrointestinal tract. Citric acid is added to diets containing enzymes to activate the enzyme by lowering the diet and gut pH. In addition, a drop in gastrointestinal pH may inhibit proliferation of pathogenic bacteria. Feed ingredients and feed additives are necessary and useful components of the nursery diet. Addition of feed ingredients or feed additives to a corn-soybean meal diet may ease the pig's transition from a liquid to a solid diet, which would otherwise be an abrupt change.

The Nursery Pig

To clearly define the type of animal that will be studied, a nursery pig must first be defined by age, wt, physiological development, and ability to thrive independently, at weaning.

At 3 to 4 wk pigs are weaned off the sow and transitioned from a liquid to a solid diet. The gastrointestinal tract of the newly weaned pig is adapted to a milk based diet with high activity of lactase and sufficient levels of lipases and proteases (Maxwell and Carter, 2001) but enzyme activity is depressed by weaning (Hedemann and Jensen, 2001). An anorexic period caused by decreased feed consumption (Le Dividich and Sève, 2000) results in epithelial atrophy of the small intestine (Coffey and Cromwell, 1995; Boudry et al., 2004). In addition, hydrochloric acid secretion is low resulting in a more basic pH which inhibits digestion of plant based proteins and supports proliferation of pathogenic bacteria (Barrow et al., 1977b; Ravindran and Kornegay, 1993; Boudry et al., 2004; Cheeke and Dierenfeld, 2010; Choct et al., 2010). This transitional period alters the nutritional, environmental, physiological and psychological habits of a nursery pig and leads to slow growth, inappetence, scours, illness, or death (Mathew et al., 1993; Ravindran and Kornegay, 1993). Ultimately weaning leads to inefficient gastrointestinal function (Beers-Schreurs et al., 1998). Therefore nursery pigs require nutrient dense, highly digestible feedstuffs to improve growth performance at weaning. Inclusion of animal protein, highly digestible plant protein and liquid feed have been shown to improve feed intake and growth rate (Hancock et al., 1990; Friesen et al., 1993; Kats et al., 1994; Owusu-Asiedu et al., 2003).

Age and Weight at Weaning

Immaturity of the nursery pig gastrointestinal tract at weaning is a major concern when evaluating weaning age. Increasing the age at weaning ensures more rapid adaptation to the postweaning environment, greater ADG, improve feed efficiency, decreased mortality and increased viability (Leibbrandt et al., 1975; de Grau et al., 2005; Main et al., 2004, 2005; Cabrera et al., 2010) but it is inefficient and costly to maintain pigs on a sow when milk supply cannot meet the demands of litter consumption. At 18 to 20 d of age the sow's milk supply cannot maintain a litter of 10 or more piglets indicating piglet growth rate will slow unless supplementary feed is offered (Zijlstra et al., 1996; Kyriazakis and Whittemore, 2006). Weaning age has varied in previous studies (Table 1) but 21 d of age is generally accepted as the standard in order to maintain an economically viable herd (Main et al., 2005; Dritz et al., 2007) without compromising pig viability (Main et al., 2004; de Grau et al., 2005; Cabrera et al., 2010). In a national survey of 2,499 swine production facilities, the USDA's National Animal Health Monitoring System found that pigs weaned early (18 or 19 d of age) spent more time in the nursery and did not leave the nursery at heavier wt than pigs weaned at an older age (26 d of age) (APHIS, 2002). Early weaning is motivated by the economic benefit of increasing farrowing rates.

Weaning wt is another benchmark to determine if a pig is ready to be weaned due to the effect of wt on a pig's resultant growth performance. At weaning, a 0.91 to 1.81 kg wt variation will increase the heavier pig's potential to consume more feed and gain at a higher rate when experiencing the same environment and management as lighter counterparts (ADM, 2013). Across 355 farms the average weaning wt was 5.5 kg (Olson, 2012). Southern and Lewis (2001) offer a range from 4.5 to 7 kg for a weaned pig. A minimum of 5.5 kg weaning wt is recommended to ensure an efficient growth rate to finishing (Mahan et al., 1996; Cabrera et al., 2010).

Weight and age benchmarks continue to play a role in piglet performance in the nursery, in regards to average daily gain (ADG), average daily feed intake (ADFI) and gain:feed ratio (G:F). Increasing age (Main et al., 2004) and wt (Mahan and Lepine, 1991) increased ADG, ADFI, and G:F. As previously highlighted, benchmarking weaning age and wt is based on physiological development corresponding to the age or wt.

Nursery Pig Housing Environment

A nursery is a facility or building designed specifically to house newly weaned pigs until they reach the grower/finisher stage (APHIS, 2002). Addressed by the USDA's National Animal Health Monitoring System (NAHMS), most nursery pigs are raised in an all-in, all-out management system to minimize disease exposure. Walls and flooring are sealed and nonporous to withstand high power pressuring washing and to minimize moisture retention and bacteria growth. Floors are nonslick to minimize injury due to slipping. Walls are solid plastic to minimize nose-to-nose disease transmission and floors are slotted (0.95 cm open space) (Coffey et al., 1995) at a dimension small enough to prevent trapping feet but large enough to allow waste to pass through.

Cleanliness of the housing environment affects the newly weaned pig's ability to thrive. Coffey and Cromwell (1995) reported pigs in an experimental nursery (new, clean, and unused) outperformed pigs in a continuous flow on-farm nursery during a 28 d trial ($P < 0.001$). Effect of the diet on pig performance resulted in a greater growth rate and feed intake ($P < 0.05$) by pigs in the conventional nursery resulting in an environment × diet interaction ($P < 0.05$). This study highlights the importance of regular sanitation and all-in, all-out practices in order to reduce pathogens, which impede pig performance.

Stress of weaning compromises the pig's immune system and ability to grow, therefore the nursery should be clean, warm, dry and draft-free to minimize stress associated with the living environment. A building with temperature, humidity and ventilation regulation is necessary to accommodate the animal's thermal neutral zone. The thermal neutral zone is the temperature range in which the body temperature is maintained without disrupting normal metabolic function (International Commission of Agricultural Engineering and Munack, 2006). Wet surfaces or high temperatures divert energy from growth to thermoregulation (International Commission of Agricultural Engineering and Munack, 2006). The importance of regulated temperature is demonstrated by Le Dividich (1981).

Pigs housed in an environment with continual temperature fluctuation (23.5 ± 3°C) exhibited poor performance when compared to pigs housed at a constant temperature (23.5 ± 0.5°C). Le Dividich (1981) also noted optimized growth performance when the temperature was lowered by 2° from 28°C each wk. This temperature setting agrees with findings of Le Dividich et al. (1980). In Coffey and Cromwell (1995) temperature fluctuation between 22 and 31°C resulted in poor growth performance when compared to a regulated temperature of 34°C with a weekly decrease of 1.5°C. In contrast to a well regulated temperature, Wang et al. (2012) found temperature fluctuation could occur, if it was regulated to one constant temperature for day and one constant temperature for night. In the study an 8° lower temperature at night did not decrease growth performance or general activity, only time spent lying sternal changed and as a result incidences of belly nosing decreased (Wang et al., 2012). Maintaining a high ambient temperature (26°C) throughout the nursery period has been examined. Pig growth performance was not impacted until the 4th wk post weaning, at which point growth performance declined (Le Dividich et al., 1980). Depending on the season maintaining a high ambient temperature could be a more costly endeavor and is not the ideal situation for pigs because they grow best with a high start temperature that is regularly reduced. A standard minimum temperature recommended by Southern and Lewis (2001) is 26°C, however this was considered a high temperature by Le Dividich et al. (1980) and they considered 28 to 20°C to be the optimal temperature range. Coffey et al. (1995) considers 32°C the appropriate temperature for 14 d old nursery pigs with a 1 to 2°C decline/wk.

In addition to monitoring temperature, piglet observation offers a reference to the pigs experience of the thermal environment. Crowding, or pigs piled on one another, indicates pigs are chilled. Piglets distantly spread, with minimal contact, indicate the piglets are hot. Sprawling increases body surface area exposed to circulating air, allowing heat to dissipate and the body to cool. Piglets in the thermal neutral zone can be identified by moderate contact without piling.

Ventilation is important to remove excess moisture as well as gaseous fumes; however, high rates of ventilation will chill the animal. Midwest Plan Service (1983) recommends for a 6.80 to 22.68 kg pigs 2 to 3 cfm/head in winter and 10 to 15 cfm/head in summer. With air movement regulated it is important to minimize drafts, which increase air movement above the necessary level and may chill the animal.

Housing requirements are based on the individual space requirement for a pig. Space required for a pig is based on linear dimensions of the pig, percentage of space allotted to recumbent vs. sternal lying, floor type, and pigs/pen. In an environmentally controlled housing environment with fully slotted floors $0.05W^{0.66}$ m^2 (W, live wt, kg) is adequate space allotment/pig and leaves 1/3 of the floor vacant (Kyriazakis and Whittemore, 2006). For 5 to 20 kg pigs this would equate to 0.14 to 0.36 m^2 lying area/pig. Coffey et al. (1995) recommended slightly larger space accommodations, 0.31m^2 floor space for every 4.54kg. A nursery pen should be a minimum of 1.22 m wide if accommodating 11.34 kg pigs (Coffey et al., 1995).

Health of the Nursery Pig

Appropriate weaning time is crucial to the survival of weaned piglets. Crossover immunity does not exist between the sow and the fetus. As a result, the pig is deprived of passive immunity until it consumes colostrum (Coffey and Cromwell, 1995). Passive immunity is highest at birth and quickly declines within the first 3 to 4 wk of life. As a result, passive immunity is declining through the weaning and the nursery period, which is a time of high stress that challenges the immature immune system. Stress and an immature immune system make the pig very vulnerable to disease. In addition, weaning tests the functionality of the gastrointestinal tract.

The most commonly reported diseases among nursery pigs include *Streptococcus suis* (meningitis), *Staphylococcus hycius* (greasy pig disease), *E. coli* diarrhea, mycoplasma pneumonia, roundworms, and porcine reproductive and respiratory syndrome (PRRS) (APHIS, 2002). Of these conditions, respiratory problems were the most common cause of death in nursery pigs, around 30% of nursery deaths for the surveys in 1995 and 2000 (APHIS, 2002). Scours and starvation were each responsible for about 12% of deaths. The remaining causes of death were unknown (about 20%) or known diseases (~20%) including *Streptococcus suis,* greasy pig disease, *E. coli*, mycoplasma, pneumonia, roundworms, and PRRS, of which *Streptococcus suis* was the most prevelant (APHIS, 2002).

Addition of antibiotic to the nursery diet protects the pig from disease during the nursery phase when passive immunity is declining and active immunity is low (Coffey et al., 1995). Summarized in a review, addition of antibiotic resulted in a 16.4% improvement of ADG and a 6.9% improvement in G:F for a population of 32,555 pigs in 1,194 experiments (Coffey et al., 1995).

Copper sulfate is an antimicrobial that showed improved growth rate and feed efficiency in a review of 12 studies when added at a rate of 125 to 250 ppm (Coffey et al., 1995). Addition of antibiotics and copper sulfate together were reviewed in 14 experiments with 1,700 pigs and the findings revealed a compounding effect: growth performance was improved more by addition of both additives when compared to addition of either additive independently (Coffey et al., 1995).

Decreased feed intake, and stress on the nursery pig, result in morphological changes to the gastrointestinal tract. Reduction in villus height and intestinal wt are common observations at weaning (Cera et al., 1988). Jejunal villi of weaned pigs are shorter than villi of nursing pigs of the same age (Cera et al., 1988). Intestinal wt is lower for 21 d old weaned pig compared to the suckling counterpart (Cera et al., 1988). Villous height declines in the suckling pig starting at d 2 but it is drastically shortened by 3 d postweaning (21 d), with less drastic shortening seen if the pig is weaned at 35 d of age (Cera et al., 1988). Shortening of the villi is partnered with increased villi diameter which results in a doubling of the absorptive capacity (Cera et al., 1988).

Corn oil has a direct effect on villous shortening in the weaned pig from 14 to 28 d postweaning (Cera et al., 1988). High corn starch diets result in larger villi heights (Cera et al., 1988)

Feed Consumption and Diet

At weaning nursery pigs are in a negative energy balance because metabolic activity is high but feed intake is low. Although nursery pigs consume solid diets earlier than 25 d of age, the gastrointestinal tract of the newly weaned pig is adapted to a milk based diet as a result of high levels of lactase (Coffey and Cromwell, 1995; Maxwell and Carter, 2001). Around three wk of age the ability to metabolize milk (lactase) declines while the ability to digest starch, fat and protein (amylase, lipase, and protease) increases (Coffey et al., 1995). The stress of this transition is compounded by dramatic change to diet, environment, and social structure. Kyriazakis and Whittemore (2006) claim nursing pigs offered solid feed will not consume notable amounts until 25 d of age. In the first day postweaning pigs rarely consume the recommended 300g of solid feed (Kyriazakis and Whittemore, 2006). A 28 d old weaned pig should be given creep feed prior to weaning and maintained on the same diet after weaning until reaching a wt of 10 kg live wt (Kyriazakis and Whittemore, 2006). An undernourished nursery pig may sacrifice fat deposition to maintain protein accretion (Maxwell and Carter, 2001) and body lipid content may drop to 10% of the body wt (Kyriazakis and Whittemore, 2006). According to Mavromichalis (2006) the priority of lipid deposition over protein deposition is an evolutionary advantage to survival. When offered ad libitum access to an easily digestible feed a newly weaned pig can consume nearly 15% of its body wt/d (Kyriazakis and Whittemore, 2006). To maintain the high postnatal growth rate (Hollis, 1993) the nursery pig should be offered a palatable, highly digestible and nutrient dense diet. The NRC (2012) recommends 904 kcal/day ME for a 5 to 7 kg pig and 1,592 kcal/day ME for a 7 to 11kg pig. Relying on compensatory gain, in the finisher stage, to make up for low nursery wt results in longer time to finish wt and less efficient growth (Kyriazakis and Whittemore, 2006).

To ease the abrupt change from liquid to solid diet, the nursery diet should be fed in multiple phases. Earlier phase diets for a pig < 4.54 kg should contain high concentrations of milk and animal products, higher levels of fat, higher rates of lysine, and a greater proportion of corn: SBM (Coffey et al., 1995). First phase diets are generally pelleted and more costly to produce so they should not be fed longer than 7 d to 10 d, or until the pig reaches 2.27 to 4.54 kg. Although higher in cost, pelleted diets minimize food wastage that is more common in newly weaned nursery pigs (Coffey et al., 1995). Inclusion of fishmeal, fat, or blood proteins in the earlier diet will be low in concentration or removed when the pig reaches 6.80 to 11.34 kg body wt and the ratio of

SBM:corn will increase (Coffey et al., 1995). Lysine will be lowered in the diet of the 4.54 to 6.80 kg pig and will continue to decline in the diet of the 6.80 to 22.68 kg pig (Coffey et al., 1995). Adherence to the guidelines of phase feeding will optimize growth performance at the lowest possible cost (Coffey et al., 1995). A wt increase of 0.91 kg when leaving the nursery has been shown to increase ADG by 0.03 kg/day in the finisher which can shorten finishing time by 5 to 10 d (Coffey et al., 1995). In the swine industry, pigs are moved based on a time schedule, not by desired wt, phase feeding has the ability to enhance growth within the allotted time period (Coffey et al., 1995).

Corn and soybean meal formulate the bulk of swine diets because they are low cost energy dense ingredients. Soybean meal (SBM) is an optimal feedstuff for pigs because of its high protein content and excellent amino acid profile that supports protein synthesis (Cromwell, 2000). Soybean meal contains over 30% total carbohydrates (Grieshop et al., 2003). Soybean oligosaccharides, also known as α-galacto-oligosaccharides, raffinose oligosaccharides, or α-galactosides (Zdunczyk et al., 2011) comprise between 5 and 8% soybean meal dry matter (DM) (Coon et al., 1990; Grieshop et al., 2003; Kempen et al., 2006) but concentrations were reported as low as 2.5 to 3.5% (Parsons et al., 2000; Smiricky et al., 2002). The raffinose oligosaccharides are the main group of oligosaccharides in SBM (Han and Baik, 2006) of which raffinose and stachyose are the two major contributors to oligosaccharide composition in SBM. Raffinose is a trisaccharide of fructose, glucose, and galactose. Stachyose is a tetramer compromised of two units galactose plus glucose and fructose. Both oligosaccharides are characterized by the α-1,6 bond between galactose and the neighboring molecule and are considered indigestible in the upper intestinal tract of the nonruminant animal (Naumoff, 2004). In absence of α-galactosidase, the enzyme required for digestion, there is no indication that galactose molecules are released from α-galactoside (Gitzelmann and Auricchio, 1965). As a result, α-galacto-oligosaccharides, along with other nonstarch polysaccharides (NSP), are broken down by microbial fermentation into short-chain fatty acids (SCFA) and lactic acid (Lindberg and Ogle, 2001) along with gaseous products in the large intestine.

Bacterial fermentation of α-galactoside has both bifidogenic and antinutritional effects. Fermentation of NSP produces short chain fatty acids (SCFA) (Smiricky-Tjardes et al., 2003) which have trophic effect on intestinal epithelial by increasing epithelial growth and gastrin secretions (Reilly et al., 1995) which improves sodium absorption, stimulates blood flow, and regulates nutrient absorption with pH decreasing as fermentation time increases (Smiricky-Tjardes et al., 2003).

Antinutritional effects have been observed in relation to soybean oligosaccharides, particularly in rations with high concentrations. In one of the first studies of antinutritional factors of soybean oligosaccharides rats were fed 3 to 5 g of raffinose/meal which resulted in severe diarrhea (Kuriyama and Mendel, 1917). Supplemental α-galactosidase is designed to improve digestibility of soybean oligosaccharides in nursery diets of newly weaned pigs. However, the first study to use fungal α-galactosidase in a legume based piglet diet did not alleviate the adverse effects of α-galactosides (Veldman et al, 1993). Rather it was hypothesized that increasing the concentration of fermentable substance in the lower digestive tract may have disrupted the microbial balance and increased diarrhea (Veldman et al, 1993). Pluske et al. (1998) found increased concentration of NSP in the large intestine resulted in swine dysentery, proliferation of *E. coli*, and poor growth performance. In addition some soybean meal proteins (glycinin and beta-glycinin) have been reported to cause an allergic reaction in 2 and 3 wk old nursery pigs due to a hypersensitivity response (Coffey et al., 1995). The allergic response damages the intestinal wall which disrupts absorptive and immune capacity of the gastrointestinal tract (Coffey et al., 1995). Alternatives to SBM in the young pig's diet include highly digestible animal proteins and modification of soybean meal to lower antinutritional factors.

Removal of the antinutritional factor α-galactoside in SBM can be accomplished by alcohol extraction, water extraction or genetic modification. Water extraction can lower stachyose and raffinose levels which increases digestible energy (Seve et al., 1989). With ethanol extraction total metabolizable energy (TME) can be increased by 574 kcal/kg SBM when 95% of stachyose and raffinose are removed from SBM (Coon et al., 1990). Leske et al. (1993) concludes that 80% of stachyose should be removed to maximize TME. Removal of stachyose and raffinose using ethanol extraction or alpha-galactosidase did not improve TME (Irish et al., 1995). Low-oligosaccharide SBM is arising as an alternative method to enhancing SBM digestibility (Kerr and Sebastian, 1998; Neus et al., 2005). Low-oligosaccharide SBM has very low levels of α-galactosides (0.2 to 0.5% DM) and the genetic modification increased CP and sucrose concentrations (Parsons et al., 2000).

Nursery feed is generally medicated subtherapeutically to prevent scours and retardation of growth during weaning and in the transition from a liquid to solid diet. Addition of 450 to 900 g of copper sulfate to a 907.19 kg diet, in addition to antibiotics, improves growth more than feeding either alone (H. Stein, University of Illinois, Urbana, IL, hstein@uicu.edu).

Several methods have been investigated which lower the incidence of scours, bacterial infection or colonization without use of subtherapeutic antibiotics. Stein and Kil (2006) suggest a reduction of CP from the normal 21 to 23% range to 15 to 18% CP and replacement with crystalline amino acids may reduce scours without affecting long term growth performance of the pig. When two levels of CP were added to the diets for d 0 to 14 (15% vs. 20% CP) and d 14 to 35 (19% vs. 17%), the lower level of CP for d 0 to 14 did not negatively impact overall growth performance but did decrease scouring rate (Stein and Kil, 2006). Overall wt gain was similar for both regimens (Stein and Kil, 2006). Addition of synthetic amino acids to a low-protein diet did not result in greater growth performance and incidence of diarrhea were not decreased (Reynoso et al., 2004). When Nyachoti et al. (2006) reduced CP concentration from 23 to 17% there was a linear ($P < 0.001$) and quadratic ($P < 0.05$) effect on ADG and there was a linear ($P < 0.01$) effect on ADFI and G:F across the 21 d study and fecal consistency scores were not influenced by dietary treatment. Two studies found that pigs fed diets based on cooked white rice and animal protein did not develop swine dysentery when infected with a population of 10^{10} viable *S. hyodysenteriae* (dysentery causing bacteria) cells while pigs from all other diets containing cereal grains exhibited swine dysentery (Pluske et al., 1996, 1998). The rice and animal protein diet exhibited less fermentation which minimized the amount of nutrients for pathogenic microbes in the large intestine (Pluske et al., 1996; Stein and Kil, 2006). However diets based on corn silage successfully lowered the gastrointestinal pH and inhibited development of swine dysentery (Prohaszka and Lukacs, 1984).

Addition of organic acid is researched as an alternative to antibiotic with the hypothesis that organic acid can reduce gastric pH which would inhibit pathogenic bacteria growth. Paulicks et al. (2000) reported decreased incidence of diarrhea upon addition of FormiLHS (formic acid anhydrate) to cereal grain diets. Paulicks et al. (2000) did not however report gastrointestinal pH values, only diet pH values, which decreased from 6.2 to 5.3.

A pelleted nursery diet is preferred to a ground diet. Feed efficiency improves with pelleted feed, as a result of partial gelatinization of starch which improves nutrient digestibility. (Holden et al., 1990). Pelleted feed also reduces sorting, feed wastage, and destroys some feed-borne pathogens, e.g., salmonella, in excess of 82.2 to 87.8°C (180 to 190°F) (Holden et al., 1990). Pelleted diets are higher in cost than ground diets so newly weaned pigs generally only receive this diet during the first 1 to 7 d after weaning.

Liquid feeding, another feeding method, generally results in decreased gastrointestinal distress because the newly weaned pig is not yet accustomed to a solid diet. In selected experiments of Zijlstra et al. and Jensen and Mikkelsen (1996; 1998) early-weaned pigs fed liquid diets had 12.3% or greater improvement to performance over pigs fed dry diets due to the similarity to the preweaning diet and ease of digestibility. In addition, liquid diets have a lower pH which may reduce or inhibit the growth of pathogens in the intestinal tract (Geary et al, 1996; van Winsen et al, 2000). Atrophy of the intestinal diet is observed in nursery pigs fed a dry diet and it can be prevented with a liquid diet (Deprez et al, 1987; Gu et al, 2002; Scholten et al, 2002). An intestinal tract not disturbed by villous atrophy and crypt hyperplasia is thought to result in better growth performance (Pluske et al., 1997).

Fermented liquid feed is a feed and water mixture stored for a specified time and at a specified temperature before being fed to the animal (Canibe and Jensen, 2003). There are two phases that occur in the fermentation of feed. In the initial phase of fermentation the feed is not an ideal composition for nursery pigs due to low levels of lactic acid, lactic acid bacteria and yeast while the pH and enterobacteria count is high (Canibe and Jensen, 2003). In the second phase lactic acid bacteria, lactic acid and yeast levels are high while the pH and enterobacteria counts are low (Canibe and Jensen, 2003). Fermented feed should be fed once it has reached the second phase (Canibe and Jensen, 2003).

Fermented liquid feed decreases nonstarch polysaccharide concentrations by 2% when compared to dry feed and nonfermented liquid feed (9.6 ± 0.45 vs. 11.0 and 11.1 ± 0.78) (Canibe and Jensen, 2003).

Fermentation of liquid has shown further improvements to intestinal tract health (Geary et al, 1996; Scholeten et al, 1999; Brooks et al, 2003). Fermented liquid feed decreased gastric pH when compared to nonfermented liquid feed and dry feed and increased lactic acid bacteria in the stomach and small intestine (Canibe and Jensen, 2003). Presence of lactic acid bacteria via fermentation provides probiotic effects (Brooks et al, 2003). When compared to other feeding methods, fermented liquid feed resulted in an increased growth rate of 13.4% when compared to nonfermented liquid feed and 22.3% increase when compared to dry feed (Jensen and Mikkelsen, 1998). A process such as fermentation increases bioavailability of soybean protein to a relative 99.1% of plasma protein. Use of up to 6% fermented soybean meal (FSBM) replacing soybean meal in a standard nursery diet improved ($P < 0.05$) G:F (Kim et al, 2010). Fermentation of SBM had minimal effect on amino acid availability but lowered metabolizable energy when compared to conventional soybean meal (Rojas and Stein, 2013). Fermentation of the entire diet, however, may reduce the G:F ratio of the diet as a result of sugar and amino acid fermentation (Jensen and Mikkelsen, 1998). However, fermentation of only the carbohydrate fraction improves ADG and G:F (Scholten et al, 2002). Both liquid and fermented liquid diets have higher concentrations of short-chain fatty acids and reduced microbial activity, as a result the ability of these feeds to improve immune status is superior to dry diets (Scholten et al, 1999).

Feed Ingredients and Feed Additives

Diet formulation and feeding strategies may be used to boost the pig's immune system and reduce the negative impact of weaning. Nutritionists face a great challenge when designing plant-based diets for nursery pigs that are as effective at delivering nutrients as milk from the sow while maintaining a low cost. "At birth, the pig secretes abundant quantities of enzymes that are needed to digest the proteins and fats contained in milk" (Coffey & Cromwell, 1995). At weaning, the pig is still dependent on these nutrients. Feed additives to improve nursery pig performance are numerous with various modes of actions to improve physiological function of the pig.

Milk and Whey

Traditionally dried skim milk was used as a protein source for the young nursery pig (Coffey et al., 1995). Milk is an excellent feed due to the nutrient composition, high digestibility, and similarity to a sow's milk (Coffey et al., 1995). Addition of milk products to a corn-soybean meal diet improves growth performance during the nursery period and subsequent growth in the finisher period (Tokach et al., 1995; Zijlstra et al., 1996). Dried whey is added to the nursery diet as a source of highly digestible carbohydrate which allows the pig to more easily transition from a milk based diet to a solid plant based diet (Coffey et al., 1995). Dried whey is added by spray-drying or roller-drying liquid whey and contains 70% lactose and 12% protein (Coffey et al., 1995). Quality and nutritional value of dried whey depends on the drying process. Whey dried at too high a temperature is susceptible to the Maillard reaction, which binds lysine and lactose and decreases their availability (Coffey et al., 1995). Lower cost alternatives to dried whey are whey permeate (80% lactose) and 100% lactose.

Pigs weaned at 21 d and fed a milk replacer + starter diet for 4 d followed by a starter diet had better growth performance when compared to pigs fed only the starter diet (Zijlstra et al., 1996). For pigs weaned at 18 d and fed milk replacer to 25 d, they had significantly ($P < 0.05$) higher water, fat, and protein accretion than 18 d old suckling pigs, 25 d old suckling pigs, and 25 d old nursery pigs on a starter diet (Zijlstra et al., 1996). Addition of whey or casein added in combination and at variable rates to improve growth response. Addition of 20% whey and skim milk to a corn-soybean meal diet results in greater growth response, in the first 14 d post weaning, in comparison to addition of whey alone (Hansen et al., 1993). Pigs fed plasma protein in addition to whey and lactose have greater growth performance (Hansen et al., 1993). However pigs fed high protein (73% CP) whey in a corn-soybean meal diet showed greater growth performance than pigs fed plasma protein across a 35 d study (Grinstead et al., 2000). Despite high digestibility, milk is an expensive feedstuff (Coffey et al., 1995).

Blood Meal

Blood meal is substituted in nursery pig diets as a less expensive digestible animal based feedstuff. Greatest performance improvements were seen in various phases of the nursery period. Pigs fed SDBM in a corn-soybean meal diet for 28 d following weaning had greater ADFI and ADG than pigs fed a high whey diet the first 7 d postweaning (Kats et al., 1994). Kats et al. (1994) noted similar growth performance of pigs fed SDPP and SDBM, however, pigs fed SDPP had better growth performance earlier in the feeding trial (d 7 to 28) and pigs fed SDBM had better growth performance latter in the feeding trial (d 28 to 56). Hansen et al. (1991, 1993) also noted a growth performance response later in the nursery period with addition of SDBM. Despite latent growth performance, pigs fed SDBM had greater growth performance across the entire nursery period (Hansen et al., 1991, 1993; Kats et al., 1994). SDBM improves long term feed intake, when pigs are no longer fed SDBM (Hansen et al., 1993; Kats et al., 1994).

Blood used to make blood meal may be stored for several days prior to drying. This storage period has potential for microbial populations to increase and for blood to become more acidic (DeRouchey et al., 2003). Decreased pH of blood meal creates an unpleasant odor that may reduce palatability but it did not affect feed intake (DeRouchey et al., 2003). Blood meal, can be irradiated to decrease bacteria content without decreasing protein content, improved ADG and G:F when compared to blood not irradiated.

Blood meal varied in CP and lysine content (Kratzer and Green, 1957). Three samples of blood meal were 88, 92, and 96% CP with 11.9, 16.9 and 16.4% lysine (Kratzer and Green, 1957).

Blood Plasma

Replacement of dried skim milk with plasma protein can improve growth performance as much as 40% (Hansen et al., 1991). In a review by Coffey et al. (1995) 11 studies comparing pigs averaging 21.4 ± 5.5 d of age demonstrated 41% improvement to ADG and 35% improvement to ADFI. Improved performance of plasma protein in comparison to milk protein maybe the result of the high level of biologically active proteins (70%) (Hansen et al., 1993). Pigs fed plasma protein seem to experience a postweaning lag during weaning if plasma protein is removed from the diet (Hansen et al., 1993).

Spray-dried plasma, a by-product of the meat packing industry, is a highly digestible protein additive with a balanced amino acid profile (Coffey et al., 1995; Cho et al., 2010). Blood is collected from animals at slaughter and the plasma is separated with centrifugation. Plasma is stored in refrigeration until it is sprayed into a heat chamber removing the liquid, leaving an off-white powdered protein (Coffey and Cromwell, 1995). Spray-dried plasma protein is high in protein (78%), lysine (6.9%), tryptophan, and threonine, and low in concentrations of methionine and isoleucine (Coffey et al., 1995). Spray dried plasma, spray dried blood plasma, or spray dried blood is generally porcine or bovine derived and are supplied at a rate of 3 to 7% of the weanling pig diet. Immunoglobulin G is the predominant antibody, which is responsible for its immune boosting capability(Coffey and Cromwell, 1995; Cho et al., 2010).

Despite excellent performance improvements, SDPP is an expensive feedstuff, like dried skim milk. For this reason, it is recommended that SDPP be fed for only the first 7 to 10 d after weaning (Coffey et al., 1995). The excellent growth performance response beyond 10 d encourages producers to continuing feeding the additive beyond the point of being economically justified (Coffey et al., 1995). Addition of a lower cost feed additive that offers similar growth performance improvements could be added to the nursery diet at weaning or 10 d postweaning.

Other animal plasma proteins, such as dried porcine solubles (DPS) and spray-dried blood cells, are less expensive and viable alternatives to SDPP but are not as commonly researched or utilized in the swine industry (Cho et al., 2010). DPS are the byproduct of heparin extraction from porcine intestines and intestinal mucosa (Cho et al., 2010). DPS can be dried using a carrier (DPS 30) , like soybean hulls, or without a carrier (DPS 50RD), which results in a higher protein, lower fiber product (Cho et al., 2010)

Egg

Egg protein is produced from unviable eggs. Egg standards of the USDA (2000) evaluating the egg white, yolk, shell, cleanliness and air cell determine if the egg is viable or unviable. Egg products containing a specific antibody are produced by vaccinating the hens against the antigen of interest (Marquardt et al., 1999; Chalghoumi et al., 2009). Eggs are being sought after as an alternative to antibiotics for their immunological properties and low cost, compared to other forms of immunotherapy (Xu et al., 2011).

Enzymes

Production of endogenous enzymes necessary for digestion of more complex proteins and carbohydrates is insufficient until the pig reaches 4 to 6 wk of age (Coffey et al., 1995). Addition of enzymes like α-galactosidase and β-mannose to the diet may increase carbohydrate digestion by increasing digestibility of non-starch polysaccharides which are indigestible by gastrointestinal tract of the nursery pig. Citric acid, fumaric acid, formic and lactic acids are added to decrease the gastrointestinal and diet pH. This function activates enzymes, inhibits growth of pathogenic bacteria, and promotes growth of intestinal flora. Fermentation improves digestibility by converting indigestible or lowly digestible nutrients to a more highly digestible nutrient.

Non-starch polysaccharides such as those in soybean meal fed to newly weaned nursery pigs are indigestible causing decreased feed intake and nutrient utilization. Use of enzymes to digest non-starch polysaccharides into digestible nutrients for nursery and growing pigs has been investigated with variable growth performance results (Zijlstra et al, 2010). Owusu-Asiedu et al propose the variability is due to a mismatch of enzymes to non-starch polysaccharides when multiple are present in a feedstuff (2012). The enzyme α-galactosidase catalyzes the cleavage of the α-1, 6 linkage between galactose and neighboring molecules on α-D-galactosides, including galactose, oligosaccharides, galactomannanes, and galactolipids (Gitzelmann and Auricchio, 1965; Ademark et al., 2001; Naumoff, 2004).

Activity of α-galactosidase is optimal at a pH of 4.5 (Ademark et al., 2001; Fialho et al., 2008), with the pH of a standard corn-soybean diet at 6 (Ao et al., 2009) presence of inorganic acids in the diet may provide the pH drop necessary to activate the enzyme.

Organic Acids

Inorganic acidifiers, as well as organic acidifiers, are added to the diet as low cost strategy for improving pig performance. According to Kim et al., (2005) dietary acidifiers lower gastric pH, resulting in increased activity of proteolytic enzymes, improved protein digestibility and inhibition of proliferation of pathogenic bacteria in GI tract. In addition it is hypothesized that decrease stomach pH reduces the rate of stomach emptying, thus increasing protein digestion. And reduced stomach pH reduces proliferation of coliforms and other pathogens in the upper GI tract (Holden et al., 1990).

The ability of a feed to bind acid is its acid-binding capacity (ABC) (Lawlor et al., 2005). The ABC influences the pH of the pig's stomach (Lawlor et al., 2006). Acidogenic feed additives, like calcium benzoate, lower gut pH (Mroz et al., 2000) through fermentation of the diet. Che et al. (2012) measured a diet's ability to lower pH of the gastrointestinal tract with buffering capacity. Buffering capacity and acid-binding capacity both measure a feed's ability to resist pH change and the methods only differ by the unit of measurement. When the following dietary acids were added: 0.1 or 0.2% phosphoric acid alone or in combination with 1% or 2% organic acid mixture (50% citric acid and 50% fumaric acid) to the nursery diet diet pH was maintained around 6.5 (Che et al., 2012). Partial replacement of 1.2% limestone with 2.4% Ca benzoate resulted in a lowered dietary buffering capacity pH by 0.4 units (Mroz et al., 2000). Addition of fumaric acid in a nursery diet formulated to meet or exceed NRC requirements reduced buffering capacity resulting in a reduced gastric pH (Lawlor et al., 2006). The diet of Lawlor et al. (2006) was formulated primarily of plant based ingredients which are more responsive than animal based diets containing milk powder and fishmeal. (Giesting 1986 Utilization of Soy Protein by the Young Pig soy-protein diet has greater growth performance than casein diet)This is because lactose will ferment to lactic acid lowering the gut pH to a point that fumaric acid is ineffective in lowering the gut pH any further (Lawlor et al., 2006). Similarly, fermented liquid feed produces high levels of lactic acid, and a low pH in the stomach, jejunum and ileum (Canibe and Jensen, 2003).

Study I

Although most studies of spray dried porcine plasma have shown to increase growth rate and feed intake over improvements by spray-dried skim milk (Gatnau and Zimmerman, 1990; Sohn et al., 1991; Hansen et al., 1993; Rantanen et al., 1994), the magnitude of increase has been somewhat variable, indicating inclusion rate of SDPP in the diet may have contributed to differences in growth enhancement (Coffey and Cromwell, 1995). The dietary level of SDPP needed to maximize early weaned pig performance has been reported to be 6% (Gatnau, et al., 1991) (Gatnau & Zimmerman, 1992), between 8 and 10% (Kats et al., 1994), or up to 13.4% (Hansen, et al., 1993), with response still noted at 2.5 and 5% inclusion rate of spray-dried plasma (Grinstead et al, 2000).

Cho et al. (2010) evaluated the preference of dried porcine solubles (DPS 30) vs. SDPP and spray-dried blood cells (SDBC) and each diets effect on growth performance of Hampshire × (Landrace ×Yokshire) pigs in 4 experiments. Exp. 1evaluated DPS 30 relative to SDPP (Cho et al., 2010). Diets included control (CNTL1) [corn (C) (47.95%), SBM (20%), and dried whey (DW) (20%)] and CNTL1 + 3% SDPP or DPS 30 (SDPP3, DPS3) or + 6% SDPP or DPS 30 (SDPP6, DPS6) (Cho et al., 2010). One-hundred fifty pigs (27 ± 1.58 d, 7.42 ± 0.68 kg) were split into six replicate feeding trials, housed 5 pigs/pen (1.22 m^2), and fed one of the five diets for 4 wk (Cho et al., 2010). The required lysine requirement was not met so pigs on the control diet had reduced growth rate (Cho et al., 2010). If Lys, along with Met and Thr, requirements are met then pigs fed DPS 30 would grow as well or better than SDPP (Cho et al., 2010). Exp. 2 evaluated DPS 30 relative to spray-dried blood cells (SDBC) in Phase II of the nursery period. Diets included control (CNTL2) (46.92% C, 25.00% SBM, and 20% DW) and CNTL2 + 3.0% SDBC (BC3), CNTL2 + 1.5 DPS 30 + 1.5% SDBC (DPBC1.5), 3.0% DPS 30 (DPS3), or 5.0% DPS 30 (DPS5) (Cho et al., 2010). One-hundred sixty-five pigs (20 ± 1.95 d, 6.30 ± 0.90 kg) were allotted to one of the four treatments across 6 replicates, housed 5 or 6 pigs/pen (1.22 m^2), and fed for 4 wk (Cho et al., 2010). Feed intake was not significantly different for BC3, DPBC1.5, and DPS3 from 0 to 21 d (Cho et al., 2010). Feed intake for DPS5 was significantly ($P < 0.05$) lower from d 0 to 7 and 14 to 28 (Cho et al., 2010). ADFI of BC3 was significantly ($P < 0.05$) higher than DPBS1.5 and DPS5 from d 21 to 28 (Cho et al., 2010). ADG did not significantly differ throughout the trial (Cho et al., 2010). Exp. 3 evaluated the preference of 80 pigs (22 ± 2.45 d) for 0, 2.5, or 5% addition of DPS 30 (DPS0, DPS2.5, DPS5) to a diet containing 32.14% Phase (PH) 1 and 43.68% PH 2 C; 30.40% PH 1 and 27.50% PH 2 SBM; and 25% PH 1 and 20% PH 2 DW (Cho et al., 2010). Pigs were housed 4/pen with two feeders/ pen and a total of 20 pens for the study (Cho et al., 2010). In one set of 10 pens, DPS0 was added to one feeder and DPS2.5 was added to the other feeder; in the other set of 10 pens, DPS2.5 was added to one feeder and DPS5 was added to the other feeder (Cho et al., 2010). Feeders were rotated three times a wk to minimize preference of a feed due to location of the feeder (Cho et al., 2010). Pigs preferred DPS2.5 in both sets of 10 pens (Cho et al., 2010). By d 4 to 7 in the first 10 pens and d 8 to 14 in the second 10 pens more than 2/3 of feed consumed was DPS2.5 (Cho et al., 2010). Exp. 4 evaluated the preference of 56 pigs (21 ± 2.45) for one of the following diets: 5% SDPP (SDPP5) or 2.5% SDPP + 2.5% DPS 30 (DUAL2.5) fed in first 7 pens; 3% DPS 30 (DPS3) or 1.5% DPS 50RD (DPSR1.5) fed in the second 7 pens formulated with 30 to 32% PH 1, 40 to 45% C; 31 or 35% PH 1, 25 or

32% PH2 SBM; and 25% PH 1, 20% PH 2 DW. Pigs were housed 4/pen (1.22 m^2) and fed for 4 wk (Cho et al., 2010). In the first 7 pens $^4/_7$ of feed consumption was the DUAL2.5 from d 1 to 14. From d 15 to 21, preference for DUAL2.5 increased its consumption to $^5/_7$ in d 15 to 21 and then to approximately ¾ in d 22 to 27 (Cho et al., 2010). Across the 27 d trial the mean consumption for DPS3 and DPSR1.5 was 52.94 and 47.06%, respectively. Indicating DPS 50RD with higher CP and ME can successfully replace twice the rate of DPS 30 (Cho et al., 2010). This study indicated that SDPP can be partially or completely replaced with DPS 30 and DPS 50RD which offer similar growth performance but are considered a lower cost ration.

In a study by Chalghoumi et al. (2009) 1d old male *Salmonella*-free broiler chicks were exposed to *Salmonella* and given egg yolk powder (EYP) to combat the bacteria. EYP was either hyperimmunized EYP (HEYP) (egg yolks obtained from hens immunized with *Salmonella* Enteritidis and *Salmonella* Typhimurium) or nonimmunized EYP (NEYP). There were 5 experimental treatments (T1-5), 1 positive control (PC), and 2 negative controls (NC1, NC2). EYP was supplied as 5% of the diet in T1-5 and Treatments consisted of HEYP: NEYP, (T1 100:0; T2 75:25; T3 50:50; T4 25:75. T5 0:100), PC was EYP-free but chicks were challenged with *Salmonella*, and NC1 and NC2 contained 5% HEYP and NEYP, respectively and chicks were not challenged with *Salmonella* (Chalghoumi et al., 2009). Three d after birds began receiving feed they were orally inoculated with *Salmonella*, all pens tested positive for *Salmonella* 2 d post-inoculation (Chalghoumi et al., 2009). Birds were fed for 28 d (Chalghoumi et al., 2009). IgY concentrations was similar in all EYP-supplemented feed (Chalghoumi et al., 2009). Antibody titer rates differed in accordance with different levels of HEYP addition

(Chalghoumi et al., 2009). Antibody titer was measured in blood serum of pigs fed NC2 and T5 diets despite receiving the NEYP diet the titer was 8 to 12.5 times lower than titer from *Salmonella* Treatments and was considered non-negligible (Chalghoumi et al., 2009). Titer in T1 was highest for both anti-*Salmonella* Enteritidis (1:1,600) and anti-*Salmonella* Typhimurium (1:2,500) (Chalghoumi et al., 2009). Mortality rate was not affected by *Salmonella* infection (Chalghoumi et al., 2009). There was no growth performance difference in NC1 vs. NC2 indicating anti-*Salmonella* spp. IgY offered no added benefit to an animal not challenged by *Salmonella* (Chalghoumi et al., 2009). Feed intake (g/bird/day) (FI), body wt gain (g/bird/day) (BW), and feed conversion ratio (g of feed:g of gain) (F:G) did not significantly differ for T1-5 (Chalghoumi et al., 2009). FI, BW, and F:G for T1-5 was significantly ($P< 0.05$) higher than PC (Chalghoumi et al., 2009). NC1 and NC2 had significantly ($P < 0.05$) higher FI and BW than T1-5 (Chalghoumi et al., 2009). Regardless of the concentration of the anti-*Salmonella* spp. IgY in the Treatments inclusion of any concentration of EYP in the diet increased FI, BW, and F:G over the PC group (Chalghoumi et al., 2009). *Salmonella* spp. cecal colonization was not significantly different between the PC and T1-5 (Chalghoumi et al., 2009). T1 significantly ($P = 0.0315$) reduced *Salmonella* spp. cecal colonization more effectively than T2-5 when measured on d7 (Chalghoumi et al., 2009). In conclusion, this study showed that chicks negatively affected by *Salmonella* will have greater growth performance if fed EYP and HEYP maybe more beneficial than NEYP when fed to chicks < 14 d old (Chalghoumi et al., 2009).

In a study by Chernysheva et al. (2004) 48 purebred Yorkshire pigs (22 ± 3.4 d of age) were used in a study to evaluate the effect of anit-K88 IgY in egg yolk antibody

(EYA) against diarrhea caused by an oral infection of 5×10^{11} colony-forming units (CFU) K88^{+} enterotoxigenic *Escherichia coli* (ETEC). There were 12 pigs/group (G), 4 pigs/G were used in each of three replicates. Groups included G1 and G2 which contained no EYA (NoEYA) in diet and G3 and G4 which contained 3.2 g/kg (0.32% of the diet) EYA (manufacturers recommendation) and 32 g/kg (3.2% of the diet) EYA in diet, respectively (Chernysheva et al., 2004). Diets were fed ad libitum for 5 d. After 3 d acclimation, G2-4 were orally challenged with ETEC and all pigs were euthanized for necropsy 36 hrs after challenge (Chernysheva et al., 2004). In G2-4 4, 3, and 5 pigs of the 12 each/group exhibited no clinical signs of gastrointestinal disease and 2, 3, and 2 pigs were euthanized prior to the 36-hr mark due to severe watery diarrhea and dehydration (Chernysheva et al., 2004). Necropsy of early euthanized pigs revealed fluid filled intestines and enteritis consistent with *E. coli* causing diarrhea (colibacillosis) and pure growth of *E. coli* (Chernysheva et al., 2004). The mean titer value of anti-K88 IgY for G4 feed was 0.03 and the mean titer for G3 feed was 0.003 when feed samples were diluted at a rate of 1 feed: 10 diluent (Chernysheva et al., 2004). Titers for anti-K88 IgY in intestinal tissue samples were diluted at a rate of 1 tissue: 2000 diluent were extremely low and did not differ (Chernysheva et al., 2004). In conclusion, addition of EYA with anti-K88 IgY did not protect pigs against diarrhea when challenged with 5×10^{11} CFU of K88^{+} *E. coli* (Chernysheva et al., 2004). Determining K88 receptors in the pig would have excluded pigs that are not affected by the K88^{+} strain of *E. coli* (Chernysheva et al., 2004).

In a study by Pierce et al. (2005) evaluated the growth performance of 14 and 21 d old pigs (Hampshire x Yorkshire) when fed spray-dried porcine plasma (SDPP) and spray-dried blood plasma (SDBP) in a corn-SBM-soy protein concentrate-whey diet. Pigs (4 to 5 pigs/pen, Exp. 1-4; 5 to 7 pigs/pen, Exp. 5) were allotted based on weaning wt to 1 of 5 dietary treatments within blocks. In Exp. 1 pigs (5.6 kg, 21 d of age) were fed SDPP at 3 molecular wt (IgG-rich (IR), albumin-rich (AR), and low molecular wt (LW)). Each molecular wt fraction was added to a diet to equal the amount found in the diet with regular SDPP (SDPP). These diets were compared to the control (C) in a 28 d feeding trial. In the first wk, pigs fed SDPP and IR consumed more feed ($P < 0.05$) and gained more wt ($P < 0.05$) than pigs fed C. Feed intake of pigs fed SDPP was significantly ($P < 0.05$) greater than all other treatments over the entire 4 wk experimental period (Pierce et al., 2005). In Exp. 2 80 pigs (6.3 kg, 21.3 d of age) were fed varying rates of porcine IgG to determine the level that would optimize growth (Pierce et al., 2005). C and SDPP were used again. Diets 3, 4, and 5 contained 1.25, 2.50 and 3.75% IgG-rich fraction which represented 40, 80, and 120% of IgG-rich fraction in SDPP. These diets were fed for 21 d. In wk 1 and 2, pigs fed SDPP and diets 3, 4 and 5 grew faster and gained more wt ($P < 0.05$) than C. ADG was maximized at the inclusion of 80% IgG-rich fraction. Growth performance was no different between the treatments in the third wk, except for a poorer G:F in the SDPP diet. In Exp. 3 95 pigs (5.3 kg, 14.8 d of age) early-weaned pigs were fed varying levels of IgG-rich fraction (1.38, 2.76, or 4.14%) (representing 64, 128, and 192% of IgG-rich found in SDPP) were added to C and compared to C and SDPP (Pierce et al., 2005). Diets were fed for 28 d. Addition of IgG-rich fraction improved growth rate ($P < 0.05$) in wk 1, 2 and wk 4 and G:F was greater ($P < 0.05$) than that of SDPP in wk 1 and 2. Inclusion of IgG-rich fraction was optimized at the middle level of 128% of the concentration in SDPP (Pierce et al., 2005). In Exp. 4 95 pigs (5.6 kg, 19.7 d of age) were fed SDPP and SDBP to compare growth response and to assess the effect of two dietary levels of bovine IgG for early weaned pigs. To the control diet (CON) SDPP and SDBP were added to diets 2 and 3 as 8.0% of the diet (Pierce et al., 2005). Diets 4 and 5 had bovine IgG-rich fraction at 1.07 and 2.14% which is 50 and 100% of IgG supplied by SDBP. Diets were fed for 14 d, after which time pigs were fed a common diet. Pigs fed SDPP had greater growth performance ($P < 0.05$) than CON and SDBP in wk 1 and 2. Addition of the bovine IgG-rich fraction improved ($P < 0.05$) ADG and G:F in wk 1 and 2. On the standard diet for wk 3 and 4, pigs previously fed SDPP and IgG maintained higher ($P < 0.05$) ADG and ADFI (Pierce et al., 2005). In Exp. 5, 152 pigs (6.4 kg, 22.5 d of age) were fed SDBP, SDPP, and 2 levels of bovine IgG-rich fraction (2.03 and 4.06%, providing 50 and 100% IgG of SDBP) for 28 d. Diets were fed for 14 d followed by a common diet for 14 d. All experimental treatments had higher ($P < 0.05$) ADG, ADFI, and G:F than pigs fed the control diet in wk 1 and 2. Pigs fed bovine IgG rich fraction had lower ADFI ($P < 0.05$) than pigs fed SDPP or SDBP in wk 1. After feeding of a common diet, only the greater ADG of SDBP and bovine IgG-rich fraction 2.03% was maintained over the control and a greater ($P < 0.05$) ADFI than SDPP (Pierce et al., 2005). Addition of SDPP or SDBP improves feed intake and growth rate, especially in the first wk postweaning and greater growth response is seen upon addition of approximately 50% of IgG found in SDPP and SDBP to a corn-soybean meal diet.

Jaen et al. (2002) evaluated the effect of pasteurization (P) and non-pasteurized egg protein (noP) on nursery pig growth performance when fed in place of spray-dried animal plasma (SDAP). Diets included NG (no additive), SDAP5 (5% SDAP), P50 (P replacing 50% SDAP), P100 (P replacing 100% SDAP), noP50 (noP replacing 50%

SDAP) and noP100 (noP replacing 100% SDAP). A total of 216 barrows (5.59 kg, 20 d of age) were fed experimental diets for 10 d followed by a common PH 2 and 3 diets for 10 to 24 and 24 to 38 d respectively. Egg product was the same for the two types of egg product and biotin was added to the diets to alleviate negative effects of avidin. Whey was equalized in all diets. In PH 1 (d 0 to 10) ADG ($P = 0.05$) and ADFI ($P < 0.05$) was higher for pigs fed P50 vs. pigs fed P100 (Jaen et al., 2002). Pigs fed noP had imporved G:F ($P < 0.05$) over pigs fed P. Effect of P and noP carried into PH 3, with pigs previously fed noP having greater ($P < 0.05$) ADG than pigs previously fed P (Jaen et al., 2002). Decreased growth performance when pigs were fed P may be the result of denaturation and insolubilization of egg protein and decreased bioavailability of amino acids (Jaen et al., 2002). In conclusion, noP can replace 50% of SDAP in the nursery diet when SDAP is provided as 5% of the diet.

Song et al. (2012) studied the nutrient content and growth performance effect of spray-dried egg derived from unfertilized eggs on nursery pigs. In Exp. 1 and 2 168 and 140 5 kg, 16 d old nursery pigs were fed a medicated diet with and without 5% spray-dried egg (SDE) in 14 replications/experiment. Pigs were fed for 10 d. 6 pigs were housed /pen in Exp. 1 and 5 pigs/pen in Exp. 2. Inclusion of SDE improved ADG and ADFI ($P < 0.05$), but G:F was not affected. In Exp. 3 1,008 pigs (5.2 kg, 20 d of age) were fed one of five diets: CNTL or CNTL + high (H) spray-dried plasma (SDP) +/- SDE and low (L) SDP +/- SDE. Diets also contained zinc oxide and antibiotic. Pigs were fed for 6 wk: 4 wk experimental diet, 2 wk corn-soybean meal diet. SDE and SDP replaced soy protein concentrate and poultry by-product meal, rather than whey, lactose, or fishmeal (Song et al., 2012). Diets with SDE increased ADFI ($P < 0.05$) in wk 1 over

CNTL. Carry-over effect of SDE inclusion in the diet was seen in wk 5 and 6. Pigs previously fed SDE had higher ADG ($P < 0.05$) and G:F ($P = 0.061$). Medical treatment of pigs fed SDE diets was lower in wk 1 ($P < 0.05$) and tended to be lower throughout the study (P=0.062) than for pigs fed diets without SDE (Song et al., 2012). In Exp. 4 160 weaned pigs (6.7 kg, 21 d of age) were fed SDE in place of SDP. There were 10 pens/ treatment and 4 treatments: CNTL +/- SDE and SDP +/- CNTL. No diets contained antibiotic or zinc. Pigs were fed by the same feeding program of Exp. 3. SDE and SDP concentrations decreased in the diet from wk 6% (wk 1) to 4% (wk 2) to 2% (wk 3 and 4) to 0%, corn-soybean meal diet (wk 5 and 6). SDE improved ADFI ($P < 0.05$) during wk 1. SDE negatively ($P < 0.05$) impacted G:F for wk 2 to 4 and overall. In wk 3 and 4 reduction of G:F was stronger with addition of SDP and SDE (interaction, $P = 0.063$) (Song et al., 2012). Inclusion of SDE seems to improve ADFI and ADG in the first wk post weaning but responses are more variable and less positive in the remainder of the nursery period. SDE does not seem to benefit G:F at any point.

In two experiments, Hong et al. (2004) evaluated growth replacement and nutrient digestibility when spray-dried plasma protein (SDPP) and antibiotic were replaced with spray-dried egg protein (SDEP). In Exp. 1 36 pigs (6.55 kg, 21 d of age) were fed 0, 3 or 6% SDEP or SDPP. From d 0 to 7 there was not a significant difference between diets for ADG, ADFI, or G:F. From d 7 to 14 increasing levels of SDEP in the diet linearly ($P = 0.01$) decreased ADG and ADFI and quadratically ($P = 0.01$) decreased ADG and G:F. Increasing inclusion of SDEP throughout the study tended to decrease growth performance. There were no significant differences in DM or N digestibility. Hong et al. (2004) conclude that 50% SDPP could be replaced by 3% SDEP without influencing pig performance. In Exp. 2 36 pigs (2.63 kg, 10 d of age) were fed a dieting containing antibiotic or SDEP at 0.1%, or 0.2%. Pigs fed SDEP0.2 grew 24% faster than pigs fed the diet with antibiotic but the difference was not significant. ADFI was higher, although not significantly so, for pigs fed antibiotic when compared to pigs fed both SDEP diets. Pigs fed SDEP0.2 were 41% more efficient than pigs fed the antibiotic diet – this was not significantly different. Pigs fed SDEP0.2 tended to have higher apparent DM and N digestibility. Inclusion of lower levels SDEP seem to be most effective, with increasing levels of egg resulting in decreased growth performance without effect on nutrient digestibility.

Study II

Many researchers have observed that dietary acidifier supplementation improved growth performance and health status in weaning pigs (Kim, et al., 2005). Considerable variations in results of acidifier supplementation have been reported in response of weaned pigs. Inconsistent responses to dietary acidifiers could be explained by feed palatability, sources and composition of diet, supplementation level of acidifier and age of animals (Kim, et al., 2005).

A digestibility study of 18 cannulated pigs – 6 castrated Polish Landrace (18 to 24 kg) in Exp. 1 and 12 castrated Dutch Landrace × Dutch Yorkshire (11 to 15 kg) in Exp. 2 – resulted in 77% and 64% digestion of α-galactosides without α-galactosidase supplementation and 98% and 92% digestion with enzyme supplementation (Alpha Gal, 5g/kg) when fed a diet of lupin seed meal (30 to 35%), corn starch (32 to 48%), and casein (30 to 66%) for 14 d (Gdala et al., 1997). Variation in digestion rates between experiments is due, in part, to different varieties of lupin seeds. In Exp. 1 the variety fed was cvs Juno and in Exp. 2 the varities fed were cvs Amulet and cv Saturn (Gdala et al., 1997). Results of this study support the digestibility improvement to a legume based diet with addition of α-galactosidase.

Three poultry studies were completed to evaluate the effect of α-galactoside digestibility of SBM by including α-galactosidase with and without treatment of SBM in ethanol extraction (Irish et al., 1995). In Exp. 1, 0, 0.05, 0.10, or 0.20 g/kg α-galactosidase was added to a corn-soybean meal (CSBM) diet, with high levels of SBM (35%), with or without invertase (0 or 1 g/kg) (Irish et al., 1995). Results showed no significant effect on wt gain or feed utilization (Irish et al., 1995). Both enzymes caused a decrease in dietary AME_n which may be the result of the enzymes releasing nonmetabolizable monosaccharides that were excreted in the urine (Irish et al., 1995). An α-galactosidase by invertase interaction resulted in a significant ($P < 0.05$) reduction in the concentration of stachyose when 0.10 g/kg α-galactosidase was added with invertase. The study found that α-galactosidase had no effect on the breakdown of oligosaccharides in the absence of invertase (Irish et al., 1995). In Exp. 2, 5 replicates of 4 broilers were fed from 7 to 21 d of age one of four treatments (SBM, ethanol-extracted SBM, water-incubated SBM, or water + α-galactosidase-incubated SBM) formulated with a CSBM diet resulted in 88, 17 and 78% decrease in α-galactoside concentrations in the three experimental diets (Irish et al., 1995). Ethanol extraction altered the composition of SBM by increasing crude protein concentration and crude fiber concentration, as well as, decreasing fat concentration. Broilers fed ethanol extracted SBM had a significantly ($P < 0.05$) lower wt gain, G:F, and apparent protein digestibility compared to all other diets (Irish et al., 1995). Feed consumption of the ethanol extracted diet may have decreased due to decreased palatability or a decreased amino acid availability (Irish et al., 1995). Digesta pH was also measured but SBM treatments did not significantly raise digesta pH as was predicted (Irish et al., 1995). In conclusion, removal of α-galactosides from SBM by ethanol extraction or addition of α-galactosidase did not improve total metabolizable energy or broiler growth performance (Irish et al., 1995).

Kim et al. (2003) supplemented a corn (32 to 63%, Phase (PH) I-III), soybean meal (20 to 32%, PH I-III) and whey diet (25 to 20%, PH I-III) with 0.1 or 0.2% carbohydrase (7 U α-galactosidase and 22 U β-1,4-mannase for every 0.1% addition/kg diet) to evaluate the effect of enzyme addition on growth performance, as well as, increased nutrient digestibility and villous preservation. In Exp. 1, 108 pigs (Camborough-22 × line 326) (21 ± 0.1 d of age and 6.29 ± 0.08 kg) were fed the base diet with 0, 0.1%, or 0.2% addition of carbohydrase (Kim et al., 2003). ADG did not vary between treatments in PH I, II or across phases. In wk 4 postweaning (PH III) pigs fed 0.1% carbohydrase tended ($P = 0.069$) to have higher ADG than pigs fed control (Kim et al., 2003). In PH II, ADFI was higher ($P < 0.05$) for pigs fed the control diet when compared to pigs fed 0.10% carbohydrase. In PH I, III and across all phases ADFI did not significantly differ for treatments. G:F for pigs fed 0.1% carbohydrase diet was significantly greater ($P < 0.05$) than pigs fed the control in both PH III and across all phases (Kim et al., 2003). In Exp. 2, ten 3 wk old gilts (16.8 ± 0.7 kg) were cannulated to evaluate apparent ileal digestibility of energy and AA of 0.1% carbohydrase addition in PH III to the same corn-soybean meal-whey diet of Exp. 1. Pigs fed 0.1% carbohydrase had greater (P < 0.05) apparent ileal digestibility of gross energy, lysine, threonine, tryptophan, histidine, and total AA than the control diet (Kim et al., 2003). Apparent ileal digestibility of methionine, branched-chain AA, and most nonessential AA was not different between the two treatments (Kim et al., 2003). In Exp. 3 90 pigs (24.8 ± 0.3 d of age and 8.0 ± 0.1 kg) were allotted 5 pigs/pen (9 replicates) and fed 0 or 0.1% carbohydrase diet in 21 d PH III (43 to 63 d of age) to evaluate effect on gut morphology and growth performance (Kim et al., 2003). In wk 3 of PH III, ADG and G:F were greater (P < 0.05) for pigs fed 0.1% carbohydrase than for pigs fed the control diet. G:F was also greater (P< 0.05) for pigs fed 0.1% carbohydrase across all phases (Kim et al., 2003). ADFI was not affected by any treatment. Overall, addition of 0.1% carbohydrase improved ADFI in wk 2 postweaning, improved ADG and G:F in wk 4 and 5 postweaning and improved G:F across the entire nursery period.

Positive growth performance response to addition of organic acids was reported by Vogt et al, 1981; Falkowski and Aherne, 1984; Geisting and Easter, 1985; Patten and Waldroup, 1988; Bayley et al, 1974; Kirchgessner and Roth, 1982; Young et al, 1970; Forsyth, 1975; and Skinner et al, 1991 in studies with chicks and pigs. The mechanism of action improving growth performance is not known but it has been shown that organic acids have an effect on bacteria concentrations in the ceca and small intestine (Vogt et al, 1981) with bactericidal effect on salmonella in a chick crop and carcass (Thompson and Hinton, 1997).

In a study by Boling et al. (2000) PIC crossbred pigs (10 to 11 kg) were used to evaluate the effects of citric acid addition on phosphorus (P) utilization in a P deficient corn-soybean meal diet. In the first study a phosphorus deficient diet was supplemented with 0, 3, or 6% citric acid, 1,450 U/kg phytase, or 6% citric acid + 1,450 U/kg phytase. Citric acid increased gain:feed ($P < 0.05$) as a result of decreased feed intake (Boling et al., 2000). In the second study 0, 1, 2 or 3% citric acid or 1,450 U/kg phytase were added to the same P deficient base diet. Increased ADG and G:F was observed with 2% addition of citric acid (Boling et al., 2000). Chicks showed significant ($P < 0.05$) improvements in feed conversion when citric acid was added at a rate of 3% of the diet (Boling et al., 2000). This study shows that citric acid should be added to a phytate-P deficient diet at a rate of 2% or lower to increase ADG and G:F, inclusion of acid at a higher rate adversely affects feed intake.

In a study by Che et al. (2012) 8 experiment stations housed 854 crossbred pigs (21 d old, 6.2 ± 0.6 kg) to evaluate the effect of dietary acid addition on nursery pig growth performance. Dietary treatments were all medicated with carbadox, except one and formulated to include no additives (control) or 0.1 or 0.2% addition of phosphoric acid, 1 or 2% organic acid mixture (50% citric acid: 50% fumaric acid), or a combination of 0.1% phosphoric acid and 1% organic acid mixture formulated with and without antibiotic to a corn (38 to 53%) whey (22 to 10%) and soy diet (10 to 24%) diet in 3 phases (Ph) (Ph 1 = 7 d, Ph 2 = 7 d, Ph 3 = 14 d) (Che et al., 2012). Significant differences in performance reflected greater performance for pigs fed antibiotic. In phase 1, there was no significant difference between treatments but there was a trend for ADG ($P = 0.079$) to be higher in pigs fed 0.2% phosphoric acid when compared to pigs fed the diet without antibiotic (Che et al., 2012). In phase 2, diets containing antibiotic had greater ADG ($P < 0.05$) and diets with no or low acid content (control, 0.1 or 0.2% phosphoric acid and 1% organic acid) had greater ADFI ($P < 0.05$) than the combination diet without antibiotic (Che et al., 2012). The combination diet with antibiotic tended (*P* = 0.068) to have greater ADFI than pigs fed the combination diet without antibiotic (Che et al., 2012). In phase 3, there were no differences in ADG, ADFI, or G:F among dietary treatments. In this study pigs fed acid diets with antibiotic had similar performance to pigs fed the control. Addition of acid did not significantly improve performance above that offered by the control diet.

One hundred and ten crossbred (Yorkshire × Lacombe) pigs (8.7 kg) weaned at 4 wk of age, were housed in pairs and fed a diet based on 28.7% barley, 20% each wheat and oat groats and 10% each soybean meal and dried skim milk – with addition of 0, 1, or 2% fumaric (FA) or citric acid (CA) (Falkowski and Aherne, 1984). There were 22 pigs/treatment and pigs were fed for four wk. ADFI was not significantly different between diets although it tended to decrease with increasing rate of acid and ADG increased with acid addition but not significantly (Falkowski and Aherne, 1984). Feed efficiency was 5 to 10% improved ($P < 0.05$) for pigs fed diets with acid. Diet pH was lowered with increasing rates of acid addition: 5.6 (control diet) to 5.0 (1% FA), 4.5 (2% FA), 4.9 (1% CA), and 4.5 (2% CA) (Falkowski and Aherne, 1984). Addition of fumaric acid did not significantly impact growth performance, but may have a significant positive impact on growth performance with higher inclusion rates.

Demonstrating similar results to Falkowski and Aherne (1984), the following improvements to pig performance with addition of fumaric acid, may suggest citric acid inclusion would offer the same performance improvements. Feeding 8 to 25 kg starter pigs, Kirchgessner and Roth note a decrease in feed intake with inclusion of 0.5 to 4% fumaric acid and ADG was significantly faster for pigs fed 2 % fumaric acid vs. 1%

fumaric acid. (1976). However, in a follow up experiment on 5 to 23 kg starter pigs, inclusion of 1.5 to 2% fumaric acid resulted in increased feed consumption (1978). G:F reported in both studies was similar to that found in the Falkowski and Aherne article.

In three growth experiments, 392 pigs (Hampshire, Yorkshire or Duroc sire × crossbred dam) (30 ± 3 d of age; 7.5 kg in Exp. 1, 8.6 kg in Exp. 2, 10 kg in Exp. 3) were fed for four wk to evaluate the effect of organic acid on growth performance of starter pigs (Giesting and Easter, 1985). In Exp. 1 pigs were fed a 70% corn-26% soybean meal diet supplemented with 2% propionate, fumarate, or citrate (Giesting and Easter, 1985). In Exp. 2 a similar corn-soybean meal diet was utilized with addition of 4% cornstarch that was replaced by 1, 2, 3 or 4% fumaric acid in varying acid diets (Giesting and Easter, 1985). In Exp. 3 the basal diet was formulated with adequate (20%) or inadequate (16%) amino acid addition and formulated with and without 2% fumaric acid (Giesting and Easter, 1985). In Exp. 1 addition of 2% propionic and fumaric acid significantly ($P <$ 0.05) improved feed efficiency and daily feed intake. Daily gain improved ($P < 0.05$) with addition of 2% fumaric acid. In Exp. 1 addition of organic acid did not significantly decrease diet pH. In Exp. 2 addition of increasing levels of fumaric acid resulted in a linearly ($P < 0.05$) increase in feed efficiency and average daily gain and a curvilinear reduction in diet pH (Giesting and Easter, 1985). In Exp. 3 20% CP provision resulted in higher ($P < 0.01$) ADG and improved ($P < 0.0001$) feed efficiency over pigs fed a diet with 16% CP. Addition of 2% fumaric acid improved ($P < 0.01$) feed efficiency regardless of protein level. There was no interaction of protein level and acid concentration (Giesting and Easter, 1985). Results of this study suggest addition of fumaric and propionic acid improved utilization of a corn-soybean meal diet.

Progeny sire line boars (Pig Improvement Associates (PIA), Blessington, Co. Wikclow) × F1 sows (Large white × Landrace; PIA) weaned at 22 ± 0.3 d (Exp. 1), 22 ± 0.4 d (Exp. 2) and 22 ± 0.3 d (Exp. 3) (Lawlor et al., 2006) fed a diet containing barley (16%), wheat (43 to 48%), dried whey (0.5%), herring meal (0.5%), full fat soy (12.5%), and soybean meal (10%) with addition of Ca (2.8, 6.0, 9.0, 9.5, or 12.0%) and P (5.1 or 7.0%) and with or without fumaric acid (FA) (20 g/kg) or calcium formate (CF) (15 g/kg) to evaluate the effect of these additives on the growth performance of newly weaned pigs (Lawlor et al., 2006). In Exp. 1 and 2 all treatments were the same but some treatments fed two diets for x and y number of d. The number of days was different between the two experiments (Lawlor et al., 2006). In Exp. 1, performance did not significantly differ except in wk 1 when FA increased ($P < 0.05$) feed intake in the normal Ca P (9.5 and 7.0%) diet (Lawlor et al., 2006). CF tended ($P = 0.07$) to reduce feed intake in wk 3 and 4 and across the whole experiment (Lawlor et al., 2006). Daily gain tended ($P = 0.09$) to increase in the first two wk with addition of FA. CF lowered daily gain ($P > 0.05$) in the second two wk of the trial and for the entire study FA tended ($P = 0.09$) to increase daily gain while CF tended to decrease daily gain (Lawlor et al., 2006). In Exp. 2, treatments did not have significant effect on wt gain, feed intake, or feed efficiency (Lawlor et al., 2006). In Exp. 3, a significant ($P < 0.05$) interaction between acid usage and calcium level was seen when feed intake increased as Ca levels decreased in an acid free diet. In contrast to this finding, feed intake was highest for the FA diet with the highest level of Ca (Lawlor et al., 2006). In general FA significantly ($P < 0.05$) increased feed intake and wt gain in the first 14 d of trial. G:F tended ($P = 0.10$) to be higher in the first 2 wk with diets containing FA but G:F in wk 3 and 4 was similar in diets regardless of whether or not FA was included (Lawlor et al., 2006). Ca levels did not have an affect on daily feed intake or daily gain. High Ca (12.0%) and Low Ca (2.8%) inclusion rate tended (P = 0.08) to improve feed efficiency in wk 3 and 4 of the study. Inclusion of fumaric acid in the first two wk postweaning improve feed intake and daily gain in a grain, soy, and animal protein diet with normal levels of Ca and P. Inclusion of fumaric acid in a high Ca diet increased feed intake, wt gain, and feed efficiency.

Boling et al. (2000) hypothesized that the high levels of citric acid were above the level necessary to elicit a maximum response. However, the high levels of citric acid decreased feed intake, which may indicate an aversion to the taste of citric acid, rather than a decreased growth response due to the high level of citric acid. Lower inclusion rate of citric acid in an organic mixture resulted in no performance improvement to nursery pigs within phases or over an entire 3 phase trial (Che et al., 2012). Poor response in both studies may be the result of inclusion rate, diet type or acid type. Giesting and Easter (1985) and Lawlor et al. (2006) found a 2% inclusion rate of fumaric acid to a corn-soybean meal diet significantly ($P < 0.05$) increased feed intake. The same 2% addition increased feed efficiency (Giesting and Easter, 1985) and tended (P =0.09) to increase daily gain (Lawlor et al., 2006). In contrast Falkowski and Aherne (1984) found inclusion of 2% fumaric acid to a grain-SBM-whey diet decreased feed intake but with increased feed efficiency.

Risley et al. (1992) decreased ($P < 0.001$) the pH of a 20% CP corn-soybean meal diet from 6.42 to 4.90 by addition of 1.5% citric acid and from 6.42 to 4.70 with addition of 1.5% fumaric acid without effect ($P < 0.10$) on the intestinal pH.

Addition of 1 or 2% fumaric or citric acid lowered the pH of the diets from 5.6 (control diet) to 5.0, 4.5, 4.9, and 4.5, respectively (Falkowski and Aherne, 1984). This reduction in pH may have decreased the pH value of stomach contents and increased pepsin activity. It was concluded by Tung and Pettigrew, in a review of acidifiers a diet with a reduced pH of 4.71, did not significantly ($p > 0.05$) reduce the stomach pH (2008). However, Scipioni et al. reported reduced coliform bacteria and anaerobic microbes in the intestinal tract of starter pigs fed fumaric and citric acid (1978).

Calorie restricted diets (2.74 Mcal of ME/kg) were fed to chicks and supplemented with α-galactosidase and 2% citric acid (Ao et al., 2009). Addition of α-galactosidase alone improved ($P < 0.01$) feed intake and retention of NDF and it improved ($P < 0.05$) average metabolizable energy, wt gain, and CP (Ao et al., 2009). Citric acid significantly increased DM ($P < 0.01$), CP ($P < 0.05$) and NDF ($P < 0.01$) retention but decreased feed intake ($P < 0.01$) and wt gain ($P < 0.01$). With addition of both citric acid and α-galactosidase, there was improvement ($P < 0.05$) to DM and AME, as well as, improvement ($P < 0.01$) to NDF retention (Ao et al., 2009). From d 1 to 14, an enzyme × citric acid interaction had significant ($P < 0.01$) deleterious effect on wt gain and gain:feed. In a second study, two diets were formulated with different energy levels (2.74 or 3.11 Mcal/kg) and supplemented with citric acid and α-galactosidase. There was no interactive effect of treatment on pH and reducing sugar content had no significant effect on energy level of the diet, additionally; there were no significant interactive effects. Citric acid significantly ($P < 0.01$) dropped digesta pH to 5.4 from 6.2 of the control diet and increased the reducing sugar population from 8.6g/kg to 12.5g/kg. α-galactosidase also significantly ($P < 0.01$) increased the reducing sugar population from

8.0 g/kg to 13.1 g/kg. The effect of treatment on growth performance and retention rates showed no significant main effect by enzyme or acid treatments. Low energy diets decreased ($P < 0.01$) body wt gain, gain:feed, average metabolizable energy, and DM intake while increasing feed intake ($P < 0.05$). A significant ($P < 0.01$) interactive effect of enzyme × citric acid on gain:feed vs. citric acid alone showed greater gain: feed for the dual diet, 0.723 vs. 0.705.

Deficiencies in the Literature

Examination of spray-dried egg with spray-dried blood plasma in one diet has been studied with variable response despite the argument that egg protein contains immunological properties that should optimize growth performance. Study I will examine the effect of addition of spray-dried blood plasma and spray-dried egg to a corn-soybean meal diet containing spray-dried plasma. Growth performance will be measured to evaluate the effect of both feed additives on nursery pig growth performance.

Joint addition of enzyme and acid has been examined in pigs, but the joint addition of citric acid and α-galactosidase has not been extensively studied. Study II will examine the effect of joint and independent addition of citric acid and α-galactosidase to a corn-soybean meal nursery diet to evaluate the effect on nursery pig growth performance.

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Tables

Table 1.1 Review of Age and Weight at Weaning for Select Studies

Author	Year	Sample Size	Age, d	Wt, kg
Cabrera et al.	2010	1,034	20 ± 0.2	
Kim et al	2010	192	19.2 ± 0.3	-
Kim et al	2010	144	22.1 ± 0.2	-
de Grau et al.	2005	3736	22	5.8 ± 1.5
Main et al.	2004	5728	12 – 22	
Schinckel et al.	2003	433	19.4 ± 2.4	6.3 ± 1.7
APHIS	2000	~2,500 sites	18 – 26	-
Schinckel et al.	1997	375	28.7 ± 0.3	14.6 ± 0.0
Coffey and Cromwell	1995	80	17 ± 1	4.9
Coffey and Cromwell	1995	160	18 ± 2	5.4
Coffey and Cromwell	1995	120	30 ± 3	7.3
Hansen et al.	1993		23	6.3
Giesting and Easter	1985	392	30 ± 3	8.7 ± 1.3
Falkowski and Aherne	1984	110	28	8.7

CHAPTER II

EFFECT OF SPRAY-DRIED BLOOD PLASMA COMPARED TO SPRAY-DRIED EGG ON NURSERY PIG GROWTH PERFORMANCE

Effect of Spray-dried Blood Plasma compared to Spray-dried Egg on Nursery Pig Growth Performance[1]

Elizabeth K. Pegg[*], Paul M. Walker[*], Rebecca L. Atkinson[†], Bud G. Harmon[‡] and Peter J. Lammers[*2]

Deparment of Agriculture, Illinois State University, Normal, IL, 61761[*]

Department of Agriculture, Southern Illinois University, Carbondale, IL, 62901[†]

Railsplitter Feed Technology Inc., Wildwood, MO, 63005[‡]

[1] Appreciation is extended to Brookside Agra L.C. and Belstra Milling Co. for contributions.

[2] Corresponding author: pjlamme@ilstu.edu

ABSTRACT: Spray-dried plasma (SDP) is included in nursery pig diets as a source of highly digestible protein and as a source of protective immunity. More recently, spray - dried chicken egg (SDE) has been used as an alternative to plasma protein. A study involving 372 weanling pigs from 2 farrowing groups were utilized in 2 trials to evaluate SDE on nursery growth performance. In each trial, pigs were weaned, ear-tagged and blocked by weight to 1 of 4 blocks. Pigs were randomly allotted within a block to 1 of 6 pens (7 or 8 pigs/pen), disregarding sex and litter. There were 3 diets: 2 diets containing SDP and whey (WHEY and PLASMA) and a diet containing SDE (EGG). Each diet was randomly assigned to 2 pens within each block. All diets were medicated with Carbadox (54.95 ppm). Diets were fed for 33 d using a 3 phase (PH) feeding program: Phase (PH) 1 = 7 d, PH 2 = 14 d (trial 1) and 11 d (trial 2), and PH 3 = 12 d (trial 1) and 15 d (trial 2). Days on PH were adjusted and then compared on the basis of 7 d for PH 1; 14 d for PH 2 and 12 d for PH 3. Feed disappearance and pig weight gain were used to calculate ADG, ADFI, and G:F. Growth performance parameters were equalized to an 8 pig/pen basis prior to statistical analysis. All data were analyzed using the MIXED procedures of SAS for a randomized complete block design. Pen was the experimental unit with the model including diet, phase, and diet × phase interaction. No significant diet × phase interaction was observed. Significant increases in ADG and ADFI were observed between Phase 1, 2, and 3 as pigs aged. No differences ($P > 0.05$) were found for ADG, ADFI, or G:F between the 3 diets. Diet costs were compared on the basis of \$/kg diet, \$/kg gain and \$/PH with the results indicating the PLASMA had the lowest \$/kg diet and \$/PH in PH 1. Since pigs fed the SDE diet had similar growth performance to pigs fed WHEY and

PLASMA, addition of SDE to a diet may be a viable feed ingredient if there is concern about feeding SDP.

Keywords: average daily feed intake, average daily gain, gain:feed, nursery pig growth performance, spray dried egg protein, spray dried plasma protein

Introduction

The nursery pig is stressed by weaning causing decreased growth performance. The transition from a liquid to a solid diet may result in less desirable micro flora colonizing the digestive tract which can lead to poor nutrient absorption and diarrhea (van de Ligt et al., 2002). Previous research has demonstrated the effectiveness of adding spray-dried plasma (SDP) to nursery pig diets to improve growth rate and feed intake post weaning (Hansen et al., 1991; Coffey and Cromwell, 1995; Grinstead et al., 2000; Bosi et al., 2004). Addition of SDP to a nursery pig diet has been shown to decrease the pigs susceptibility to illness caused by *Escherichia coli* K88 (*E. coli*) (Bosi et al., 2004). In addition, SDP is thought to influence intestinal immune status and inhibit gastrointestinal damage caused by bacteria and viruses resulting in improved function of the weaned pig's gastrointestinal tract (Coffey and Cromwell, 1995; Hong et al., 2004). This feed ingredient is high in protein (78%) and lysine (6.9%) (Coffey et al., 1995). Spray-dried egg (SDE) is being examined as an alternative to SDP. Egg is an effective feed additive due to the antibody content that may inhibit pathogenic invasion. It has been shown that antibodies found in egg yolk (IgY) were effective in protecting neonatal pigs from enterotoxigenic *E. coli* (Yokoyama et al., 1998; Marquardt et al., 1999), however, variable growth performance has been reported with addition of SDE. Addition of SDE at a rate higher than 3% decreased ADG, ADFI, and G:F (Hong et al., 2004) while addition of 5% SDE improved ADG and ADFI (Song et al., 2012). The decline inperformance is thought to be a result of increased levels of ovomucoid, a trypsin inhibitor. The objective of this study was to compare growth performance of pigs fed two variations of a corn and soybean meal (SBM) diet with SDP and whey vs. a corn-soybean meal diet with SDE to determine if the SDE diet is an economic alternative to a SDP and whey diet.

Materials and Methods

The protocol for this study was reviewed and approved by the Institutional Animal Care and Use Committee of Illinois State University (IACUC #07-2012).

Housing and Animal Management

This study was conducted at Illinois State University's Teaching and Research Farm, Lexington, IL (40° 39' 58.2978", -88° 46' 26.13"). Animals were housed in an environmentally controlled nursery room located in a farrow-nursery barn. Room temperature was initially set at 29.4°C and decreased weekly in 1° increments. Nursery rooms had slotted plastic flooring and solid plastic walls to prevent nose-to-nose contact between pens. Nurseries were sanitized weekly with Disrupt™ (Brookside-Agra, L.L.C., O'Fallon, IL), a commercial anti-microbial powder containing Fe, Cu, and Zn, by blowing the powder on all surfaces. Each pen (1.75 × 1.19 m) had a self-feeder and a bowl waterer.

Two replicate studies were completed in this experiment using 372 pigs from two consecutive farrowing groups. In each trial, pigs were weaned, ear-tagged and blocked by weight to 1 of 4 blocks. Pigs were randomly allotted within a block to 1 of 6 pens (7 or 8 pigs/pen), disregarding sex and litter. Pig weights and feed disappearance were measured weekly to calculate ADG, ADFI, and G:F.

Feeding Trial

Experimental diets were formulated by Railsplitter Feed Technology Inc. (Wildwood, MO), prepared by Belstra Milling (De Motte, IN), and shipped to the Illinois

State University farm. Diets were fed for 33 d using a 3 phase (PH) feeding program: Phase (PH) 1 = 7 d, PH 2 = 14 d (trial 1) and 11 d (trial 2), and PH 3 = 12 d (trial 1) and 15 d (trial 2). Diets included Belstra Milling commercial diet, a corn-soybean meal diet with low plasma and high whey concentrations in PH 2 and 3 (WHEY) (Table 2.1); a corn-soybean meal diet with high plasma and low whey in PH 2 and 3 (PLASMA) (Table 2.2), and a corn-soybean meal diet with EggLac Gold (SDE) (Brookside-Agra, L.L.C., O'Fallon, IL) (EGG) (Table 2.3). Dietary treatments were formulated to meet or exceed nutrient requirements of nursery pigs within each phase (NRC, 1998). All diets were medicated with Mecadox (Phibro Animal Health Corporation, Teaneck, NJ) (54.95 ppm). Days on PH were adjusted and then compared on the basis of 7 d for PH 1; 14 d for PH 2 and 12 d for PH 3.

Trial 1

In replicate one, 192 corssbred pigs (Duroc × [Chester White × Yorkshire]) were weaned (26.5 ± 1.9 d, 6.9 ± 1.35 kg**)** and sorted into 1 of 4 blocks based on weight, disregarding sex and litter. The blocks were light, medium-light, medium-heavy and heavy. Within each block there were 2 pens/treatment for a total of 6 pens/block. Pigs were randomly allotted to 1 of 3 treatments within a block resulting in 8 pigs/pen.

Trial 2

In replicate two, 180 pigs (Duroc × [Chester White × Yorkshire]) crossbred) were weaned (23.5 ± 3.6 d, 6.5 ± 1.14 kg) and sorted into 1 of 4 blocks based on weight, disregarding sex and litter. The weight blocks were light, medium-light, medium-heavy or heavy. Within each weight block there were 2 pens/treatment for a total of 6 pens/block. Pigs were randomly allotted to 1 of 3 treatments within a weight block resulting in 7 or 8 pigs/pen. Growth performance parameters were equalized to an 8 pig/pen basis by calculating an average weight and feed intake/pig then multiplying by 8, prior to analysis.

Statistical Analysis

All data were analyzed using the MIXED procedures of SAS (Version 9.1, SAS Institute., Cary, NC) for a randomized complete block design. Pen was the experimental unit with model including diet, phase, and diet × phase interaction. The effect of block was specified in the RANDOM statement. Significance was set at $P \leq 0.05$. No treatment × trial interaction was observed; therefore only treatment means are reported.

Cost Comparison

A cost comparison was completed to determine relative economics of the three dietary strategies. Bud Harmon (Railsplitter Feed Technology Inc., Wildwood, MO) supplied spring 2013 average prices for all feed ingredients (Table 2.4). Cost/unit of feed was calculated using the price of feed additives × diet formulation. The cost of feeding pigs throughout the trial was calculated using the cost/unit of feed × growth performance data.

Results

There were no significant differences in piglet performance between treatments and no treatment × phase interactions were found. Table 2.5 compares the performance of dietary treatments when all three phases are combined. There were no significant differences between treatments for ADG, ADFI, or G:F. Significant differences were found for ADG and ADFI between phases (Table 2.6), however, these differences were expected for growing pigs. ADG and ADFI increased as pigs grew with a similar trend regardless of treatment.

The $/kg diet was the same for WHEY and PLASMA in PH 1 and less costly than $/kg diet for EGG in PH 1 (Table 2.7). In PH 2 and 3 $/kg diet was lower for WHEY than for PLASMA and EGG (Table 2.7). Although the gain of PLASMA did not significantly differ from the gain of WHEY, the higher gain value for PLASMA resulted in an economic difference in the $/kg gain. In PH 1 and PH 2, $/kg gain was lower for PLASMA (Table 2.7). The one cent difference in PH 2 may have been the result of pigs fed WHEY catching up to pigs fed PLASMA. By PH 3 the $/kg gain was lower for WHEY (Table 2.7).The same pattern occurs for $/PH (Table 2.7).

Discussion

The economic comparison showed the PLASMA diet was more economical to feed in PH 1. Based on previous research, a higher rate of SDP may improve growth performance. Hansen et al. (1993) fed a similar rate of whey (16%) with a higher rate of porcine plasma (10%) resulting in greater growth performance than high rates of whey and skim milk. The PLASMA diet may not have had a high enough concentration of SDP to effect growth performance. A higher level of SDP may have been more effective in improving growth performance.

The EGG diet did not result in greater growth performance and the cost comparison showed it was more expensive to feed. The absence of whey may have limited growth performance of pigs fed EGG. In a study by Song et al (2012) growth performance was improved when the diet included 5% SDE and 15% dried whey. However, growth performance suffered when SDE concentration was increased to 6%

and whey was increased to 20% (Hong et al., 2004). Schmidt et al., (2003) modified the combination more drastically with a 7% concentration of SDE in combination with 12-13% lactose and also noted decreased growth performance. Addition of whey to the SDE diet may have improved growth performance of the nursery pigs and it may have decreased the cost of the diet. Addition of egg to a diet must be limited to prevent the negative effects of ovomucoid. Ovomucoid, a trypsin inhibitor, may have bound trypsin preventing activity of the protease (Feeney et al., 1963) leading to decreased nutrient utilization, as well as decreased growth performance . SDE may effectively replace SDP but it may not successfully replace a combination of SDP and whey.

Due to recent speculation of the link between SDP and porcine epidemic diarrhea virus (PEDV) some producers may choose to use SDE in place of SDP. With a similar response seen between the EGG and PLASMA diets, replacing SDP with SDE to produce a SDE and whey diet may be an effective alternative to SDP. In addition, the immunoglobulin present in egg , IgY, may decrease susceptibility to PEDV. When added to a diet fed to PEDV infected pigs, IgY improved the pig survival rate (Kweon et al., 2000). Since pigs fed EGG had similar growth performance to pigs fed WHEY and PLASMA, addition of SDE to a diet containing whey may be a viable alternative if there is concern about feeding SDP.

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Tables

Table 2.1 Composition of WHEY Diet Fed to Nursery Pigs in 3 Phases (as-fed basis)[1,2]

	WHEY		
Item	PH 1	PH 2	PH 3
Ingredient, %			
Corn grain	32.20	42.51	50.00
Soybean meal, w/o hulls, sol extr	25.13	27.31	33.19
Soybean hulls	0.75	2.40	2.40
Wheat middlings, < 9.5% fiber	5.00		
Dried whey	24.00	20.00	8.00
Fish menhaden meal, mech. Extr.	2.90		
White grease	1.59	1.73	1.40
Vitamin and mineral premix[3]	0.40	0.20	0.20
Methionine DL	0.012	0.03	0.015
Calcium Phosphate, dicalcium	1.26	1.70	2.07
Limestone, ground	0.69	0.70	0.60
Sodium Chloride	0.28	0.25	0.25
Zinc Oxide 72%	0.32	0.32	0.32
Blood plasma, spray dried	3.90	2.60	1.30
Fumaric acid	1.30		
Mecadox	0.25	0.25	0.25
Total	100.00	100.00	100.00
Calculated energy and nutrient content[4,5]			
ME, kcal/kg	3,515	3,445	3,379
SID Lys:ME, g/kcal	4.12	3.56	3.55
CP, %	22.66	20.85	22.05
Ca, %	0.98	0.93	0.91
P, %	0.84	0.77	0.78
Available P, %	0.55	0.51	0.50

[1]WHEY = Belstra Milling Control diet, corn-soybean meal diet with higher rates of whey then spray-dried plasma protein in PH 2 & 3

[2]Diets were fed in 3 phases: 7 d for PH 1, 14 d for PH 2, and 12 d for PH 3

[3]The vitamin and mineral premix provided the following per kg of diet: 1,250 IU Vitamin A, 125 IU Vitamin D3, 9.09 IU Vitamin E, 0.412 μg Menadione, 7.23 μg Vitamin B12, 1.46 μg Riboflavin, 4.53 μg d-Pantothenic acid, 6.80 μg Niacin, 25 μg Iron, 25 μg Zinc, 3.09 μg Manganese, 2.32 μg Copper, and 0.095 μg Iodine.

[4]CP, Ca, P, and available P provided by Bud Harmon (Railsplitter Feed Technology Inc., Wildwood, MO budgharmon@gmail.com), personal communication.

[5]ME and SID Lys:ME obtained from NRC (1998) and Meisinger (2010)

Table 2.2 Composition of PLASMA Fed to Nursery Pigs in 3 Phases (as-fed basis)[1,2]

	PLASMA		
Item	PH 1	PH 2	PH 3
Ingredient, %			
Corn grain	32.98	38.35	50.53
Soybean meal, w/o hulls, sol extr	25.00	22.46	26.08
Soybean hulls	0.75	0.75	0.75
Wheat middlings, < 9.5% fiber	5.00	5.00	5.00
Dried whey	24.00	18.72	7.80
Fish menhaden meal, mech. Extr.	2.90	2.90	2.40
White grease	1.34	4.43	0.97
Vitamin and mineral premix[3]	0.20	0.20	0.20
Methionine DL	0.034	0.06	
Lysine 78	0.02	0.10	0.11
Calcium Phosphate, dicalcium	1.38	1.05	1.64
Limestone, ground	0.40	0.73	0.83
Sodium Chloride	0.28	0.28	0.28
Zinc Oxide 72%	0.32	0.34	0.35
Blood plasma, spray dried	3.85	3.08	1.51
Fumaric acid	1.30	1.30	1.30
Mecadox	0.25	0.25	0.25
Total	100.00	100.00	100.00
Calculated energy and nutrient content[4,5]			
ME, kcal/kg	3,512	3,483	3,403
SID Lys: ME, kcal/kg	4.12	3.99	3.63
CP, %	22.64	20.82	20.93
Ca, %	0.90	0.90	0.98
P, %	0.86	0.75	0.78
Available P, %	0.57	0.48	0.50

[1]PLASMA = Corn-soybean meal diet with higher rates of spray-dried plasma protein then whey in PH 2 & 3

[2]Diets were fed in 3 phases: 7 d for PH 1, 14 d for PH 2, and 12 d for PH 3

[3]The vitamin and mineral premix provided the following per kg of diet: 1,250 IU Vitamin A, 125 IU Vitamin D3, 9.09 IU Vitamin E, 0.412 μg Menadione, 7.23 μg Vitamin B12, 1.46 μg Riboflavin, 4.53 μg d-Pantothenic acid, 6.80 μg Niacin, 25 μg Iron, 25 μg Zinc, 3.09 μg Manganese, 2.32 μg Copper, and 0.095 μg Iodine.

[4]CP, Ca, P, and available P provided by Bud Harmon (Railsplitter Feed Technology Inc., Wildwood, MO budgharmon@gmail.com), personal communication.

[5]ME and SID Lys:ME obtained from NRC (1998) and Meisinger (2010)
Bud Harmon (Railsplitter Feed Technology Inc., Wildwood, MO budgharmon@gmail.com), personal communication

Table 2.3 Composition of EGG Fed to Nursery Pigs in 3 Phases (as-fed basis)[1,2]

	EGG		
Item	PH 1	PH 2	PH 3
Ingredient, %			
Corn grain	34.59	34.78	51.00
Soybean meal, w/o hulls, sol extr	22.50	21.34	25.27
Soybean hulls	0.75	7.37	0.75
Wheat middlings, < 9.5% fiber	5.00	4.67	5.00
Fish menhaden meal, mech. Extr.	2.90	2.42	2.40
White grease		3.09	0.57
Vitamin and trace mineral mix[3]	0.20	0.20	0.20
Methionine DL	0.003	0.02	
Lysine 78	0.10	0.10	0.16
Calcium Phosphate, dicalcium	1.14	0.87	1.69
Limestone, ground	0.67	0.72	0.78
Sodium Chloride	0.28	0.26	0.28
Zinc Oxide 72%	0.32	0.33	0.35
EggLac Gold	30.00	22.42	10.00
Fumaric acid	1.30	1.21	1.30
Mecadox	0.25	0.23	0.25
Total	100.00	100.00	100.00
Calculated provisions (as-fed)[4,5]			
ME, kcal/kg	5,614	4,788	3,928
SID Lys: ME, kcal/kg	4.72	4.42	3.89
CP, %	22.26	21.26	20.67
Ca, %	0.97	0.90	0.98
P, %	0.80	0.72	0.78
Available P, %	0.59	0.51	0.53

[1]EGG = Spray-dried egg protein diet
[2]Diets were fed in 3 phases: 7 d for PH 1, 14 d for PH 2, and 12 d for PH 3
[3]The vitamin and mineral premix provided the following per kg of diet: 1,250 IU Vitamin A, 125 IU Vitamin D3, 9.09 IU Vitamin E, 0.412 μg Menadione, 7.23 μg Vitamin B12, 1.46 μg Riboflavin, 4.53 μg d-Pantothenic acid, 6.80 μg Niacin, 25 μg Iron, 25 μg Zinc, 3.09 μg Manganese, 2.32 μg Copper, and 0.095 μg Iodine.
[4]CP, Ca, P, and available P provided by Bud Harmon (Railsplitter Feed Technology Inc., Wildwood, MO budgharmon@gmail.com), personal communication.
[5]ME and SID Lys:ME obtained from NRC (1998) and Meisinger (2010)
Bud Harmon (Railsplitter Feed Technology Inc., Wildwood, MO budgharmon@gmail.com), personal communication

Table 2.4 Feed Price Index for Diet Cost Comparison[1]

Ingredients	Price, \$/kg[2]
Blood plasma, spray dried	5.17
Calcium Phosphate, dicalcium	0.12
Corn grain	0.22
Dried whey	1.01
EggLac Gold	2.04
Fish menhaden meal, mech. Extr.	1.15
Fumaric acid	0.89
Limestone, ground	0.08
Lysine 78	2.50
Mecadox	2.00
Methionine DL	4.60
Sodium Chloride	0.05
Soybean hulls	0.19
Soybean meal, w/o hulls, sol extr	0.42
Vitamin & mineral premix	1.23
White grease	0.90
Wheat middlings, < 9.5% fiber	0.15
Zinc Oxide 72%	0.60

[1]Bud Harmon (Railsplitter Feed Technology Inc., Wildwood, MO budgharmon@gmail.com), personal communication
[2]As of March 2012.

Table 2.5 Growth Performance by Diet, all Phases Combined

	WHEY	PLASMA	EGG		*P* - value
Item	PH 1 – 3	PH 1 – 3	PH 1 – 3	SEM	TRT
Pens	16	16	16		
Pigs	8	8	8		
Days on feed, d	33	33	33		
Start wt, kg/pig	14.69	14.72	14.71	0.25	0.99
End wt, kg/pig	46.17	47.17	46.12	0.62	0.45
ADG, kg	14.32	14.70	14.29	0.63	0.98
ADFI, kg	17.55	17.50	17.50	0.95	0.60
G:F	0.81	0.85	0.81	0.02	0.70

[1]Each value is the mean of 16 replicates
[3]Diets were fed in 3 phases: 7 d for PH 1, 14 d for PH 2, and 12 d for PH 3
[2]Diets were WHEY = Belstra Milling Control diet, PLASMA = spray-dried plasma protein diet, and EGG = spray-dried egg protein diet
[4]Within a row, means without a common superscript are different ($P < 0.05$).

Table 2.6 Growth Performance Presented by Phase for Each Diet[1,2,3]

Item	WHEY	PLASMA	EGG	SEM	P – value[4] TRT
		PH 1			
ADG, kg	1.33[a]	1.37[a]	1.24[a]	0.27	0.77
ADFI, kg	1.66[a]	1.59[a]	1.60[a]	0.37	0.97
G:F	0.80[a]	0.86[a]	0.77[b]	0.03	0.19
		PH 2			
ADG, kg	5.16[b]	5.67[b]	5.53[b]	0.27	0.77
ADFI, kg	6.78[b]	6.67[b]	6.59[b]	0.7	0.97
G:F	0.76[b]	0.85[a]	0.84[a]	0.03	0.19
		PH 3			
ADG, kg	7.83[c]	7.66[a]	7.52[c]	0.27	0.77
ADFI, kg	9.11[c]	9.24[c]	9.32[c]	0.37	0.97
G:F	0.88[a]	0.85[a]	0.84[a]	0.03	0.19

[1]Each value is the mean of 16 replicates
[2]Diets were fed in 3 phases: 7 d for PH 1, 14 d for PH 2, and 12 d for PH 3
[3]Diets were WHEY = Belstra Milling Control diet, PLASMA = spray-dried plasma protein diet, and EGG = spray-dried egg protein diet
[4]Within a row, means without a common superscript are different ($P < 0.05$).

Table 2.7 Cost Comparison of Diets[1,2,3]

Item	$/kg diet	$/metric ton	Gain	$/kg gain	$/PH
PH 1					
WHEY	0.70	702.42	1.33	0.88	1.16
PLASMA	0.70	697.67	1.37	0.81	1.11
EGG	0.85	849.78	1.24	1.10	1.36
PH 2					
WHEY	0.58	577.17	5.78	0.76	4.37
PLASMA	0.64	636.89	6.32	0.75	4.74
EGG	0.78	723.61	6.16	0.93	5.69
PH 3					
WHEY	0.43	426.40	7.24	0.50	3.64
PLASMA	0.45	448.00	7.05	0.55	3.87
EGG	0.49	490.43	6.94	0.61	4.26
PH Combined[4]					
WHEY	0.57	568.66	14.35	0.71	3.06
PLASMA	0.59	594.18	14.74	0.70	3.24
EGG	0.71	687.94	14.34	0.88	3.77

[1]Diets were WHEY = Belstra Milling Control diet, PLASMA = spray-dried plasma protein diet, and EGG = spray-dried egg protein diet
[2]Diets were fed in 3 phases: 7 d for PH 1, 14 d for PH 2, and 12 d for PH 3
[3]Formulas for cost analysis: $/kg diet = sum ($/kg of each ingredient × ingredient/total); $/metric ton = $/kg diet × 1000; $/kg gain = gain/d ÷ feed cost/d; $/PH = feed cost for d on PH
[4]PH Combined = average value for PH 1, 2, and 3

CHAPTER III

EFFECT OF α-GALACTOSIDASE AND CITRIC ACID ON NURSERY PIG GROWTH PERFORMANCE WHEN ADDED TO A CORN-SOYBEAN MEAL DIET

Effect of α-galactosidase and Citric Acid on Nursery Pig Growth Performance when added to a Corn-soybean Meal Diet[1]

E.K. Pegg and P.J. Lammers[*2]

Department of Agriculture, Illinois State University, Normal, IL, 61761[*]

[1] Appreciation extended to the Illinois Soybean Association for funding this project.

[2.] Corresponding author: pjlamme@ilstu.edu

ABSTRACT: Two experiments were conducted to test the hypothesis that supplementing nursery pig diets with α-galactosidase, citric acid, or both improves growth performance. In each experiment, 120 weaned pigs were sorted into 20 pens that were balanced for starting pen weight. In Exp. 1, 120 pigs were weaned at 29 ± 2 d (8.5 ± 1.7 kg) and in Exp. 2, 120 pigs were weaned at 18 ± 1.8 d (4.5 ± 0.9 kg). Pigs were housed in an environmentally controlled nursery at the Illinois State University Farm, Lexington, IL. Diets were formulated with a corn-soybean meal base according to NRC requirements. The exception was PH 1 of the standard nursery diet in Exp. 2. Alpha-galactosidase (AG) (AlphaGal^{TM} 145 Pc, Kerry Inc) was added to select diets at a rate of 0.3 g/kg soybean meal (SBM). Citric acid (CA) was added at a rate of 5% of the diet to select diets. In Exp. 1 diets included: 1) corn-SBM diet (CON); 2) corn-SBM diet + AG (ALF); 3) corn-SBM diet + CA (CIT); and 4) corn-SBM diet + AG + CA (DUA). In Exp. 2 diets included: 1) standard nursery diet (pelleted feed PH 1; corn-SBM diet PH 2) (NURS); 2) corn-SBM diet (CON2); 3) corn-SBM diet + AG (ALF2); 4) corn-SBM diet + CA (CIT2); and 5) corn-SBM diet + AG + CA (DUA2). Pigs were fed in phase for 21 d. Feed disappearance and pig BW were measured weekly to calculate pen ADFI, ADG, and G:F. Analysis of variance was performed using SAS (SAS Institute Inc., Cary, NC). Means were compared using Tukey's HSD. Pen was the experimental unit. Pigs fed ALF were less efficient ($P < 0.05$) than pigs fed CIT or DUA but had significantly higher ($P < 0.05$) ADFI than pigs fed CIT or DUA diets and higher ($P < 0.05$) ADG than pigs fed CON and CIT diets. In Exp. 2, pigs fed ALF2 had significantly ($P < 0.01$) higher ADFI than pigs fed DUA2. Pigs fed nursery diets containing animal proteins and AG had improved growth performance when compared to the control. Pigs fed nursery diets not

containing animal proteins but containing AG did not have improved growth performance over pigs fed the control.

Introduction

When fed as part of a corn-soybean meal diet, soybean meal (SBM) is an excellent feedstuff for pigs due to its amino acid profile which supports protein synthesis (Cromwell, 2000). Soybean meal contains over 30% total carbohydrates on a dry matter (DM) basis (Grieshop et al., 2003; Choct et al., 2010). Alpha-galactosides represent approximately 5% of SBM carbohydrates and are composed mainly of raffinose and stachyose (Grieshop et al., 2003; Espinosa-Martos and Rupérez, 2006; Han and Baik, 2006). Raffinose (0.5-1%) is a trisaccharide characterized by the α-1,6 bond between galactose and the glucose unit of sucrose. Stachyose (3-4%) is a tetrasaccharide characterized by the α-1,6 bond of galactose to the galactose unit of raffinose (Choct et al., 2010; Kempen et al., 2006; Espinosa-Martos and Rupérez, 2006; Grieshop et al., 2003; Parsons et al., 2000; Coon et al., 1990). Alpha-galactosidase (AG) is required to catalyze the α-1,6 bond. In the absence of AG there is no indication that galactose molecules are released from the oligosaccharide (Gitzelmann and Auricchio, 1965; Naumoff, 2004) in the small intestine of pig. Lack of digestion can increase viscosity of the digest, slowing molecule movement thereby decreasing digestion (Smiricky et al., 2002). Undigested oligosaccharides are broken down by microbial fermentation in the large intestine producing gaseous by-products (Gdala et al., 1997; Lindberg and Ogle 2001; Jarret et al., 2012). The undigested feed and gaseous by-products will increase gut fill, decreasing optimum feed consumption and nutrient utilization of the feed. Decreased feed intake and decreased nutrient utilization results in decreased growth rate.

Addition of AG to a nursery pig diet has demonstrated variable performance responses. Addition of AG to corn-soybean meal diet did not affect the breakdown of oligosaccharides for poultry (Irish et al., 1995) but addition of AG in a lupin seed, corn starch diet resulted in nearly complete (98%) digestion of α-galactosides in nursery pigs (Gdala et al., 1997). Addition of AG in conjunction with other enzymes improved nursery pig growth performance (Kim et al., 2003). Diet composition may affect activation of AG. The enzyme is active at a pH of 4.5 to 5.5 (Ademark et al., 2001) but the pH of a corn-soybean meal diet is 6.0 (Ao et al., 2009). In addition, the gastrointestinal pH increases at weaning, creating a more basic environment (Barrow et al., 1977a). As a result, both the gut and diet pH may be too basic to fully activate supplemental AG.

Addition of dietary acids in the diet may provide the pH drop necessary to activate AG. Addition of 1 or 2% citric acid (CA) to a diet containing grain, SBM, milk and fish meal diet resulted in improved feed efficiency (Falkowski and Aherne, 1984). A similar result was found with a 19% CP corn-soybean meal diet (Giesting and Easter, 1985). Addition of 1.5% CA also has been show to decrease crop content pH while increasing reducing sugar concentration in chicks (Ao et al., 2009). Addition of 1.5% CA has been shown to decrease diet pH without lowering the intestinal pH of the pig (Risley et al., 1992). Addition of greater rates of CA may decrease the gastrointestinal pH to an optimum pH for AG activity. The objective of this study was to evaluate changes in nursery growth performance in response to addition of AG and CA independently and jointly.

Materials and Methods

The protocol for the study was reviewed and approved by the Institutional Animal Care and Use Committee of Illinois State University (IACUC # 08-2013).

Housing and Animal Management

Animal feeding trials were conducted at Illinois State University's Teaching and Research Farm, Lexington, IL (40° 39' 58.2978", -88° 46' 26.13"). Animals were housed in an environmentally controlled nursery room located within a farrowing and nursery barn. Nursery rooms had slotted plastic flooring and solid plastic walls to prevent nose-to-nose contact between pens. Each nursery room had 24 pens. Each pen (1.75 × 1.19 m) had a self-feeder and a bowl waterer.

Experimental diets were mixed at the Illinois State University farm and formulated to meet or exceed NRC (2012) nutrient requirements for the respective phases (PH). Pigs were weighed weekly and feed disappearance was measured to ADG, ADFI, and G:F

Experiment 1

In Exp. 1, 120 pigs were weaned (29 ± 2 d) and sorted into 20 pens (3 gilts and 3 barrows/pen). Pigs (8.5 ± 1.7 kg) were sorted into pens such that pen wt was similar for all pens (51.53 ± 0.27 kg). Following a 7 d adjustment period pens were assigned to 1 of 4 dietary treatments. Diets were fed for 21 d in 2 phases (PH 1 = 7 d, PH 2 = 14 d). The control diet was a corn-soybean meal diet with no additives (CON1). Alpha-galactosidase (AlphaGal™ 145 Pc, Kerry Inc) was added to CON1 at a rate of 0.3 g/kg soybean meal (SBM) to produce ALF1. Citric acid was added to CON1 at a rate of 5% to produce CIT1. Both α-galactosidase and citric acid were added to CON1 at the given rates to produce DUA1. Complete composition of the control diet for Exp. 1 can be found in Table 3.1.

Experiment 2

In Exp. 2, 120 pigs were weaned (18 ± 1.8 d) and sorted into 20 pens (3 gilts:3 barrows in 15 pens; 4 gilts:2 barrows in 5 pens). Pigs (4.5 ± 0.9 kg) were sorted into pens such that pen wt was similar for all pens (26.90 ± 0.34). Following a 3 d adjustment period pens were assigned 1 of 5 dietary treatments. Diets were fed for 21 d in 2 PH. The control diet was a corn-soybean meal diet with no additives (CON2). Alpha-galactosidase (AlphaGal™ 145 Pc, Kerry Inc) was added to CON2 at a rate of 0.24 g/kg diet to produce ALF2. Citric acid was added to CON2 at a rate of 5% of the diet to produce CIT2. Both α-galactosidase and citric acid were added at the given rates to CON2 to produce DUA2. A standard nursery diet was also fed: PH 1 was a pelleted nursery diet, PH 2 was a corn-soybean meal diet with higher rates of animal protein (NURS). Complete composition of the standard nursery and control diets for Exp. 2 can be found in Table 3.2.

Statistical Analysis

All data were analyzed using the ANOVA procedure of SAS (SAS Institute Inc., Cary, NC). The UNIVARIATE procedure was used to check normal distribution of model residuals and to check for equal variance. In Exp. 1 means were not normally distributed so the data was log transformed to create a more normal distribution. Means were backtransformed. The SEM was determined by backtransforming the mean ± SEM then subtracting the mean leaving SEM. In Exp. 2, the residual vs. predicted plot confirmed equal variance. Means were compared using Tukey's HSD. The model statement included the individual and combined effect of α-galactosidase and citric acid on growth performance in individual PH and in PH combined. All results are reported as least square means. An α-value of 0.05 indicated a significant difference among means.

Cost Comparison

In Exp. 1, a cost comparison of diets was completed to determine the cost of adding α-galactosidase. Steve Kuerth (JBS United Inc., Gridley, IL) provided high, low and current prices at the time of the trial (April 2013) for all feed ingredients and feed additives used in the diets. From these values an average cost was determined. (Table 3.3). Cost/unit of feed was calculated using the price of feed additives × diet formulation. The cost of feeding pigs throughout the trial was calculated using the cost/unit of feed × growth performance data.

Results

In Exp. 1, PH 1 no treatments significantly differed from the control diet in ADG, ADFI, or G:F, nor did any treatments significantly differ in G:F. Pigs fed ALF1 had a higher ($P < 0.01$) ADG and ADFI than pigs fed CIT1 and DUA1. In PH 2, no treatments significantly differed in ADG. Pigs fed ALF1 had a higher ($P < 0.001$) ADFI than pigs fed CIT1 and DUA1. Pigs fed CIT1 ($P < 0.01$) and DUA1 ($P < 0.0001$) had higher G:F than pigs fed ALF1 and CON1. When PH were combined pigs fed ALF1 had a higher ($P < 0.05$) ADG than CON1 and CIT1. Across PH, pigs fed ALF1 had a higher ($P < 0.001$) ADFI than pigs fed CIT1 or DUA1. Pigs fed CON1 also had a higher ($P < 0.05$) ADFI than DUA1. Across PH, pigs fed DUA1 had a higher ($P < 0.001$) G:F than pigs fed CON1 and ALF1. Across PH, CIT1 had a higher ($P < 0.001$) G:F than CON1 and a higher ($P < 0.05$) G:F1 than ALF.

In PH 1 of Exp. 2, the end wt (ENDWT) for pigs fed NURS was higher ($P < 0.001$) than all other treatments. The ENDWT for pigs fed ALF2 was higher ($P < 0.05$) than the ENDWT for pigs fed CIT2 and DUA2. Pigs fed NURS had higher ($P < 0.0001$) ADG than all other treatments. Pigs fed CON2 ($P < 0.05$) and ALF2 ($P < 0.01$) had a higher ADG than pigs fed DUA2. Pigs fed NURS had a higher ($P < 0.001$) ADFI than pigs fed CIT2 and a higher ($P < 0.0001$) ADFI then pigs fed DUA2. Pigs fed CON2 had a higher ($P < 0.01$) ADFI than pigs fed DUA2. Pigs fed ALF2 had a higher ($P < 0.01$) ADFI than pigs fed DUA2. The G:F of pigs fed NURS was higher ($P < 0.0001$) than all other treatments and G:F did not significantly differ among all other treatments.

In PH 2 of Exp. 2, ENDWT for pigs fed NURS was higher ($P < 0.001$) than pigs fed ALF2 and higher ($P < 0.0001$) than all other treatments. ADG for pigs fed NURS was higher ($P < 0.01$) than all other treatments. ADG did not significantly differ for all other treatments. ADFI for pigs fed NURS was higher ($P < 0.01$) than pigs fed CON2, higher ($P < 0.001$) than pigs fed CIT2, and higher ($P < 0.0001$) than pigs fed DUA2. Pigs fed CON2 had a higher ($P < 0.05$) ADFI than pigs fed DUA2. Pigs fed ALF2 had a higher ($P < 0.01$) ADFI than pigs fed DUA2. The G:F for pigs fed NURS was higher ($P < 0.05$) than CON2 and ALF2. The G:F for pigs fed CIT2 and DUA2 was higher ($P < 0.01$) than for pigs fed CON2 and ALF2.

In the combined PH of Exp. 2, the ENDWT for pigs fed NURS was higher ($P < 0.001$) than for pigs fed ALF2 and higher ($P < 0.0001$) than all other treatments. The ADG for pigs fed NURS was higher ($P < 0.0001$) than all other treatments. The ADG for pigs fed ALF2 was higher ($P < 0.05$) than for pigs fed DUA2. The ADFI for pigs fed NURS was higher ($P < 0.01$) than for pigs fed CON2 and higher ($P < 0.0001$) than for pigs fed CIT2 and DUA2. The ADFI for pigs fed CON2 was higher ($P < 0.01$) than for pigs fed DUA2. The ADFI for pigs fed ALF2 was higher ($P < 0.05$) than for pigs fed CIT2 and higher ($P < 0.001$) than for pigs fed DUA2. Pigs fed G:F for NURS was higher ($P < 0.0001$) than all other treatments. G:F did not significantly differ for all other treatments.

Discussion

In Exp. 1 pigs fed CIT1 and DUA1 had lower ADG and ADFI throughout the study despite a higher G:F. Feed intake was likely lower due to an aversion to the taste of citric acid in the feed. The higher G:F of pigs fed CIT1 and DUA1 suggests pigs more efficiently converted their given feed intake into an optimum gain. Boling et al. (2000) found the same response. The G:F increased with higher rates (3 and 6%) of citric acid despite no change in wt gain and a decrease in feed intake (Boling et al., 2000). In a study feeding 1% fumaric or citric acid in a corn-soybean meal diet the G:F was improved ($P < 0.05$) due to greater ADG while maintaining intake similar to the control (Falkowski and Aherne, 1984). Addition of dietary acid has improved nursery pig growth performance when added at rates as low as 0.1% (Thacker and Haq, 2009) and as high as 4% (Giesting and Easter, 1985) but success of growth response varies with acid type (Walsh et al., 2007; Omogbenigun et al., 2003; Li et al., 1999; Radcliffe et al., 1998; Thacker et al., 1992). Variability in growth performance response to dietary acidifiers may be the result of feed palatability issues, source and composition of the diet, inclusion rate of acidifier, and animal age (Kim et al., 2005).

In PH 1 of Exp. 1, there was a trend for pigs fed ALF1 to have a higher ($P = 0.0559$) ADG than pigs fed CON1. Based on a significant difference across PH, a larger sample size in PH 1 may have resulted in a significant difference between ALF1 and CON1. In PH 1 there was a trend for the ADFI of pigs fed CON1 to be higher (*P* = 0.0771) than for pigs fed DUA1. When PH were combined the ADFI was significantly different for pigs fed CON1 and DUA1. This may suggest a larger sample size in PH 1 may have resulted in a significant difference between CON1 and DUA1. A trend also existed for pigs fed CON1 to have a higher (*P* = 0.0686) ADFI than pigs fed CIT1 when PH were combined, again a significant difference may exist with a larger sample. These findings may suggest that a larger sample size may be more sensitive to the differences in growth performance caused by the treatments. In regards to pigs fed ALF1, a larger sample size may make the growth performance improvement of α-galactosidase addition more prevalent.

The cost comparison revealed an economic value for feeding α-galactosidase when compared to CON1 (Table 3.10). Across the 21 d trial, pigs fed ALF1 gained 1.35 kg more than pigs fed CON1. Despite a higher $/PH for ALF1, due to a higher feed intake, the $/kg gain was lower with the addition of α-galactosidase. For a nursery pig, greater growth rate is more important than improved feed efficiency because a higher feed intake is an avenue for achieving maximum growth performance. In addition, it has been suggested that a wt advantage of 0.91 kg when leaving the nursery may increase ADG by 0.03 kg/day in the finisher. This can lead to a 5 to 10 d shorter finishing period (Coffey et al., 1995).

In Exp. 2 NURS had greater growth performance than all other treatments in PH 1, 2, and PH combined. Although the CON2 and experimental diets contained 10% whey, the inclusion of animal protein, corn and soybean meal in the first PH of NURS was formulated to optimize newly weaned pig performance. The greater growth performance of pigs fed NURS is likely evidence of the optimum formulation.

In PH 1 of Exp. 2 inclusion of citric acid did not seem to affect the ADG and ADFI of CIT2 when compared to ALF2 while DUA2 did differ from ALF2. A similar response is seen for ADFI in PH 2. When PH are combined, CIT2 and DUA2 had lower ADFI than ALF2 and DUA2 had a lower ADG than ALF2. Based on performance in PH 1, PH 2, and across PH, inclusion of citric acid alone was less detrimental than inclusion of α-galactosidase and citric acid together (DUA2) when compared to ALF2. In PH 2 CIT2 and ALF2 had similar ADG and ADFI but G:F was higher for CIT2 suggesting pigs fed CIT2 grew better than pigs fed ALF2.

In PH 2 of Exp. 2 the superior growth performance of NURS was likely a combination of greater growth performance in PH 1 and a lower rate of SBM in the PH 2 NURS. Pigs fed ALF2 in this PH had an ADFI similar to NURS which may be a result of slower growth performance for pigs fed NURS or more effective feed utilization by pigs fed ALF2.

Given the similar performance of CON2 and ALF2, α-galactosidase did not improve the base diet in Exp. 2. Perhaps greater growth performance would be seen in Exp. 2 if ALF2 were formulated with the standard nursery diet as the base diet. Diet formulation of NURS in PH 2 was the same diet formulation as the base diet in PH 1 of Exp. 1 and the pigs fed NURS PH 2 were a similar age (25 d of age) to pigs in Exp. 1 (29 d of age). Given the greater growth performance when 29 d old pigs were fed a corn, soybean meal, and animal protein diet supplemented with α-galactosidase, the 25 d old pigs of Exp. 2 may have shown similar growth performance improvements if α-galactosidase was added to the diet with the same corn, soybean meal, and animal protein formulation. Results of Exp. 1 may suggest α-galactosidase more effectively improves growth performance in older nursery pigs fed diets containing higher rates of animal protein.

A poor growth response in young nursery pigs (21 – 35 d) fed a corn-soybean meal diet was observed in a study by Kim et al. (2003). At 42 d old nursery pigs began showing performance improvements when fed a 34% SBM diet (Kim et al., 2003). The authors state the lack of response earlier postweaning is due to lower feed intake and a lower rate of SBM in the diet (Kim et al., 2003).

In both Exp., despite improved G:F of CIT1, CIT2, DUA1 and DUA2, addition of citric acid, in general, decreased feed intake. Poor growth performance of pigs fed DUA1 and DUA2 may suggest the addition of citric acid did not improve enzyme activity. Across the two studies, addition of citric acid at a rate of 5% of the diet seemed to adversely affect pig growth performance.

There is potential that inclusion of citric acid in the dual diets did not activate α-galactosidase via acidification of the gastrointestinal tract. This may have occurred as a result of the acid being digested (Boling et al., 2000). Encapsulation of dietary acids and feeding acid in the form of salt have been effective methods of preventing digestion of the acid and have successfully lowered gastrointestinal pH (Piva et al., 2007; Canibe et al., 2001).

Implications

Addition of citric acid to a corn-soybean meal diet regardless of animal protein inclusion rate is not recommended based on the resultant poor growth performance. The inclusion of citric acid and α-galactosidase did not improve the activity of the enzyme as predicted based on the resultant poor growth performance. Addition of α-galactosidase may improve growth performance of 25 – 29 d old pigs if added to a corn-soybean meal diet supplemented with animal protein.

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Tables

Table 3.1 Composition of the CON1 in Exp. 1 (as-fed)[1,2]

Item	Content	
	PH 1	PH 2
Ingredient, %		
Corn grain	52.0	63.63
Soybean meal, 48%	26.2	28.64
JBS W 150	-	7.48
JBS SS 400 WOA	19.6	-
Soybean oil	2.0	-
Engage M	0.049	0.05
CTC 100	0.2	0.2
Total		
Calculated provisions (as-fed)		
ME, kcal/kg	3,214	3,223
Lys:ME, g/kcal	4.17	4.16

[1]CON1 = corn-soybean meal diet with no additives
[2]Diets were fed for 2 PH: PH 1 = d 0 to 7 post weaning and PH 2 = d 7 to 21 post weaning

Table 3.2 Composition of NURS and CON2 Diets in Exp. 2 (as-fed basis)[1,2]

Item	NURS, PH 2	CON2, PH 1	CON2, PH 2
		Content	
Ingredient, %			
Corn grain	51.95	60.2	58.14
Soybean meal	26.2	20.0	35.0
Soybean oil	2.0	2.0	-
Dried Whey	-	10.0	-
Monocalcium	-	0.99	1.0
Sodium Chloride	-	1.0	1.0
JBS SS 400 WOA	19.6	-	-
JBS #5455-GF 4 Vit and Min	-	4.0	4.0
L-Lysine	-	1.0	0.31
DL-Methionine	-	0.16	0.1
L-Threonine	-	0.25	0.1
Optiphos	-	0.1	0.1
Engage	0.05	0.1	0.05
CTC100	0.2	0.2	0.2
Total	100	100	100
Calculated Provisions (as-fed)			
ME, kcal/kg	3,214	3,259	3,140
SID Lys:ME, g/kcal	4.17	2.46	3.35

[1]NURS = standard nursery diet: PH 1 pelleted feed, PH 2 corn-soybean meal diet, CON2 = corn-soybean meal diet with no additives

[2]Diets were fed for 2 PH: PH 1 = 7 d post weaning and PH 2 = 14 d post weaning

Table 3.3 Price Index for Cost Comparison[1,2]

Item	Average	High	Low	Current
Ingredient ($/kg)				
Corn grain	0.23	0.28	0.16	0.26
Soybean meal	0.61	0.66	0.54	0.63
JBS SS 400 WOA	2.15	2.19	2.12	2.13
JBS #5455-GF 4 Vit and Min	2.18	2.18	2.18	2.18
W 150	2.10	2.16	2.07	2.08
Soybean oil	2.03	0.00	0.00	2.03
Dried Whey	1.56	0.00	0.00	1.56
Monocalcium	0.80	0.80	0.80	0.80
Sodium Chloride	0.21	0.21	0.21	0.21
L-Lysine	2.32	2.88	1.94	2.13
DL-Methionine	4.48	4.48	4.48	4.48
L-Threonine	3.21	3.67	2.99	2.99
Optiphos	3.14	3.14	3.14	3.14
Engage M	4.62	4.62	4.62	4.62
CTC100	5.84	5.99	5.66	5.88
α-galactosidase	2.05	0.00	0.00	6.16
Citric acid	2.68	2.81	2.81	2.42

[1]Steve Kuerth (JBS United Inc., Gridley, IL), personal communication
[2]As of April 2013

Table 3.4 Effect of Dietary Supplementation on Nursery Pigs, Exp. 1, PH 1[1,2,3,4]

	CON1	ALF1	CIT1	DUA1	*P*-value[5]
Pens	5	5	5	5	—
Pigs	30	30	30	30	—
Days on feed, d	7	7	7	7	—
Start wt, kg/pig	10.66 ± 0.25	11.11 ± 0.27	10.94 ± 0.26	10.83 ± 0.26	0.59
End wt, kg/pig	13.19 ± 0.34	14.22 ± 0.36	13.3 ± 0.34	13.20 ± 0.34	0.12
ADG, g/d	417.66^{ab} ± 20	517.38^{a} ± 30	390.43^{b} ± 20	392.41^{b} ± 20	< 0.05
ADFI, g/d	566.02^{ab} ± 30	632.76^{a} ± 30	489.63^{b} ± 20	471.46^{b} ± 20	< 0.01
G:F, g:g	0.74 ± 0.02	0.82 ± 0.03	0.80 ± 0.02	0.83 ± 0.03	0.06

[1] A total of 120 pigs (Chester White × Duroc; weaned at 29 ± 2 d of age; initial BW = 8.5 ± 1.7 kg) were used in this 21 d study; 5 pens/treatment and 6 pigs/pen

[2] Diets were fed for 2 PH: PH 1 = 7 d post weaning and PH 2 = 14 d post weaning

[3] Dietary treatments were CON1 = corn-soybean meal based diet; ENZ1 = CON1 + at least 75 ppm α-galactosidase, CIT1 = CON1 + 5% citric acid, DUA1 = CON1 + at least 75 ppm α-galactosidase + 5% citric acid

[4] LS Means are presented on a/pig basis

[5] Within a row, means without a common superscript differ ($P < 0.05$).

Table 3.5 Effect of Dietary Supplementation on Nursery Pigs, Exp. 1, PH 2[1,2,3,4]

	CON1	ALF1	CIT1	DUA1	P-value[5]
Pens	5	5	5	5	—
Pigs	30	30	30	30	—
Days on feed, d	14	14	14	14	—
Start wt, kg/pig	13.19 ± 0.34	14.22 ± 0.36	13.30 ± 0.34	13.20 ± 0.34	0.16
End wt, kg/pig	20.30 ± 0.47	22.04 ± 0.52	20.51 ± 0.48	20.52 ± 0.48	0.08
ADG, g/d	473.33 ± 10	521.23 ± 20	478.36 ± 10	487.72 ± 10	0.15
ADFI, g/d	742.77^{ab} ± 20	826.20^{a} ± 20	667.19^{b} ± 20	665.64^{b} ± 20	< 0.001
G:F, g:g	0.64^{a} ± 0.01	0.64^{a} ± 0.01	0.72^{b} ± 0.01	0.73^{b} ± 0.01	< 0.01

[1] A total of 120 pigs (Chester White × Duroc; weaned at 29 ± 2 d of age; initial BW = 8.5 ± 1.7 kg) were used in this 21 d study; 5 pens/treatment and 6 pigs/pen
[2]Diets were fed for 2 PH: P1 = d0 to d7 post wean and P2 = d7 to d21 post wean
[3]Dietary treatments were CON1 = corn-soybean meal based diet; ENZ1= CON1 + at least 75 ppm α-galactosidase, CIT1 = CON1 + 5% citric acid, DUA1 = CON1 + at least 75 ppm α-galactosidase + 5% citric acid
[4]LS Means are presented on a/pig basis
[5] Within a row, means without a common superscript differ ($P < 0.05$).

Table 3.6 Effect of Dietary Supplementation on Nursery Pigs, Exp. 1, PH Combined[1,2,3,4]

	CON1	ALF1	CIT1	DUA1	P-value[5]
Pens	5	5	5	5	—
Pigs	30	30	30	30	—
Days on feed, d	21	21	21	21	—
Start wt, kg/pig	10.66 ± 0.25	11.11 ± 0.27	10.94 ± 0.26	10.83 ± 0.26	0.59
End wt, kg/pig	20.30 ± 0.47	22.04 ± 0.52	20.51 ± 0.48	20.52 ± 0.48	0.08
ADG, g/d	457.61^{b} ± 10	520.03^{a} ± 20	453.69^{b} ± 10	461.19^{ab} ± 10	< 0.05
ADFI, g/d	692.94^{ab} ± 20	767.19^{a} ± 20	616.72^{bc} ± 20	610.37^{c} ± 20	< 0.05
G:F, g:g	0.66^{a} ± 0.01	0.68^{a} ± 0.01	0.74^{b} ± 0.01	0.76^{b} ± 0.01	< 0.05

[1] A total of 120 pigs (Chester White × Duroc; weaned at 29 ± 2 d of age; initial BW = 8.5 ± 1.7 kg) were used in this 21 d study; 5 pens/treatment and 6 pigs/pen

[2] Diets were fed for 2 PH: P1 = d 0 to d 7 post wean and P2 = d 7 to d 21 post wean

[3] Dietary treatments were CON1 = corn-soybean meal based diet; ENZ1 = CON1 + at least 75 ppm α-galactosidase, CIT1 = CON1 + 5% citric acid, DUA1 = CON1 + at least 75 ppm α-galactosidase + 5% citric acid

[4] LS Means are presented on a/pig basis

[5] Within a row, means without a common superscript differ ($P < 0.05$).

Table 3.7 Effect of Dietary Supplementation on Nursery Pigs, Exp. 2, PH 1[1,2,3,4]

	NURS	CON2	CIT2	ALF2	DUA2	*P* – value[5]
Pens	4	3	4	3	4	—
Pigs	24	18	24	18	24	—
Days on feed, d	7	7	7	7	7	—
Start wt, kg/pig	4.93 ± 0.41	4.91 ± 0.47	4.86 ± 0.41	5.13 ± 0.47	4.98 ± 0.41	0.13
End wt, kg/pig	7.17^{a} ± 0.70	5.83^{bc} ± 0.81	5.55^{c} ± 0.70	6.11^{b} ± 0.81	5.41^{c} ± 0.70	<0.05
ADG, g/d	319.81^{a} ± 0.01	130.95^{b} ± 0.01	98.21^{bc} ± 0.01	140.84^{b} ± 0.01	60.61^{c} ± 0.01	<0.05
ADFI, g/d	320.35^{a} ± 0.01	264.43^{ab} ± 0.02	206.44^{bc} ± 0.01	274.89^{ab} ± 0.02	173.43^{c} ± 0.01	<0.01
G:F	1.00^{a} ± 0.05	0.50^{b} ± 0.05	0.48^{b} ± 0.05	0.51^{b} ± 0.05	0.33^{b} ± 0.05	<0.0001

[1] A total of 120 pigs (Chester White × Duroc; weaned at 18 ± 1.8 d of age; initial BW = 4.5 ± 0.9 kg) were used in this 21 d study; 5 pens/treatment and 6 pigs/pen

[2] Diets were fed for 2 PH: PH 1 = d 0 to 7 post weaning and PH 2 = d 7 to 21 post weaning

[3] Dietary treatments were NURS = pelleted nursery diet; CON2 = corn-soybean meal based control diet + minimal animal protein; CIT2 = CON2 + 5% citric acid; ENZ2 = CON2 + 239.36ppm α-galactosidase ; DUL2 = CON2+ 239.36ppm α-galactosidase + 5% citric acid

[4] LS Means are presented on a/pig basis

[5] Within a row, means without a common superscript differ (*P* < 0.05).

Table 3.8 Effect of Dietary Supplementation on Nursery Pigs, Exp. 2, PH 2[1,2,3,4]

	NURS	CON2	CIT2	ALF2	DUA2	P – value[5]
Pens	4	3	4	3	4	—
Pigs	24	18	24	18	24	—
Days on feed, d	14	14	14	14	14	—
Start wt, kg/pig	$7.17^{a} \pm 0.70$	$5.83^{bc} \pm 0.81$	$5.55^{c} \pm 0.70$	$6.11^{b} \pm 0.81$	$5.41^{c} \pm 0.70$	< 0.05
End wt, kg/pig	$12.88^{a} \pm 1.76$	$9.76^{b} \pm 2.04$	$9.70^{b} \pm 1.76$	$10.30^{b} \pm 2.04$	$8.93^{b} \pm 1.76$	< 0.001
ADG, g/d	$407.87^{a} \pm 0.02$	$280.66^{b} \pm 0.02$	$296.54^{b} \pm 0.02$	$298.99^{b} \pm 0.02$	$251.76^{b} \pm 0.02$	< 0.01
ADFI, g/d	$590.58^{a} \pm 0.02$	$465.17^{b} \pm 0.02$	$414.96^{bc} \pm 0.02$	$501.19^{ab} \pm 0.02$	$354.46^{c} \pm 0.02$	< 0.05
G:F, g/g	$0.69^{a} \pm 0.02$	$0.60^{b} \pm 0.02$	$0.71^{a} \pm 0.02$	$0.60^{b} \pm 0.02$	$0.71^{a} \pm 0.02$	< 0.05

[1] A total of 120 pigs (Chester White × Duroc; weaned at 18 ± 1.8 d of age; initial BW = 4.5 ± 0.9 kg) were used in this 21 d study; 5 pens/treatment and 6 pigs/pen
[2] Diets were fed for 2 PH: PH 1 = d 0 to 7 post weaning and PH 2 = d 7 to 21 post weaning
[3] Dietary treatments were NURS = corn-soybean meal based diet + high animal protein; CON2 = corn-soybean meal based diet + minimal animal protein; CIT2 = CON2 + 5% citric acid; ENZ2 = CON2 + 239.36ppm α-galactosidase; DUA2 = CON2 + 239.36ppm α-galactosidase + 5% citric acid
[4] LS Means are presented on a/pig basis
[5] Within a row, means without a common superscript differ ($P < 0.05$).

Table 3.9 Effect of Dietary Supplementation on Nursery Pigs, Exp. 2, PH Combined[1,2,3,4]

	NURS	CON2	CIT2	ALF2	DUA2	P – value[5]
Pens	4	3	4	3	4	—
Pigs	24	18	24	18	24	—
Days on feed, d	21	21	21	21	21	—
Start wt, kg/pig	4.93 ± 0.41	4.91 ± 0.47	4.86 ± 0.41	5.13 ± 0.47	4.98 ± 0.41	0.13
End wt, kg/pig	$12.88^{a} \pm 1.76$	$9.76^{b} \pm 2.04$	$9.70^{b} \pm 1.76$	$10.30^{b} \pm 2.04$	$8.93^{b} \pm 1.76$	<0.001
ADG, g/d	$363.84^{a} \pm 0.01$	$205.81^{bc} \pm 0.01$	$197.38^{bc} \pm 0.01$	$219.91^{b} \pm 0.01$	$156.18^{c} \pm 0.01$	<0.05
ADFI, g/d	$455.47^{a} \pm 0.01$	$364.80^{bc} \pm 0.02$	$310.70^{cd} \pm 0.01$	$388.04^{ab} \pm 0.02$	$263.95^{d} \pm 0.01$	<0.05
G:F, g:g	$0.85^{a} \pm 0.03$	$0.55^{b} \pm 0.03$	$0.60^{b} \pm 0.03$	$0.55^{b} \pm 0.03$	$0.52^{b} \pm 0.03$	<0.0001

[1] A total of 120 pigs (Chester White × Duroc; weaned at 18±1.8 d of age; initial BW = 4.5 ± 0.9 kg) were used in this 21 d study; 5 pens/treatment and 6 pigs/pen

[2] Diets were fed for 2 PH: PH 1 = d 0 to 7 post weaning and PH 2 = d 7 to 21 post weaning

[3] Dietary treatments were POS = pelleted nursery diet (PH 1), corn-soybean meal based control diet + 0.5% TiO_2 (PH 2); NEG = corn-soybean meal based experimental diet + 0.5% TiO_2; CIC = NEG + 5% citric acid + 0.5% TiO_2; EZY = NEG + 239.36ppm α-galactosidase + 0.5% TiO_2; DUL = NEG + 239.36ppm α-galactosidase + 5% citric acid + 0.5% TiO_2

[4] LS Means are presented on a/pig basis

[5] Within a row, means without a common superscript differ ($P < 0.05$).

Table 3.10 Economic Value of α-galactosidase Addition to a Corn-soybean Meal Diet, Exp. 1[1,2,3]

	CON1			ALF1		
	PH 1	PH 2	Combined	PH 1	PH 2	Combined
Gain	2.94	6.636	9.58	3.63	7.297	10.92
$/kg gain	1.01	0.762	0.93	0.92	0.76	0.91
$/PH	3.00	5.06	8.06	3.33	5.58	8.91
$/metric ton	748.94	484.78	616.86	749.37	485.27	617.32
Gain/metric ton	740	637	661	818	635	678

[1]CON = corn-soybean meal base diet, ALF = base diet + 75 ppm α-galactosidase

[2]Diets were fed in 2 phases: 7 d for PH 1 and 14 d for PH 2

[3]Formulas for cost analysis: $/kg gain = gain/d ÷ feed cost/d; $/PH = ADFI, kg × d on feed × $/kg diet; $/metric ton = $/kg diet × 1000; gain/metric ton = ADG × 1000

this class date has not formed

CHAPTER IV

SUMMARY AND SYNOPSIS

Feed management practices in the swine industry are the most manageable method of improving pig growth performance at weaning and through the nursery period. The ability to formulate cost effective diets that optimize growth performance continues to drive nutrition research. Inclusion of highly digestible proteins in the nursery pig diet is constantly evaluated to make a more digestible feed that is lower in cost and includes fewer negatively viewed feed additives, such as antibiotics. As external industries develop, use of given feed ingredients have the potential to increase in cost. Corn is an excellent energy source for nursery pigs because it is highly digestible but the co-products of corn, such as ethanol, increase the value of this product which increases the cost to feed the feed ingredient to livestock. Alternative diet formulations are being examined to limit inclusion of higher cost feed ingredients and to optimize nutrients of feed ingredients in the diet. Examination of feed additives and feed ingredients which increase nutrient utilization of the lower cost feedstuffs thereby improving nursery pig growth performance was the focus of this thesis.

Chapter 1 offered background knowledge of management practices and feeding the nursery pig. A 21 d weaning was justified as a method to increase production rates in the swine industry. Although this practice benefits industry productivity overall the pig has difficulty adjusting to the non-milk based diet. Stressors on the pig were addressedincluding, social, psychological, physiological, and environmental. The characteristic feeding practices required to transition the nursery pig were discussed and the limitations of the literature were identified in order to situate the work of this thesis within the areas of deficiency.

Chapter 2 examined the effectiveness of adding the feed ingredient spray-dried egg protein in place of spray-dried plasma and whey. No significant differences were noted between the three diets fed, however, the economic comparison indicated the diet higher in spray-dried plasma protein was less expensive to feed in phase 1. The growth performance did not suffer when spray-dried egg replaced spray-dried plasma and whey but it was suggested that inclusion of a diet with spray-dried egg and whey may have improved growth performance. With concerns in the industry of a link between porcine epidemic diarrheal virus and spray-dried plasma protein, it was suggested that spray-dried egg protein fed with whey may be a viable alternative to feeding spray-dried plasma protein.

Chapter 3 examined the effectiveness of adding the feed additives α-galactosidase and citric acid. Addition of α-galactosidase did improve the growth performance of nursery pigs when added to a corn-soybean meal diet with higher rates of animal protein. However, the addition of α-galactosidase to a corn-soybean meal diet low in animal protein was less effective at improving growth performance when compared to a standard nursery diet. Citric acid was not effective in improving growth performance when added to corn-soybean meal diet regardless of the animal protein level. Although it was suggested that inclusion of citric acid may improve the activity of α-galactosidase this was not observed in the growth performance of the pigs fed both feed additives. In fact, growth performance was generally lowest when pigs were fed both feed additives. It was recommended that α-galactosidase be fed to 4 wk old nursery pigs as part of a corn-soybean meal diet with higher rates of animal protein.

Animal nutrition will continue to develop new diets to better optimize the most cost effective feed ingredients. Feeding nursery pigs will never be a static practice due to the changes in regulation and fluctuation in feed costs as a result of the feeds value in external industries. As a result, feeding practices require continuing modification. For the present time, nursery pig feeding strategies utilizing highly digestible animal proteins, enzymes and dietary acids are relevant to the demands of the industry.