EVALUATION OF WHEAT GLUTEN IN PHASE 1 NURSERY PIG DIETS

by

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(Under the Direction of Michael J. Azain)

ABSTRACT

The objectives of these experiments were to evaluate the effect of glutamate and glutamine (Glx) content in wheat gluten (WG) in nursery diets on pig performance. Three experiments were conducted previously to determine if WG could be included in the nursery diet. The results of these experiments indicated that WG could substitute for expensive animal protein ingredients typically included in the nursery diet. A defining feature of WG is a high proportion of Glx. It was hypothesized that adding Glx to the diet at the same level found in WG would lead to a similar growth response. The results of this experiment indicated that Glx may not be the responsible party for the growth response seen when WG is added to the nursery diet.

INDEX WORDS: Nursery diet, Pigs, Wheat gluten, Glutamate, Glutamine

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CHAPTER 1

INTRODUCTION

The post-weaning period in pork production is characterized by a lag in development. This post-weaning lag is typically manifested as weight loss and poor feed intake during the first week post-weaning. In the nursery phase, the nutritional needs of the pig change rapidly, and so nursery diets are usually fed in 2 to 3 phases. A phase 1 nursery diet typically includes animal protein sources and milk products that improve both palatability and digestibility, making the nursery phase extremely expensive in terms of feeding costs. In phase 2, specialty ingredients are decreased, and in phase 3, the diet is almost entirely corn and soybean meal based.

Traditionally, nursery diets contain ingredients like fishmeal, plasma protein, and whey. These are important sources of protein and lactose, as nursery pigs do not digest plant protein well. However, since these ingredients tend to be expensive, alternative feed ingredients that do not compromise growth are of great interest. One alternative ingredient that has been tested is wheat gluten, and it was found that wheat gluten could be included in the diet in the place of the total or partial amount of ingredients like plasma protein and fish meal.

Wheat gluten is a high protein ingredient, with the majority of that protein coming from the Glx (glutamate and glutamine) content. Although these amino acids are

considered non-essential, there has been research to show that glutamate and glutamine may play important roles in the gut.

The stress of weaning influences the development of the gastrointestinal tract. This results in negative changes that include decreased villus height and compromised intestinal barrier. The role of Glx coupled with the negative gut changes that are characteristic of nursery pig, suggests that the Glx content of wheat gluten may be responsible for its success as a protein source for nursery pigs.

CHAPTER 2

LITERATURE REVIEW

The Weaned Pig

The trend in the swine industry is to wean pigs as early as possible in order to maximize use of farrowing facilities, which are an expensive part of the operation. Weaning age can impact nursery growth as well as sow fertility, so it is important that weaning age be optimized to maximize the profitability of pork operations (Smith et al., 2008). Prior to weaning, the digestive system of the pig has increased secretion of digestive enzymes for digesting milk components such as lactase, lipases, and proteases. As the post-weaning period progresses, the pigs must adapt to a new diet, and thus changes to the pattern of enzyme secretion occur (Maxwell and Carter, 2001). There is a decrease in the activity of several enzymes at weaning (Jensen et al., 1997). In a study conducted by Lindemann et al (1986) it was found that lipase activity increases during nursing, but decreases post-weaning, which is not unexpected as sow milk has a much higher fat content than a starter diet. There is a drop in amylase at weaning before quickly increasing (Lindemann et al., 1986, Jensen et al., 1997). It is hypothesized that this is due to the need to digest dietary starches (Lindemann et al., 1986). In the same study conducted by Lindemann et al (1986), pancreatic proteolytic enzymes increased 11.5-fold from birth to weaning, declined at weaning, and then increased 3.9-fold one week post-weaning, again, this was attributed to response to

diet. These data suggest that that dietary demand has a greater influence than age on the ability to digest dietary components (Lindemann et al., 1986). It is critical to take all of this into account when providing a post-weaning diet (Maxwell and Carter, 2001). Feeding the nursery pig can be incredibly challenging compared to other phases of feeding (Johnston et al., 2013).

Some typical ingredients in the post-weaning diets include milk products like whey and dried skim milk, fish meal, plasma protein and soybean protein. The earlier that weaning occurs, the more complex the post weaning diet must be. Over time, the nutritional needs of weaned pigs change rapidly, so a phase feeding program is typically implemented to guide the transition from a complex diet to a simple corn-soybean meal diet (Maxwell and Carter, 2001). Two to three weeks post-weaning, the energy requirement of the pig can be met from plant sources and fats or oils (Johnston et al., 2013), but a complex diet immediately post-weaning is an essential part of maximizing feed intake and gain (Maxwell and Carter, 2001). Bayley and Carlson (1970) found that a complex diet supported greater levels of performance in nursery pigs compared to simple diets. These findings agree with the results of Himmelberg et al. (1985), who found that pigs fed a complex starter diet had increased gain, feed intake, and improved feed conversion compared to pigs fed a simple starter diet.

Weaning is a period during which pigs are introduced to several stressors. This stress can cause several physiological issues in the pig including intestinal and immune dysfunction (Campbell et al., 2013). Because of this, initial post-weaning performance is poor. Post-weaning performance can be influenced by a number of factors such as age

at weaning, weight, health, and more, as well as an interaction of these factors. Because of this, the first phase in the nursery post-weaning typically requires a more complex, nutrient-dense diet (Mahan and Lepine, 1991). However, these diets tend to be more expensive (Mahan et al., 1998). In a farrow-to-finish pork production system, feed and piglet costs are the largest variable production cost items (Niemi et al., 2010). Despite the cost, Mahan et al. (1998) concluded that the starter diet is critical to the overall growth of the pig. The benefit of the phase 1 diet in the nursery carries over into the grower and finisher phases (Mahan et al., 1998). In fact, Mahan et al. (1998) found that 2 weeks on a starter diet was the most beneficial compared to feeding a starter diet for 1 week.

One of the most important factors in post-weaning performance is weaning weight; however, there is usually a wide range of weight within a litter at weaning (Mahan et al., 1998). Feeding a simple diet in the initial nursery phase can cause increased lipid accretion and decreased protein accretion (Dritz et al., 1996). Mahan et al. (1998) found that both lighter-weight pigs and heavier-weight pigs have similar responses to feeding a complex diet in phase 1. Dritz et al. (1996) found that pigs weaned at either 9 or 19 days of age both had increased average daily feed intake (ADFI) and average daily gain (ADG) when fed a complex diet, and these pigs were similar ages when they reached a weight of 109 kg.

In the first few weeks of life, the structure of the small intestine in piglets is subject to major changes, which can be seen in the changes in height, shape, and density of the villi. Ideally, villi should be healthy and well-defined meaning that they lack signs of

apoptotic cells and have sufficient mucin production (Cabrera et al., 2013). Researchers evaluated markers for post-weaning events in terms of development of the gastrointestinal tract. The development of the gastrointestinal tract in weaned pigs was monitored for 15 days, and researchers ultimately divided this period into 2 phases: the acute post-weaning phase, and the more maturational phase (Montagne et al., 2006). Adeola and King (2006) found that both small intestine weight and length increase in the first 9 weeks of age. Not only did the tissue weight increase, but the mucosal weight increased as well. These findings indicated that there are substantial changes in the small intestine of pigs in the first 9 weeks of age that allow for the pig to process nutrients (Adeola and King, 2006). However, Montagne et al. (2006) found that the first 5 days post-weaning are characterized by deterioration of the gut integrity. This deterioration was indicated by decreases in villous length as well as total brush border enzyme activities (Montagne et al., 2006). Wang et al.(2016) found that weaning at d 14 led to a decrease in the villus height to crypt depth ratio and cell proliferation in the small intestine. These changes in the intestine can negatively impact small intestine functions such as digestive, absorptive, and secretory (Campbell et al., 2013). In addition to the functions of the small intestine, weaning stress also influences the integrity of the intestinal barrier, which can lead to inflammation via toxins, bacteria, or feed-associated antigens (Campbell et al, 2013). Wang et al. (2016) concluded that promoting intestinal maturation and the restoration of epithelium could potentially reduce the negative impact of weaning (Wang et al., 2016).

Typical Protein Ingredients in the Nursery Diet

Introduction

Animal-based proteins, which are highly digestible, are fed post-weaning to stimulate average daily feed intake (ADFI) and ADG and help avoid the period of transient hypersensitivity to soy protein (Jones et al., 2010). Protein ingredients used in the nursery diet include fish meal, spray-dried plasma protein, spray-dried blood meal, blood cells, whey and soybean meal. A composition of nursery diet protein ingredients can be found in Table 2-1.

Fish Meal

Fish meal is an advantageous ingredient in nursery diets. Fish meal is a protein source that has been studied in several animal species. Generally, fish meal is a valuable source of omega-3 fatty acids like eicosapentaenoic acid (20:5 n-3). However, the quality and composition of fish meal is affected by what type and which part of the fish is used to make the fish meal (Kim and Easter, 2001, Folador et al., 2006). Kim and Easter (2001) found that using a high quality fish meal reduces the amount of fish meal needed in the diet by at least 20%. Quality of fish meal can be indicated by chemical composition, protein quality assessments, and palatability tests (Folador et al., 2006). Apparent ileal digestibility of fish meals can be different due to species of fish and how it is processed (Kim and Easter, 2001). For example, pigs fed mackerel fish meal had greater ileal digestibility of amino acids and growth performance as compared to pigs fed menhaden fish meal (Kim and Easter, 2001).

Stoner et al (1990) found that select menhaden fish meal (SMFM) could substitute for the entire portion of soybean meal (SBM) in the nursery diet, and 4% SMFM can substitute for half the dried whey in a nursery diet containing 20% whey. Fish meal has similar apparent digestibility values to skim milk powder for nitrogen and amino acids, and the ileal digestibility of amino acids in fish meal is 92.0% (Viljoen et al., 1998). Bergstrom et al. (1997) found that feeding pigs 2.5% menhaden fish meal from d 7-14 post-weaning resulted in improved gain to feed ratio as compared to pigs fed a simple corn-SBM diet.

Spray-dried plasma protein

Adding spray-dried plasma protein (SDPP) to the diet of the weaned pig has been shown in many cases to improve the performance of weaned pigs (Coffey and Cromwell, 1995, Grinstead et al., 2000, Pierce et al., 2005). There are different molecular weight fractions of plasma protein, and high-molecular-weight fraction plasma protein not only meets the nutritional need, but also seems to have some biological function beyond that (Maxwell, Jr. and Carter, 2001). Optimum inclusion rate of SDPP is influenced by weight, age, and health status of the pig (Coffey and Cromwell, 1995).

Coffey and Cromwell (1995) found that pigs raised in a conventional nursery had a positive growth response to SDPP as compared to dried skim milk (DSM) in the diet. As the level of SDPP increased (0-10%), daily gain increased linearly, with maximum feed intake occurring at 8.5% SDPP. A proposed mechanism for how SDPP improves performance is by improving the immunocompetence in the nursery pig via immunoglobulins in the SDPP, which may prevent viruses and bacteria from damaging

the gut wall. In addition to this, there is a carry-over effect from feeding SDPP from d 0 to 14 post-weaning when the pigs are switched to a common diet on d 14 to 28 post-weaning (Coffey and Cromwell, 1995). Pierce et al (2005) concluded that the initial growth response to SDPP can be attributed to the IgG-rich fraction rather than the albumin-rich or other low molecular weight fractions of plasma. Grinstead et al. (2000) found that feeding SDPP to nursery pigs improved both growth performance and health status.

Spray-dried blood cells and blood meal

Blood cells are produced as a byproduct of spray-dried animal plasma production, and appear to have a similar nutrient profile to blood meal (DeRouchey et al., 2002). Dried blood meal contains over 80% protein (Wahlstrom and Libal, 1977). Spray-dried blood meal appears to be a readily available source of lysine, but relatively low in both methionine and isoleucine (Kats et al., 1994). Wahlstrom and Libal (1977) found that the lysine availability of dried blood meal is approximately 70%.

In calves, hydrolyzed spray-dried blood cells can replace up to 43% of the CP from whey (Quigley et al., 2000). Kerr et al (2004) found that spray-dried blood cells can be added to nursery pig diets at high levels as long as the isoleucine requirement is met. When pigs were fed either blood meal or blood cells d 5-12 post-weaning, these pigs exhibited improved G:F, compared to pigs fed a control diet, and pigs fed blood meal had improved ADG, ADFI, and G:F compared to pigs fed blood cells. As blood meal or blood cells increased in the diet, ADG and G:F increased linearly. The ADFI seen in pigs fed blood meal was attributed to the fact that blood meal contains the

plasma fraction while blood cells do not. Beyond d 12 post-weaning, the response to blood meal decreased, and in the overall experimental period (d 5-19 post-weaning), there was no difference in the improvements in ADG and G:F between blood meal and blood cells (DeRouchey et al., 2002). Kats et al. (1994) found that spray-dried blood meal is an effective source of protein in phase 2 diets for early-weaned pigs, but does not seem to improve performance beyond the phase 2 period.

Whey

During cheese manufacturing, part of the milk separates from the curd, and this is called whey. Whey typically contains about 90% of the lactose, 20% of the protein, 40% of the calcium, and 43% of the phosphorous that was originally present in the milk (Leibbrandt and Benevenga, 1991). Whey powder typically has between 10 and 15% CP (Kim et al., 2012). Dried whey is often included in the nursery diet because lactose is an important sugar source for weaned pigs. Dried whey enhances growth performance in weaned pigs (Mahan, 1992).

The inclusion of dried whey in the diet leads to both improved gain and improved feed efficiency. It is more likely that the positive response to dried whey is derived from the lactose rather than the lactalbumin (Mahan, 1992). This is not to say that lactalbumin does not contribute as an important source of amino acids, but in a study conducted by Mahan (1992) comparing a diet containing lactose and amino acid mixture and a diet containing lactalbumin and corn starch, gains were improved when pigs were fed the lactose diet, but not when pigs were fed the lactalbumin diet. Overall,

the inclusion of dried whey is important in the nursery pig diet and the positive response justifies the cost of inclusion (Mahan, 1992).

Soybean meal

Soybean meal is the most widely used protein source in the swine diet. The proper proportion of soybean meal used in conjunction with corn produces a balanced amino acid source for pigs (Southern et al., 1990). However, soybean meal that has been normally processed has been found to be detrimental to the intestinal tract leading to the alteration of the villi (Mahan, 1992). It has been shown that piglets fed a diet where soybean meal is the primary protein source have depressed weight gain, abnormal villus morphology and increased serum IgG titers that are specific to soybean protein (Li et al., 1990). Li et al. (1990) found that nursery pigs fed SBM have shorter villus height, greater crypt depth and greater lymphocyte density in villi than nursery pigs fed a diet with milk protein. It was also found that the nursery pigs fed SBM had decreased ADG, decreased apparent N digestibility, and poor feed-to-gain ratios at 14 d post-weaning compared to pigs fed milk protein in the diet.

Feeding Alternative Feed Ingredients

Feeding alternative feedstuff can provide an economic benefit for swine production (Johnston et al., 2013) and be good sources of amino acids, energy, and minerals for pigs (Woyengo et al., 2014). There are risks to feeding alternative feedstuffs due to factors like availability and nutritional value (Woyengo et al., 2014).

Thus, these alternative ingredients are subject to evaluation in order to manage that risk. Three major categories of alternative feedstuffs include developments in traditional crops, alternative crops, and co-products. A good alternative feed source may reduce the feed costs, but it should do so without challenging growth performance, health, carcass characteristics, quality, and environmental footprint (Johnston et al., 2013).

Wheat Gluten

Wheat gluten (WG) is prepared by removing starch from wheat flour and drying the remaining high protein gluten. A nutrient composition of WG is listed in Table 2-2. While WG is relatively high in CP, it is relatively low in lysine, threonine, and tryptophan, which are limiting amino acids in nursery diets (Lawrence et al., 2004). Because of this Chae et al. concluded that WG in the diet works best when supplemented with essential amino acids (1998). Two main forms of WG are vitalized and devitalized. Devitalized WG undergoes denaturation that is irreversible and it cannot revitalize. The vital property of WG is related to the degree of viscoelasticity (Esteller et al., 2005). Helland et al. (2006) found that wheat gluten could replace fish meal as a protein source in Atlantic halibut diets, but this should be done with caution unless lysine is being supplemented in the diet.

A study conducted by Richert et al. (1994) found that weanling pigs fed WG had lower N excretion in the feces and greater apparent N digestibility than weanling pigs fed soybean meal (SBM). Additionally, Richert et al. (1994) found that replacing SBM with WG resulted in an increase in ADG. Another study found that weanling pigs fed a

diet containing WG had an improved gain to feed ratio as compared to weanling pigs fed a diet with SBM (Lawrence et al., 2004). In contrast with Richert et al., this study found that when WG replaced SBM, there was no increase in ADG (Lawrence et al., 2004).

Richert et al.(1994) found that weanling pigs fed a common diet on d 14-35 post-weaning after eating a diet containing WG on d 0-14 post-weaning had higher average daily gain (ADG) and gain to feed ratios than weanling pigs previously fed a diet with dried skim milk (DSM). These findings indicated that there may be some sort of carry-over effect, which the authors attributed to wheat proteins stimulating the digestive function development, which acted as preparation for common diet fed in phase 2. In another study, weanling pigs fed WG had greater ADG and gain to feed ratios than pigs fed DSM (Burnham et al., 2000).

Wheat gluten has also been found to be a suitable substitute for fishmeal in diets for Atlantic halibut (Helland et al., 2006). Both halibut fed fishmeal and halibut fed WG doubled in weight during the study and had similar specific growth rates as well as similar feed efficiency ratios (Helland et al., 2006). Blasco et al.(2005) found that there was no difference in growth or feed to gain ratio between weanling pigs fed either a diet with fishmeal or WG, additionally, the diet containing WG had a higher total tract digestibility of dry matter, organic matter, and crude protein. The authors concluded that the absence of differences in growth between the fishmeal diet and the WG diet is promising result, thus, WG could serve as a viable substitution for fishmeal. The authors also concluded that the improved apparent digestibility of the WG diet as compared to

the fishmeal diet may have been because WG reduces the negative impact on the enteric mucosa by weaning (Blasco et al., 2005).

In a study where WG was compared to animal plasma in the weanling pig diet, weanling pigs fed a diet with 9.25% spray dried plasma protein had greater ADG and ADFI than weanling pigs fed a diet with 8.88% WG (Lawrence et al., 2004). It was also found that increasing WG concentration in diet caused a decrease in ADG while ADG increased as concentration of animal plasma increased. It was concluded that WG could not substitute for animal plasma in the diet of weanling pigs (Lawrence et al., 2004). Burnham et al. reported that weanling pigs fed plasma protein on d 0-14 post-weaning had greater ADG and ADFI as compared to weanling pigs fed WG. However, d 14-21 post-weaning when a common diet was fed, the pigs initially fed WG had greater ADG and ADFI than pigs initially fed plasma protein. Weanling pigs fed a blend of plasma protein and WG performed well, suggesting that WG could substitute for a portion of plasma protein, thus reducing diet costs. Overall, the author concluded that replacing half of the portion of plasma protein in the nursery diet with WG can allow the producer to reap the benefits of plasma protein in the early nursery phase, but also the benefits of WG in later nursery phases (Burnham et al., 2000).

Importance of Glutamate and Glutamine in the Nursery Pig

Early life

Most species, including pigs, have a high glutamine and glutamate content in their milk (Manso et al., 2012). The most abundant free amino acid in sow's colostrum is taurine, and glutamate and glutamine are considered abundant as well. As days of

lactation increase, free glutamate and glutamine rapidly increase two- to threefold. By day 22 of lactation, glutamine is the most abundant free amino acid in sow's milk, and glutamate is also considered abundant. Glutamate plus glutamine are the most abundant protein-bound amino acids in both sow's colostrum and milk (17% and 19% respectively) (Wu and Knabe, 1994). Davis et al (1994) also found that the proportion of glutamate increased about 25% as lactation progressed from colostrum to mature milk in the pig. The results of the study conducted by Wu and Knabe (1994) indicated that the increase in free glutamine in sow's milk was concomitant with the increase in importance of glutamine as fuel in the small intestine of a piglet. In addition, the authors concluded that both the abundance of free glutamine and protein-bound glutamine and glutamate are consistent with proposed functions of these amino acids in the GI tract of piglets.

Wheat gluten

While WG is relatively low in lysine, threonine, and tryptophan, which are limiting amino acids in nursery diets (Lawrence et al., 2004), it has a high Glx (Glutamine + Glutamate) content (Rombouts et al., 2009). The glutamate content of wheat gluten has been estimated to 23.87% (NRC, 2012). Rombouts et al. (2009) found that the Glx content in wheat gluten is 2450 μmol/g, which indicated that Glx was a major amino acid component of wheat gluten.

Glutamate

Glutamate is an amino acid that is typically considered to be non-essential; however, there is evidence that glutamate may be conditionally essential in the nursery pig. Glutamate is the single most important oxidative substrate in the intestinal mucosa, and it plays a role in the biosynthesis of proline and arginine, which are considered to be conditionally essential. These pieces of information suggest that dietary glutamate may be essential for mucosal health (Reeds et al., 2000). Li et al. (2016) found that glutamate-deficiency led to decreased proliferation of pig intestinal epithelial cells, which suggests that glutamate deficiency can disturb the renewal of intestinal epithelial cells in pigs.

Glutamate plays a role in decreasing the degradation of the gut. When nursery pigs were supplemented with 1.0% glutamate, villus height was increased as compared to pigs that were not supplemented with 1.0% glutamate (Liu et al., 2002). Post-weaning, villus height decreases and crypt depth deepens, which is an adverse condition (van Beers-Schreurs et al., 1998). Thus, the increased villus height seen in the study conducted by Liu et al. (2002) shows that glutamate may play a role in maintaining the structure of the small intestine in weanling pigs, alleviating some of the weaning stress.

Glutamate also serves as a precursor in enterocytes for several amino acids including alanine, aspartate, ornithine, and proline as well as reduced glutathione (GSH), which plays a role in both detoxification and the redox state of enterocytes (Blachier et al., 2009). Reeds et al. (1997) found that in the fed state, the mucosal GSH

pool is almost entirely derived from enteral glutamate, which implies that the source of glutamate is the diet.

Glutamine

Like glutamate, glutamine is traditionally classified as a non-essential amino acid; however, glutamine also has been hypothesized to be conditionally essential in the nursery pig diet (Wu et al., 2011). Dietary glutamine plays roles in maintaining intestinal health, improving growth performance, enhancing expression of genes, preventing oxidative stress, enhancing nutrient absorption, and stimulating cell growth (Wang et al., 2008, Zhou et al., 2012). Metabolic needs of glutamine include metabolic fuel for oxidation, protein synthesis, generating biologically-active substances, and the formation of tissue- or sex-specific products (Wu et al., 2011).

Supplementing glutamine in the diet of weaned pigs is advantageous. Supplemental glutamine is a direct source of glutamine for the physiological need in the small intestine, and supplemental glutamine can play a role in sparing both essential and non-essential amino acids from conversion to glutamine by the extra-intestinal tissues. This improves the efficiency of the utilization of dietary amino acids (Wu et al., 2011). Wang et al. (2008) found that supplementing 1.0% L-glutamine in the nursery diet led to an increase in ADG. Supplementing 1.0% L-glutamine also increased jejunal villus height by 38%, and downregulated genes that caused intestinal damage and upregulated genes that enhanced intestinal cell proliferation (Wang et al., 2008).

Like glutamate, glutamine also plays a role in reducing oxidative stress. Weaned pigs supplemented with 1.0% L-glutamine had enhanced jejunal GSH by 29% and reduced jejunal oxidized glutathione (GSSG) by 18%, thus reducing the GSSG:GSH ratio by 38%, which indicated that glutamine alleviated oxidative stress (Wang et al., 2008). Also like glutamate, glutamine has been shown to improve villus height. Increased villus height can increase absorption area, which can lead to increased nutrient transport (Cabrera et al., 2013).

Glutamine may also play a role in crypt width and depth. Treating weaned pigs with AminoGut (mixture of L-glutamine and L-glutamate) led to deep and wide crypts, which Cabrera et al. (2013) hypothesized was because glutamine donated it's amide group for the biosynthesis of purines and pyrimidines, supporting DNA production for dividing cells in the crypt walls.

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Table 2-1 Composition of Protein Ingredients in Nursery Diets

Ingredient	Whey	Blood Plasma	Fish Meal (Combined)	Blood Meal	Blood Cells	SBM 48%
Amino Acids %						
Essential						
ARG	0.26	4.39	3.84	3.83	3.37	3.45
HIS	0.21	2.53	1.44	5.39	5.84	1.28
ILE	0.64	2.69	2.56	0.97	0.31	2.14
LEU	1.11	7.39	4.47	11.45	12.72	3.62
LYS	0.88	6.90	4.56	8.60	7.75	2.96
MET	0.17	0.79	1.73	1.18	0.97	0.66
PHE	0.35	4.25	2.47	6.15	6.66	2.40
THR	0.71	4.47	2.58	4.36	3.43	1.86
TRP	0.20	1.41	0.63	1.34	1.72	0.66
VAL	0.61	5.12	3.06	7.96	8.44	2.23
Nonessential						
ALA	0.54	4.01	3.93	7.29	-	2.06
ASP	1.16	7.39	5.41	7.78	-	5.41
CYS	0.26	2.60	0.61	1.26	0.58	0.70
GLU	1.95	10.92	7.88	7.18	-	8.54
GLY	0.20	2.75	4.71	3.69	-	1.99
PRO	0.66	4.30	2.89	5.03	-	2.53
SER	0.54	4.15	2.43	4.64	-	2.36
TYR	0.27	3.89	1.88	2.66	2.32	1.59
Dry Matter %	97.15	91.97	93.70	93.23	93.43	89.98
ME, kcal/kg	3415	4017	3528	3773	-	3294
Crude Protein %	11.55	77.84	63.28	88.65	92.83	47.73
Crude Fiber %	0.08	-	0.24	-	-	3.89
Ether Extract %	0.83	2.00	9.71	1.45	1.50	1.52
Calcium %	0.62	0.13	4.28	0.05	0.02	0.33
Phosphorus %	0.69	1.28	2.93	0.21	0.34	0.71

Values determined from 2012 NRC

Table 2-2 Composition of WG

	WG
Amino Acids %	
Essential	
ARG	2.67
HIS	1.66
ILE	2.66
LEU	5.06
LYS	1.27
MET	1.08
PHE	3.91
THR	2.42
TRP	1.03
VAL	2.88
Nonessential	
ALA	2.12
ASP	3.08
CYS	1.48
GLU	23.87
GLY	2.74
PRO	9.67
SER	4.07
TYR	2.42
Dry Matter %	-
ME, kcal/kg	-
Crude Protein %	72.11
Crude Fiber %	-
Ether Extract %	-
Calcium %	-
Phosphorus %	-

Values determined from 2012 NRC

CHAPTER 3

REPLACING TYPICAL PROTEIN INGREDIENTS IN THE NURSERY DIET WITH WHEAT GLUTEN

[1]

[1] De Mille, C.M., C.R. Dove and M.J. Azain. To be submitted to *Journal of Animal Science.*

Abstract

Three experiments were conducted to determine if wheat gluten (WG) could effectively be substituted into the nursery diet in the place of commonly used ingredients. In the first experiment, WG was added to the diet at 5% and 10% at the expense of corn and SBM. It was determined that WG at the level of 5% in the phase 1 nursery diet improved both growth performance ($P<0.05$) and feed efficiency ($P<0.05$). Follow-up experiments focused on substituting WG for fishmeal (FM) and plasma protein (SDPP), which are common, expensive protein sources in the nursery diet. The second experiment had 4 dietary treatments in phase 1: 1) control (5% FM, 5%PP), 2) 5% WG in place of FM, 3) 5% WG in place of SDPP, and 4) 5% WG replacing ½ of each FM and SDPP. It was found in this experiment that WG could substitute for FM, but not SDPP. It was also found that pigs that ate the diet where WG replaced ½ of each SDPP and FM performed similarly to pigs on the control diet, but had improved feed efficiency ($P<0.05$). The third experiment utilized 5 dietary treatments during phase 1: 1) positive control (PC, 5% FM, 5% SDPP), 2) negative control (NC, 2.5% FM, 2.5% SDPP), 3) NC + 2.5% WG, 4) NC + 5% WG, and 5) NC + 7,5% WG. Overall (0-21 d), there was a quadratic effect of the level of WG on ADG ($P < 0.05$). Pigs fed the NC tended to have reduced ADG compared to the PC treatment ($P = 0.06$). There was a quadratic effect of level of WG on ADFI ($P < 0.05$). Pigs fed the NC tended to have reduced intake compared to those fed the PC ($P = 0.06$). There was no effect of diet on G:F. In this study, 2.5% WG was the optimal level of inclusion. The results indicate

that reduction in the content of PP and FM in the phase 1 diet results in a loss of performance which was restored with the addition of 2.5% WG.

Introduction

The first phase in the nursery post-weaning typically requires a more complex, nutrient-dense diet (Mahan et al., 1991). However, these diets tend to be more expensive (Mahan et al., 1998) because they contain ingredients including milk products like whey and dried skim milk, fish meal, and plasma protein (Maxwell and Carter, 2001). Feeding alternative feedstuffs can provide an economic benefit for swine production. A good alternative feed source may reduce the feed costs, but it should do so without compromising growth performance, health, carcass characteristics, quality, and environmental footprint (Johnston et al., 2013).

Wheat gluten (WG) is prepared by washing the starch from wheat flour and drying the remaining high protein gluten. While WG is relatively high in CP, it is relatively low in lysine, threonine, and tryptophan, which are limiting amino acids in nursery diets (Lawrence et al., 2004). Two main forms of WG are vitalized and devitalized. Devitalized WG undergoes denaturation that is irreversible and it cannot revitalize. The vital property of WG is related to the degree of viscoelasticity (Esteller et al., 2005). A study conducted by Richert et al. (1994) found that weanling pigs fed WG had lower N excretion in the feces, greater apparent N digestibility, and increased ADG compared to weanling pigs fed soybean meal (SBM). Another study found that weanling pigs fed a diet containing WG had an improved gain to feed ratio as compared to

weanling pigs fed a diet with SBM (Lawrence et al., 2004). Blasco et al.(2005) found that there was no difference in growth or feed to gain ratio between weanling pigs fed either a diet with fishmeal or WG, additionally, the diet containing WG had a higher total tract digestibility of dry matter, organic matter, and crude protein. The authors concluded that the absence of differences in growth between the fishmeal diet and the WG diet was a promising result. Thus, WG could serve as a viable substitution for fishmeal (Blasco et al., 2005). A study conducted by Burnham et al. (2000) found that weanling pigs fed plasma protein immediately post-weaning had greater ADG and ADFI as compared to weanling pigs fed WG. However, in later nursery phases when a common diet was fed, the pigs initially fed WG had greater ADG and ADFI than pigs initially fed plasma protein. Weanling pigs fed a blend of plasma protein and WG performed well, suggesting that WG could substitute for a portion of plasma protein, thus reducing diet costs. Overall, the authors concluded that replacing half of the portion of plasma protein in the nursery diet with WG can allow the producer to reap the benefits of plasma protein in the early nursery phase, but also the benefits of WG in later nursery phases (Burnham et al., 2000).

The objective of these studies was to determine the viability of including WG in the nursery diet in the place of more common ingredients like SBM, fish meal, and plasma protein.

Materials and Methods

The experimental protocols used in this study were approved by the Animal Care and Use Committee of the University of Georgia (UGA) (UGA Animal Care and Use, A2015 01-007-Y2-A0).Wheat gluten was provided by Manildra (Manildra Group USA, Leawood, KS.).

In all experiments, pigs from the University of Georgia (UGA) Swine Center were used (PIC C 29xTrue Choice EBX). Pigs were weaned at 21 d and allotted into pens based on weight. Sex was balanced within pens in a weight block. Dietary treatments were randomly assigned within weight blocks to pens. All diets were formulated to meet or exceed all nutrient requirements based on the 2012 NRC. Diets were produced at the UGA Poultry Science Department Feed Mill and fed in pellet form. Wheat gluten was provided by Manildra (Manildra Group USA, Leawood, KS.). Diet costs were estimated from Feedstuffs (Penton Ag,). Ingredient costs used were WG $0.90/lb, FM $0.75-1.00/lb, SDPP $2.00-3.00/lb, corn $0.10/lb, SBM $0.19/lb, DDGS $0.10/lb and Whey $0.50/lb. These estimates were used to calculate cost of gain. All studies were conducted in the Large Animal Research Unit (LARU) at the UGA Animal Science Complex in an environmentally controlled nursery with continuous artificial lighting, pits and wire flooring. Pens were 0.94m in width by 1.83m in length. The temperature was maintained within 28-31 degrees Celcius

Experiment 1

A total of 72 pigs were allotted to 24 pens (3 pigs per pen). There were 6 phase 1 dietary treatments administered d 0-14: 1) Control, 2) Control with DDGS, 3) 5% vitalized wheat gluten (VWG), 4) 10% VWG, 5) 5% devitalized wheat gluten (DWG), and 6) 10% DWG (Table 3-1). A common phase 2 diet was fed to all pigs d 14-27. Bodyweight (BW) and feed intake were monitored on d 0, 7, 14, 21, and 27 post-weaning. Ingredient amino acid profile was determined at the Agricultural Experiment Station Chemical Laboratories (University of Missouri-Columbia, College of Agriculture, Food and Natural Resources) (Table 3-2).

Experiment 2

There were 2 trials of 48 pigs utilized in this study. In each trial, pigs were allotted into 16 nursery pens (3 pigs per pen). There were 4 phase 1 (d 0-14) dietary treatments: 1) control (5% FM and 5% SDPP), 2) 5% WG, 0% FM, 3) 5% WG, 0% SDPP, and 4) 5% WG, 2.5% FM, 2.5% SDPP (Table 3-3). All pigs were fed a common phase 2 diet d 14-21. BW and feed intake were monitored on d 0, 7, 14, and 21.

Experiment 3

Experiment 3 was carried out in 2 trials. In the first trial, 75 pigs were allotted to 25 pens (3 pigs per pen). In the second trial, 60 pigs were allotted to 20 pens (3 pigs per pen). Five phase 1 dietary treatments were administered d 0-14: 1) positive control

(UGA standard diet) (PC), 2) negative control (2.5% FM, 2.5% SDPP, 0% WG) (NC), 3) NC + 2.5% WG, 4) NC + 5% WG, and 5) NC + 7.5% WG (Table 3-4). A common phase 2 diet was administered to all pigs d 14-21. BW and feed intake were monitored on d 0, 7, 14, and 21. Diet samples were collected during phase 1 (d 0-14). Diet amino acid profile was determined at the Agricultural Experiment Station Chemical Laboratories (University of Missouri-Columbia, College of Agriculture, Food and Natural Resources).

Statistical Analysis

All experiments were conducted as randomized complete block design. Data were analyzed using the General Linear Model procedure (PROC GLM) of SAS 9.4 (SAS Institute, Inc., Cary, NC). The model included trial, block, diet and trial-by-diet. In experiments 1 and 3, orthogonal contrasts were used to test for linear, quadratic and cubic effects of WG inclusion. In experiment 3 the PC and NC diets were compared by T-test. Differences were considered significant at $P < 0.05$. A trend was suggested at $0.05 \leq P \leq 0.01$.

Results

Experiment 1

We determined that we would not move forward with the use of DWG due to reduced growth performance. There were no differences in performance between the two control groups, so the following results are a comparison between the control diet

that included DDGS treatment group (0% WG), the 5% VWG treatment group (5% WG) and the 10% VWG treatment group (10% WG). Pigs fed the 5% WG diet had increased BW at the end of phase 1 (11.80 kg) compared to pigs fed 0% WG (10.88 kg) or 10% WG (10.39 kg, quadratic, $P < 0.05$). This effect carried over into phase 2 with pigs fed 5% WG having increased BW on d 27 (21.20 kg) compared to pigs fed 0% WG (19.50 kg) or 10% WG (18.60 kg, quadratic, $P < 0.05$). These same pigs also showed greater ADG (398 g/d) throughout the study as compared to pigs fed the control diet (331 g/d) or 10% WG (300 g/d, quadratic, $P < 0.05$) during phase 1 (d 0-14). Finally, pigs fed the 5% WG diet also had improved feed efficiency (G:F, 0.87) as compared to pigs fed the control diet (0.80) or 10% WG (0.80, $P < 0.05$). There was a trend for pigs fed the 5% WG diet to have decreased cost of gain (1.14$/kg) compared to the control (2.02$/kg) and the 10% WG diet (2.10$/kg, $P<0.01$) in phase 1 (d 0-14). This trend was also present for the overall study (control 2.02, 5% WG 1.95, 10% WG 2.19$/kg, $P=0.10$). While the 5% WG was more expensive, the increase in performance resulted in a lower cost of gain for these pigs compared to the control group. Data are shown in Table 3-6.

Experiment 2

Pigs fed the diet with 0% SDPP, 5% WG had numerically lower ADG (396 g/d) than pigs fed control (435 g/d), 0% FM, 5% WG (423 g/d), or 2.5% FM, 2.5% SDPP, 5% WG (440 g/d, $P < 0.20$). Pigs fed the diet with 2.5% FM, 2.5% SDPP, 5% WG had improved G:F (0.89) compared to pigs fed control (0.84), 0% FM, 5% WG (0.84), or 0%

SDPP, 5% WG (0.83, P < 0.02). There was a trend for pigs fed 2.5% FM, 2.5% SDPP, 5% WG to have decreased cost of gain (0.95$/kg) compared to thecontrol (1.06$/kg), the 0% FM, 5% WG diet (1.05 $/kg), and the 0% SDPP, 5% WG diet (1.02 $/kg, P=0.05). This was significant for the overall study (control 1.80, 0% FM, 5% WG 1.79, 0% SDPP, 5% WG 1.78, 2.5% FM, 2.5% SDPP, 5% WG 1.68 $/kg, P < 0.05) in phase 1 (d 0-21). Pigs on the 2.5% FM, 2.5% SDPP, 5% WG treatment achieved similar performance of the control, but at a lower cost and more efficiently. Data are shown in Table 3-7.

Experiment 3

Overall (0-21 d), pigs fed the NC diet tended to have reduced ADG (356 g/d) compared to pigs fed the PC diet (394 g/d) (P = 0.06). There was a quadratic effect of the level of WG on ADG (0-21 d). Pigs fed a 2.5% WG diet had significantly higher ADG (398 g/d) compared to pigs fed the NC diet (356 g/d), 5.0% WG diet (377 g/d), or 7.5% WG diet (362 g/d) (P < 0.05). Pigs fed the NC diet tended to have decreased ADFI (432 g/d) compared to pigs fed the PC diet (471 g/d) (P = 0.06). There was a quadratic effect of the level of WG on ADFI. Pigs fed the 2.5% WG diet had improved ADFI (471 g/d) compared to pigs fed the NC diet (432 g/d), 5.0% WG diet (446 g/d), or 7.5% WG diet (433 g/d) (P < 0.05). There was no effect of diet on feed efficiency. Pigs fed the PC treatment had the highest cost of gain (1.31 $/kg) compared to other treatment groups, while pigs fed the NC diet and the NC + 2.5% WG diet had the lowest cost of gain (1.07

and 1.06 $/kg respectively) compared to the NC + 5.0% WG (1.20 $/kg) and the NC + 7.5% WG (1.18 $/kg, P < 0.0001) during phase 1 (d 0-14). Overall (d 0-21), this effect was significant (PC 2.13, NC 1.91, NC + 2.5% WG 1.92, NC + 5.0% WG 2.02, NC + 7.5% WG 2.03 $/kg, P < 0.0001). The pigs fed the NC + 2.5% WG had performance that was similar to the level of performance of pigs fed the PC diet, but a lower cost of gain. Data are shown in Table 3-8. As expected, the addition of WG to the NC diet led to an increase in Glx content, which increased as WG level increased from 2.5% to 7.5% of the diet. The amino acid profile of the experimental diets is listed in Table 3-5.

Discussion

After analyzing the data, it was determined that we would not move forward with the use of DWG due to the reduced performance. Because of this, data from these groups are not included. The difference between VWG and DWG is that DWG is heat denatured during processing, which causes the loss of the viscoelasticity associated with WG, but this does not explain the differences that we observed. Our results in exp. 1 indicated that WG at the 5% level led to improvement in growth parameters compared to a typical phase 1 nursery diet, but growth improvements were not seen when WG was included at the 10% level. In a study conducted by Richert et al (1994), growth improvements were seen when WG was included at levels ranging from 8.65% to 22.16%, which would suggest that WG could be fed at high levels and still improve growth in the nursery pig.

Our finding that WG can replace SBM and improve ADG agrees with the results of Richert et al (1994). However, Lawrence et al (2004) did not see an improvement in ADG when WG was added at the expense of SBM. Our finding that WG improved feed efficiency (G:F) in nursery pigs agrees with observations made by Lawrence et al (2004).

The results of exp. 1 indicate that 5% WG can be added to the phase 1 nursery diet at the expense of corn and SBM with no detrimental effects, and 5% WG inclusion can lead to improvement in pig performance.

The results of exp. 2 show that replacing FM with WG does not have any detrimental effects on pig performance and agrees with the findings of Blasco et al (2005) that WG can serve as a viable substitute for FM in the nursery pig diet. However, our results indicate that WG could not substitute for SDPP in the nursery pig diet. This finding agrees with previous work that has shown that replacing SDPP in the nursery diet with WG results in reduced pig performance (Burnham et al., 2000 and Lawrence et al., 2004). This observation may be due to the growth response to SDPP being attributed to the IgG-rich fraction of SDPP (Pierce et al., 2005), which may contribute to the immunocompetence of the weaned pig by preventing viruses and bacteria from damaging the gut wall (Coffey and Cromwell, 1995). The most interesting result from this study was that WG could substitute for half the typical portion of FM and half the typical portion of SDPP in the nursery diet. Burnham et al (2000) found replacing a portion SDPP with WG in the nursery diet resulted in a reduced cost diet that was not

detrimental to pig performance. In this study, it was found that the replacing half the portion of FM and half the portion of SDPP with WG resulted in a more efficient pig with a lower cost of gain. These data indicate that WG can substitute for FM in the diet, but not SDPP. In addition, WG can substitute for half the portion of FM and half the portion of SDPP.

In exp. 3, the objectives were to repeat the observation that WG could substitute for a portion of FM and SDPP in the nursery diet and to determine the dose response to WG. It was determined that removing half the portion of FM and half the portion of SDPP in the nursery diet results in decreased performance. Our results indicated that this reduction in performance could be improved by the addition of WG, and restored to the level of pigs fed the PC diet by adding 2.5% WG to the NC diet. Thus, it was concluded that 2.5% WG was the optimal inclusion in this experiment.

In exp. 1, the cost of gain was significantly lowered by the addition of wheat gluten, but there was a trend suggesting that the performance that resulted from the addition of 5% WG at the expense of corn and SBM outweighed the higher cost of the diet. In exp. 2 and exp. 3, the cost of gain was decreased by the addition of WG, as WG was replacing specialty protein ingredients that are higher cost. In particular, the 2.5% FM, 2.5% SDPP, 5.0% WG in exp. 2 had lower cost of gain due to a more efficient pig and the NC + 2.5% WG diet in exp. 3, had lower cost of gain due to a lower cost diet, but similar performance compared the PC treatment, which is typical of the industry. While cost of gain can be variable, these data may be of interest to the industry

because the results indicate that these diets will reduce diet costs without compromising performance.

Wheat gluten has a unique amino acid profile. While it is relatively low in lysine, threonine, and tryptophan (Lawrence et al., 2004), it has a high Glx (Glutamine + Glutamate) content (Rombouts et al., 2009). The Glx content of wheat gluten has been estimated to be 23.87% (NRC, 2012). There is evidence that Glx are conditionally essential amino acids in nursery pigs (NRC, 2012 and Wu et al., 2011), which could be the reason that WG can be a successful protein source in the nursery diet. Functions of Glx in the gut include protecting against degradation in the gut (Liu et al., 2002 and Cabrera et al., 2013), alleviating oxidative stress (Blachier et al., 2009, Reeds et al., 2000, and Wang et al., 2008), improving the efficiency of the utilization of dietary amino acids (Wu et al, 2000), and regulating genes involved in gut health (Wang et al., 2008). These functions of Glx may explain success of using WG in the nursery diet.

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Table 3-1 – Composition of Experimental Nursery Diets (as-fed basis, Exp. 1)

Treatment	Control	Control w/ DDGS	5% VWG or DWG	10% VWG or DWG
PHASE I				
Ingredient, %				
Corn	38.21	23.94	20.47	16.94
Soybean Meal	18.75	12.76	12.07	10.38
DDGS	-	20.00	20.00	20.00
Wheat Gluten	-	-	5.00	10.00
Whey	27.50	27.50	27.50	27.50
Fish meal	5.00	5.00	5.00	5.00
Plasma Protein	5.00	5.00	5.00	5.00
Fat	1.63	1.49	1.70	1.91
Limestone	0.87	0.97	0.98	0.99
Dical	0.16	-	-	-
Salt	0.20	0.20	0.20	0.20
Vitamin premix	0.25	0.25	0.25	0.25
Mineral premix	0.15	0.15	0.15	0.15
Lysine	0.24	0.30	0.30	0.30
Methionine	0.15	0.07	-	-
Antibiotic	1.00	1.00	1.00	1.00
Zinc Oxide	0.38	0.38	0.38	0.38
Calculated				
Composition				
ME, kcal/kg	3400	3400	3400	3400
Crude Protein, %	22.90	24.67	27.10	29.57
SID lysine, %	1.48	1.48	1.48	1.48
TSAA, %	0.96	0.96	0.98	1.08
Thr, %	1.05	1.19	1.18	1.26
Ca, %	0.85	0.85	0.85	0.85
Total P, %	0.67	0.76	0.71	0.71
Avail. P, %	0.45	0.48	0.47	0.47

Table 3-2 Amino Acid Profile of Protein Ingredients Used in Experimental Diets (analyzed values)

Treatment	WG	SBM	SDPP	FM
Amino Acids, %				
Taurine	0.05	0.07	0.01	0.50
Hydroxyproline	0.00	0.00	0.00	0.60
Aspartic Acid	2.41	5.28	7.68	5.28
Threonine*	1.86	1.80	5.08	2.41
Serine	3.36	2.12	4.86	2.13
Glutamic Acid	28.12	8.66	10.54	7.83
Proline	9.07	2.40	3.97	2.97
Lanthionine	0.00	0.00	0.00	0.00
Glycine	2.54	2.08	2.79	4.83
Alanine	1.92	2.05	3.84	3.93
Cysteine	1.37	0.62	2.27	0.46
Valine*	2.97	2.34	5.57	2.88
Methionine*	1.16	0.66	0.91	1.62
Isoleucine*	2.86	2.31	2.46	2.51
Leucine*	5.32	3.71	7.48	4.28
Tyrosine	2.61	1.72	3.72	1.80
Phenylalanine*	3.86	2.48	4.15	2.39
Hydroxylysine	0.01	0.02	0.00	0.21
Omithine	0.01	0.02	0.02	0.08
Lysine*	1.31	3.06	6.93	4.59
Histidine*	1.53	1.23	2.38	1.27
Arginine*	2.58	3.5	4.45	3.62
Tryptophan	0.824	0.66	1.52	0.66
Total	75.74	46.79	80.63	56.85

*Denotes essential amino acids
Values determined at Agricultural Experiment Station Chemical Laboratories, University of Missouri-Columbia, College of Agriculture, Food and Natural Resources

Table 3-3 – Composition of Experimental Nursery Diets (as-fed basis, Exp. 2)

Treatment	Control	0% FM	0% SDPP	2.5% FM,2.5% SDPP
PHASE 1				
Ingredient, %				
Corn	23.94	17.32	17.93	17.63
Soybean Meal	13.76	18.75	18.75	18.75
DDGS	20.00	20.00	20.00	20.00
Wheat Gluten	-	5.00	5.00	5.00
Whey	27.50	27.50	27.50	27.50
Fish meal	5.00	-	5.00	-
Plasma Protein	5.00	5.00	-	-
Fat	1.49	2.28	2.27	2.27
Limestone	0.97	1.34	0.87	1.10
Dical	-	0.48	0.15	0.32
Salt	0.20	0.20	0.20	0.20
Vitamin premix	0.25	0.25	0.25	0.25
Mineral premix	0.15	0.15	0.15	0.15
Lysine	0.30	0.33	0.47	0.40
Methionine	0.07	0.02	0.08	0.05
Zinc Oxide	0.38	0.38	0.38	0.38
Antibiotic	1.00	1.00	1.00	1.00
Calculated Composition				
ME, kcal/kg	3400	3400	3400	3400
Crude Protein, %	24.67	27.09	26.42	26.76
SID lysine, %	1.48	1.48	1.48	1.48
TSAA, %	0.96	0.96	0.96	0.96
Thr, %	1.19	1.15	1.05	1.09
Ca, %	0.85	0.85	0.85	0.85
Total P, %	0.76	0.70	0.72	0.71
Avail. P, %	0.48	0.45	0.45	0.45

Table 3-4 Composition of Experimental Diets (Exp. 3)

Treatment	PC	NC	NC + 2.5% WG	NC + 5% WG	NC + 7.5% WG
PHASE 1					
Ingredient, %					
Corn	23.94	22.40	20.17	17.63	15.09
Soybean Meal	13.76	18.75	18.75	18.75	18.75
DDGS	20.00	20.00	20.00	20.00	20.00
Wheat Gluten	-	-	2.50	5.00	7.50
Whey	27.50	27.50	27.50	27.50	27.50
Fishmeal	5.00	2.50	2.50	2.50	2.50
Plasma Protein	5.00	2.50	2.50	2.50	2.50
Fat	1.49	2.05	2.16	2.27	2.38
Salt	0.20	0.20	0.20	0.20	0.20
Limestone	0.97	1.35	1.11	1.10	1.10
Dical	-	0.46	0.31	0.32	0.33
Vitamin Premix	0.25	0.25	0.25	0.25	0.25
Mineral Premix	0.15	0.15	0.15	0.15	0.15
Zinc Oxide	0.38	0.38	0.38	0.38	0.38
Lysine	0.30	0.39	0.43	0.40	0.37
Methionine	0.07	0.12	0.10	0.05	-
Enzyme	-	0.54	0.54	0.54	0.54
Antibiotic	1.00	1.00	1.00	1.00	1.00
Calculated Composition					
ME, kcal/kg	3400	3400	3400	3400	3400
Crude Protein, %	24.67	23.71	25.23	26.76	28.28
SID lysine, %	1.48	1.48	1.48	1.48	1.48
TSAA, %	0.96	0.96	0.96	0.96	0.96
Thr, %	1.19	1.08	1.17	1.09	1.13
Ca, %	0.85	0.85	0.85	0.85	0.85
Total P, %	0.76	0.72	0.71	0.71	0.71
Avail. P, %	0.48	0.45	0.45	0.45	0.45

Table 3-5 Amino Acid Profile of Experimental Diets (Exp. 3, analyzed values)

Treatment	PC	NC	NC + 2.5% WG	NC + 5% WG	NC + 7.5% WG
PHASE 1					
Amino Acids, %					
Taurine	0.14	0.14	0.14	0.14	0.12
Hydroxyproline	0.03	0.01	0.01	0.03	0.00
Aspartic Acid	2.09	2.01	2.09	2.22	2.27
Threonine*	1.02	0.95	0.99	1.04	1.10
Serine	1.01	0.95	1.03	1.09	1.19
Glutamic Acid	3.55	3.47	4.06	4.55	5.31
Proline	1.36	1.28	1.49	1.64	1.88
Lanthionine	0.00	0.00	0.00	0.00	0.00
Glycine	1.01	0.92	0.97	1.04	1.10
Alanine	1.23	1.15	1.19	1.23	1.27
Cysteine	0.40	0.35	0.37	0.44	0.46
Valine*	1.19	1.11	1.19	1.26	1.34
Methionine*	0.45	0.42	0.41	0.48	0.45
Isoleucine*	0.98	0.96	1.03	1.11	1.18
Leucine*	2.08	1.98	2.11	2.22	2.35
Tyrosine	0.76	0.71	0.78	0.83	0.88
Phenylalanine*	1.07	1.02	1.12	1.21	1.31
Hydroxylysine	0.03	0.02	0.02	0.02	0.02
Omithine	0.02	0.02	0.02	0.02	0.02
Lysine*	1.64	1.59	1.65	1.71	1.74
Histidine*	0.58	0.55	0.58	0.62	0.66
Arginine*	1.25	1.18	1.27	1.37	1.41
Tryptophan	0.31	0.29	0.31	0.33	0.34
Total	22.10	21.00	22.80	24.60	26.30

*Denotes essential amino acids
Values determined at Agricultural Experiment Station Chemical Laboratories, University of Missouri-Columbia, College of Agriculture, Food and Natural Resources

Table 3-6 Effect of WG in Nursery Diets on Post-weaning Pig Performance (Exp. 1)

Treatment	Control	5% WG	10% WG	SEM	P
Body Weight, kg					
Day 0	6.24	6.22	6.19	0.12	NS
Day 14	10.88[b]	11.80[a]	10.39[b]	0.27	0.01
Day 27	19.54[b]	21.17[a]	18.62[b]	0.49	0.01
Daily gain, g/d					
Day 0-14	331[b]	398[a]	300[b]	18.0	0.01
Day 14-27	660[b]	720[a]	633[b]	23.0	0.01
Day 0-27	492[b]	553[a]	460[b]	17.0	0.01
Daily feed, g/d					
Day 0-14	371	393	318	15.0	NS
Day 14-27	886[a]	906[a]	864[b]	48.0	0.03
Day 0-27	619	640	581	25.0	NS
Gain:Feed					
Day 0-14	0.89[b]	1.02[a]	0.94[b]	0.03	0.03
Day 14-27	0.76	0.80	0.74	0.03	NS
Day 0-27	0.80[b]	0.87[a]	0.80[b]	0.02	0.03
Cost of gain $/kg					
Day 0-14	1.21	1.14	1.32	0.06	0.10
Day 14-27	0.81	0.81	0.87	0.02	NS
Day 0-27	2.02	1.95	2.19	0.06	0.10

Results represent a total of 24 pens (4 pens per diet) and have been co-varied for initial weight. Pigs were fed experimental diets from day 0-14 post-weaning and a common diet for days 14-27.
Means within a row lacking a common superscript letter differ at respective p-level

Table 3-7 Effect of WG in Nursery Diets on Post-weaning Pig Performance (Exp. 2)

Treatment	Control	0% FM	0% SDPP	2.5% FM,2.5% SDPP	SEM	P
Body Weight, kg						
Day 0	6.48	6.45	6.43	6.35	0.38	NS
Day 14	10.80	10.80	10.41	10.83	0.41	NS
Day 21	15.62	15.33	14.76	15.59	0.51	NS
Daily gain, g/d						
Day 0-14	308	311	283	320	13	NS
Day 14-21	689	647	621	681	23	0.20
Day 0-21	435	423	396	440	15	0.20
Daily feed, g/d						
Day 0-14	352	354	322	340	10	0.20
Day 14-21	844	801	786	815	32	NS
Day 0-21	516	503	476	498	16	NS
Gain:Feed						
Day 0-14	0.88	0.87	0.88	0.94	0.02	0.10
Day 14-21	0.82	0.81	0.79	0.84	0.02	0.20
Day 0-21	0.84[b]	0.84[b]	0.83[b]	0.89[a]	0.01	0.02
Cost of Gain $/kg						
Day 0-14	1.06	1.05	1.02	0.95	0.03	0.05
Day 14-21	0.74	0.75	0.76	0.72	0.02	NS
Day 0-21	1.80[b]	1.79[b]	1.78[b]	1.68[a]	0.03	0.001

Results represent a total of 48 pens (8 pens per diet) and have been co-varied for initial weight. Pigs were fed experimental diets from day 0-14 post-weaning and a common diet for days 14-21
Means within a row lacking a common superscript letter differ at respective p-level

Table 3-8 Effect of WG in Nursery Diets on Post-Weaning Pig Performance (Exp. 3)

Treatment		WG Inclusion					P-value		
	PC	NC	NC + 2.5% WG	NC + 5.0% WG	NC + 7.5% WG	SEM	PT[1]	PQ[2]	P[3]
Body Weight, kg									
Day 0	7.34	6.98	7.32	7.30	7.32	0.15	NS	NS	NS
Day 14	10.30	9.78	10.43	10.05	10.04	0.27	NS	NS	NS
Day 21	14.17	13.35^{b}	14.22^{a}	13.78^{ab}	13.49^{b}	0.30	0.06	0.03	0.07
Daily gain, g/d									
Day 0-14	318	280	327	299	298	20	NS	NS	NS
Day 14-21	545	506	535	518	490	20	NS	0.08	NS
Day 0-21	395	357^{b}	395^{a}	376^{ab}	363^{b}	15	0.06	0.03	0.10
Daily feed, g/d									
Day 0-14	339	304	332	319	308	16	NS	NS	NS
Day 14-21	757	704	763	713	694	18	NS	0.05	NS
Day 0-21	479	437	476	450	437	16	0.06	0.10	0.10
Gain:Feed									
Day 0-14	0.92	0.92	0.98	0.93	0.96	0.02	NS	NS	NS
Day 14-21	0.73	0.73	0.71	0.74	0.71	0.02	NS	NS	NS
Day 0-21	0.82	0.82	0.83	0.84	0.83	0.02	NS	NS	NS
Cost of Gain $/kg									
Day 0-14	1.31^{c}	1.07^{a}	1.06^{a}	1.20^{b}	1.18^{b}	0.02	-	-	<0.0001
Day 14-21	0.82	0.83	0.85	0.82	0.85	0.03	-	-	NS
Day 0-21	2.13^{c}	1.91^{a}	1.92^{a}	2.02^{b}	2.03^{b}	0.03	-	-	<0.0001

[1] P-values is for PC vs. NC
[2] Quadratic effect of WG level in the diet
[3] P-values are for 5 treatments
Means within a row lacking a common superscript differ at respective PQ-level

CHAPTER 4

THE EFFECTS OF ADDING GLUTAMATE AND GLUTAMINE IN THE FORM OF AMINOGUT TO THE NURSERY DIET AT THE SAME LEVEL OF GLUTAMATE AND GLUTAMINE CONTENT FOUND IN WHEAT GLUTEN

[2]

[2] De Mille, C.M., C.R. Dove and M.J. Azain. To be submitted to *Journal of Animal Science.*

Abstract

A total of 180 weanling pigs were used in an experiment to evaluate the effect of the glutamate and glutamine content of wheat gluten (WG) in nursery starter diets on performance via AminoGut. There were 6 dietary treatments in phase 1 (d 0-10): positive control (PC), negative control (NC), 2.5% WG, 5% WG, 0.5% AminoGut, and 1.0% AminoGut. A common diet was fed in phase 2 (d 10-21). The study was conducted as randomized complete block design. There was no effect of diet on BW, ADG, ADFI and G:F. On d 5 pigs fed the PC or 5% WG diet tended to have increased serum urea nitrogen (SUN) compared to other treatments (P = 0.05). At the end of phase 1 (d 10), pigs fed the PC, 2.5% WG and 5% WG had increased SUN compared to other treatment groups (P < 0.05). It was concluded that the growth response to WG inclusion in the diet was not related to the Glx content.

Introduction

The weaning period is a time during which pigs are subject to several stressors than can lead to physiological issues like intestinal and immune dysfunction (Campbell et al., 2013). In the first few weeks of life, the structure of the small intestine in piglets is subject to major changes including changes in the height, shape, and density of the villi. Ideally, villi should be healthy and well-defined (Cabrera et al., 2013). However, post-weaning pigs often initially have decreased villous length (Montagne et al., 2006). Weaning stress can also

contribute to gut inflammation via a negative effect on the integrity of the intestinal barrier (Campbell et al., 2013).

The nutritional needs of weaned pigs change rapidly (NRC 2012), so a phase feeding program is commonly implemented to guide the transition from a complex diet to a simple corn-soybean meal diet, with a complex diet immediately post-weaning being essential to maximizing feed intake and gain (Maxwell and Carter, 2001). However, this complex diet tends to be more expensive (Mahan et al., 1998). Traditionally, post-weaning diets include fish meal, plasma protein, and milk products like whey and dried skim milk (Maxwell and Carter, 2001), but studies have found that wheat gluten (WG) can be included as a protein source in diets, and replace some higher cost protein ingredients (Richert et al., 2004, Lawrence et al., 2004, Burnham et al., 2000).

Since separate analysis of glutamate and glutamine is difficult, they are considered together and referred to as Glx. WG is a unique protein ingredient due to the high glutamine and glutamate (Glx) content (Rombouts et al., 2009). While non-essential, it has been suggested that dietary glutamate may be essential for mucosal health (Reeds et al., 2000). Some roles of dietary glutamate include proliferation of intestinal epithelial cells (Li et al., 2016), increased villus height (Liu et al., 2001), and glutamate serves as precursor in enterocytes for glutathione (GSH), which is important in the detoxification and redox state of enterocytes (Blachier et al., 2009). Similar to glutamate, glutamine is also traditionally considered to be non-essential, but is hypothesized to be

conditionally essential in the nursery pig (Wu et al., 2011). Roles of dietary glutamine include maintaining intestinal health, improving growth performance, enhancing expression of genes, preventing oxidative stress, enhancing nutrient absorption, and stimulating cell growth (Wang et al., 2008, Zhou et al., 2012).

Because of both the success of WG inclusion in nursery diets as protein source and the unique amino acid makeup of WG, and given the possible importance of Glx in the nursery pig, the objective of this experiment was to determine if the Glx content of WG is responsible for the positive performance response of pigs when WG is included in the diet.

Materials and Methods

The experimental protocols used in this study were approved by the Animal Care and Use Committee of the University of Georgia (UGA) (UGA Animal Care and Use, A2015 01-007-Y2-A0). Wheat gluten was provided by Manildra (Manildra Group USA, Leawood, KS.), AminoGut was provided by Ajinomoto (95% L-Glu and L-Gln, Ajinomoto Heartland, Inc.).

A total of 180 (96 f, 84 m) pigs (CG32xEBX, CG32xEB5) (initial weight = 5.49 ± 0.11 kg) from the UGA Swine Center herd were weaned (21 d) and were allotted into 48 pens based on weight and sex with 3-4 pigs per pen. Sex was balanced within pens in a weight block. Dietary treatments were randomly assigned within weight blocks to pens. Pen was considered the experimental unit. The study was conducted in two trials at the Large Animal Research Unit

(LARU), UGA Animal Science Complex in an environmentally controlled nursery with continuous artificial lighting and woven wire flooring. Pens were 0.94m wide by 1.83m long. The temperature was maintained within 28-31 degrees Celcius. In each trial, pigs were placed into 24 pens with 3-4 pigs per pen. There were six dietary treatments administered in phase 1: 1. Postive Control (PC, 5% FM 5% SDPP), 2. Negative Control (NC, 2.5% FM 2.5% SDPP), 3. NC + 2.5% WG, 4. NC + 5.0% WG, 5. NC + 0.5% AminoGut, 6. NC + 1.0% AminoGut. In all diets, SBM and whey were maintained. WG was added to diets 3 and 4 at 2.5% and 5.0% respectively, largely replacing corn. AminoGut was added to diets 5 and 6 at 0.5% and 1.0% respectively in the place of starch. Treatments were designed to test the inclusion of AminoGut at the same level as Glx found in WG in phase 1 diets. A common diet was fed during phase 2. Diet composition of experimental diets and nutrient content are summarized in Table 4-1. Diets were formulated to meet or exceed all nutrient requirements based on the 2012 Swine NRC. Diets were formulated using the WUFFDA least cost formulation software (Pesti, 2001). Diets were produced at the UGA Poultry Science Department Feed Mill and fed in pellet form ad libitum. Diet samples were collected in phase 1 and stored for later analysis. Water was available to the pigs ad libitum through nipple waterers.

Pigs were weighed at weaning (d 0) and again at 5, 10, and 21 days post-weaning. Feed was weighed back at these same intervals to determine the feed intake of each pen. During trial 1, all pigs in a pen were bled in the morning on d

5 and 10 post-weaning to determine protein status via serum urea nitrogen (SUN). Blood was collected from the orbital sinus (Dove and Alworth, 2015). After centrifugation, blood serum was removed and frozen for later analysis.

Analysis of Phase 1 Diet Samples

Nitrogen content was determined using a nitrogen analyzer (LECO FP628 Series, LECO Corp., St. Joseph, MI). Crude protein was calculated (Table 4-2). Diet samples of phase 1 treatments were sent to Agricultural Experiment Station Chemical Laboratories (University of Missouri-Columbia, College of Agriculture, Food and Natural Resources) for amino acid analysis (Table 4-3)

Serum Urea Nitrogen

SUN was determined according to the procedure described by Chaney and Marbach (1962). This procedure was modified according to Sigma reagents U-3383 urease buffer reagent (Sigma-Aldrich Co. LLC., St. Louis, MO).

Statistical Analysis

All data were analyzed using the General Linear Model procedure (PROC GLM) of SAS 9.4 (SAS Institute, Inc., Cary, NC). The experimental unit was pen. For the growth performance data, the model included trial, block, diet, and trial-by-diet. For the SUN data, individual pig was considered the observation.

Differences were considered significant at $P < 0.05$, and a trend was suggested at $P < 0.10$.

Results

Diet Analysis

The analyzed CP content of the experimental phase 1 diets is reported in Table 4-2. As expected, removing half of the fish meal and half of the SDPP (NC) resulted in lower CP compared to the PC diet (21.36 and 19.21% respectively), and CP increased as WG was added at 2.5% (20.38%) and 5.0% (21.70%). The NC diets with AminoGut added were 19.83% CP (0.5% AminoGut) and 19.50% CP (1.0% AminoGut). Addition of either WG or AminoGut to the NC diet resulted in a higher content of Glx in the diet. The amino acid profile of the experimental phase 1 diets is reported in Table 4-3.

Growth Performance

Pigs on all treatments grew similarly to the pigs in experiments 1, 2, and 3, and they grew similarly to the historical average of the UGA Swine Center. There were no differences among treatment groups for BW, ADG, ADFI, or G:F at any time during the study. Unexpectedly, there were no differences between the PC and NC treatment groups. Performance data are reported Table 4-4.

Serum Urea Nitrogen

SUN data are reported in Table 4-5. On d 5, pigs fed the PC diet or the 5% WG diet tended to have higher SUN (6.82 and 7.59 mg/dL respectively) compared to pigs fed the NC diet, 2.5% WG diet, 0.5% AminoGut diet or 1.0% AminoGut diet (4.53, 4.96, 5.93 and 4.04 mg/dL respectively) (P=0.05). On d 10, pigs fed the PC diet, the 2.5% WG diet, or the 5% WG diet had increased SUN (7.84, 7.29 and 8.27 mg/dL respectively) compared to pigs fed the NC diet, 0.5% AminoGut diet or 1.0% AminoGut diet (5.16, 5.33 and 5.24 mg/dL respectively) (P<0.05).

Discussion

We hypothesized that the success of WG as a protein source in the phase 1 nursery diet could be attributed to the Glx content of WG. Other studies have also hypothesized that the successful use of WG may be attributed to the Glx content (Lawrence et al., 2004 and Blasco et al., 2005). Glutamate and glutamine have important roles in the gut. Both glutamate and glutamine have been shown to prevent the typical post-weaning reduction in villus height when supplemented in the starter diet (Liu et al., 2002 and Cabrera et al., 2013). Glutamate acts as a precursor in enterocytes for GSH (Blachier et al, 2009), and glutamine enhances jejunal GSH and reduces jejunal GSSG (Wang et al., 2008), suggesting that Glx is important in relieving oxidative stress. In fact, Reeds et al (1997) found that the mucosal GSH pool in the pig in the fed state is almost entirely derived from enteral glutamate, which implies that it is from the diet. Wang et al (2008) found

that supplemental glutamate in the diet upregulated genes that enhanced intestinal cell proliferation and downregulated genes that caused intestinal damage. Unlike our previous experiments, there was no difference in growth performance when pigs were fed WG. Additionally, pigs fed AminoGut had numerically decreased ADG compared to pigs fed other treatments. Thus, the Glx in WG may not be responsible for the growth response seen in previous research. Burnham et al (2000) attributed the success of WG in the nursery diet to the fact that while WG is a plant protein, it does not have the same degree of antigenicity as SBM, which may allow the nursery pig to activate enzymes used to digest plant proteins without the hypersensitive response associated with SBM.

In our previous experiments, our data indicate that removing half of the fish meal and half of the SDPP in the diet results in decreased growth performance when compared to pigs fed a typical phase 1 nursery diet. However, in this study, there was no difference among treatment groups. This was an unexpected and surprising result. Our previous work as well as previous research has determined that adequate SDPP is crucial in the phase 1 diet (Coffey and Cromwell, 1995, Grinstead et al., 2000, Pierce et al., 2005).

Serum urea nitrogen is a measure of protein metabolism and is related to protein intake as well. As amino acid utilization increases, urea synthesis will decrease, so a low SUN concentration would theoretically indicate that the absorbed amino acids are being used efficiently (Coma et al., 1995). At d 5 of our

current study, we saw a trend for the pigs fed treatments with lower CP (NC, 2.5% WG, 0.5% AminoGut, 1.0% AminoGut) to have lower SUN. At d 10, the NC diet, the 0.5% AminoGut diet and the 1.0% AminoGut diet had decreased SUN compared to other treatments, and these diets also had lower CP. These results agree with other studies that have found that the concentration of urea in the blood decreases as CP in the diet decreases (Figueroa et al., 2002, Nyachoti et al., 2006 and Yue and Qiao, 2007). As in our study, the low CP diets in these studies were supplemented with crystalline amino acids, which did not increase the SUN as crystalline amino acids are typically considered to be more bioavailable (Figueroa et al., 2002). There was some variation among pigs in the same treatment group, which can probably be attributed to the fact that the pigs had ad libitum access to feed prior to being bled.

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Table 4-1 – Composition of Experimental Nursery Diets (as-fed basis)

Treatment	PC	NC	NC + 2.5% WG	NC + 5% WG	NC + 0.5% Amino Gut	NC + 1.0% Amino Gut
PHASE 1						
Ingredient, %						
Corn	37.84	41.24	38.69	36.13	41.24	41.24
Soybean Meal	18.75	18.75	18.75	18.75	18.75	18.75
Wheat Gluten	-	-	2.50	5.00	-	-
Whey	27.50	27.50	27.50	27.50	27.50	27.50
Fish meal	5.00	2.50	2.50	2.50	2.50	2.50
Plasma Protein	5.00	2.50	2.50	2.50	2.50	2.50
Amino Gut	-	-	-	-	0.50	1.00
Fat	1.63	2.24	2.36	2.47	2.24	2.24
Limestone	0.87	0.95	0.94	0.92	0.95	0.95
Dical	0.16	0.62	0.64	0.68	0.62	0.62
Salt	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin premix	0.25	0.25	0.25	0.25	0.25	0.25
Mineral premix	0.15	0.15	0.15	0.15	0.15	0.15
Lysine	0.26	0.57	0.55	0.52	0.57	0.57
Methionine	0.01	0.15	0.09	0.04	0.15	0.15
Antibiotic	1.00	1.00	1.00	1.00	1.00	1.00
Zinc Oxide	0.38	0.38	0.38	0.38	0.38	0.38
Corn Starch	1.00	1.00	1.00	1.00	0.50	-
Calculated Composition						
ME, kcal/kg	3400	3400	3400	3400	3400	3400
Crude Protein, %	22.85	20.06	21.58	23.10	21.58	23.10
SID lysine, %	1.50	1.50	1.50	1.50	1.50	1.50
TSAA, %	0.82	0.82	0.82	0.82	0.82	0.82
Thr, %	1.05	0.88	0.92	0.96	0.92	0.96
Ca, %	0.85	0.85	0.85	0.85	0.85	0.85
Total P, %	0.66	0.65	0.65	0.65	0.65	0.65
Avail. P, %	0.45	0.45	0.45	0.46	0.45	0.46

Table 4-2 – Amino Acid Profile and Crude Protein Content of Experimental Nursery Diets (analyzed values)

Treatment	PC	NC	NC + 2.5% WG	NC + 5% WG	NC + 0.5% Amino Gut	NC + 1.0% Amino Gut
PHASE 1						
Amino Acids, %[1]						
Taurine	0.18	0.17	0.17	0.17	0.17	0.17
Hydroxyproline	0.07	0.07	0.07	0.06	0.07	0.06
Aspartic Acid	2.13	1.80	1.93	1.88	1.78	1.81
Threonine*	0.93	0.79	0.85	0.88	0.81	0.81
Serine	0.91	0.75	0.82	0.88	0.75	0.75
Glutamic Acid	3.67	3.15	3.74	4.29	3.56	3.89
Proline	1.28	1.09	1.28	1.42	1.09	1.08
Lanthionine	0.00	0.00	0.00	0.00	0.00	0.00
Glycine	0.94	0.75	0.80	0.82	0.72	0.71
Alanine	1.10	0.94	0.98	0.98	0.91	0.90
Cysteine	0.37	0.30	0.35	0.36	0.31	0.31
Valine*	1.16	0.98	1.06	1.11	0.97	0.95
Methionine*	0.45	0.38	0.42	0.37	0.40	0.40
Isoleucine*	0.96	0.84	0.92	0.94	0.83	0.83
Leucine*	1.88	1.65	1.76	1.81	1.62	1.60
Tyrosine	0.71	0.59	0.66	0.68	0.60	0.60
Phenylalanine*	1.04	0.88	0.97	1.01	0.87	0.85
Hydroxylysine	0.05	0.04	0.04	0.04	0.04	0.04
Omithine	0.01	0.01	0.01	0.01	0.01	0.01
Lysine*	1.62	1.54	1.62	1.64	1.58	1.64
Histidine*	0.54	0.46	0.50	0.51	0.45	0.44
Arginine*	1.30	1.03	1.14	1.11	1.01	1.01
Tryptophan	0.30	0.26	0.28	0.28	0.27	0.24
Total	21.60	18.47	20.37	21.25	18.82	19.10
CP, %[2]	21.36	19.21	20.38	21.70	19.83	19.50

*Denotes essential amino acids

[1]Values determined at Agricultural Experiment Station Chemical Laboratories, University of Missouri-Columbia, College of Agriculture, Food and Natural Resources

[2]Values determined at the University of Georgia

Table 4-3 Effect of WG and AminoGut in Nursery Diets on Post-Weaning Pig Performance

Treatment	PC	NC	NC + 2.5% WG	NC + 5.0% WG	NC + 0.5% AminoGut	NC + 1.0% AminoGut	SEM	P
Body Weight, kg								
Day 5	6.50	6.47	6.47	6.50	6.44	6.42	0.09	NS
Day 10	8.05	8.11	8.00	7.99	7.89	7.79	0.13	NS
Day 21	12.2	12.62	12.46	12.04	12.04	11.87	0.25	NS
Daily gain, g/d								
Day 0-5	202	196	195	201	191	184	20	NS
Day 5-10	294	302	285	279	268	257	20	NS
Day 0-10	247	250	241	241	231	231	10	NS
Day 10-21	394	430	423	418	394	387	20	NS
Day 0-21	319	339	331	328	312	303	10	NS
Daily feed, g/d								
Day 0-5	263	268	275	255	266	256	20	NS
Day 5-10	258	289	270	250	278	273	10	NS
Day 0-10	229	250	244	227	242	239	20	NS
Day 10-21	574	583	621	594	580	571	20	NS
Day 0-21	435	435	453	431	430	418	20	NS
Gain:Feed								
Day 0-10	1.05	1.00	0.97	1.03	0.94	0.92	0.04	NS
Day 10-21	0.69	0.74	0.67	0.70	0.69	0.67	0.02	NS
Day 0-21	0.74	0.78	0.73	0.76	0.73	0.72	0.02	NS

Results represent a total of 48 pens (8 pens per diet) and have been co-varied for initial weight. Pigs were fed experimental diets from day 0-10 post-weaning and a common diet for days 10-21

Table 4-4 Effect of WG and AminoGut Inclusion on Serum Urea Nitrogen Values

Treatment	PC	NC	NC + 2.5% WG	NC + 5.0% WG	NC + 0.5% AminoGut	NC + 1.0% AminoGut	SEM	P
SUN, mg/dL								
Day 5	6.82	4.53	4.96	7.59	5.93	4.04	0.87	0.05
Day 10	7.84[a]	5.16[b]	7.29[a]	8.27[a]	5.33[b]	5.24[b]	0.87	0.03

Values determined from blood collected during trial 1
Means within a row lacking a common superscript letter differ at respective p-level

CHAPTER 5

CONCLUSION

In conclusion, wheat gluten (WG) is a viable protein source to add to the nursery diet. WG can substitute for a portion of FM and SDPP in the diet without negative effects on performance, which can help to reduce the diet costs. WG is about 24% glutamate and glutamine (Glx). Glx can be considered conditionally essential in the nursery pig diet; however, our results contradicted our hypothesis that the Glx content of WG was responsible for the growth response that we saw in our previous work. In this study, it was concluded that the Glx content of WG is not responsible for the growth response in pigs fed WG despite the fact that Glx has been shown to have important roles in the gut of the nursery pig. In this particular study, pigs fed WG did not perform better than other treatments, which was a result seen in our other experiments. Additionally, pigs fed the NC diet did not perform any differently than pigs fed the PC diet, which was contradictory to our previous observations. As stated previously, WG may be a successful dietary protein in the nursery pig diet due to the lack of antigenicity compared to feeding SBM.

APPENDIX

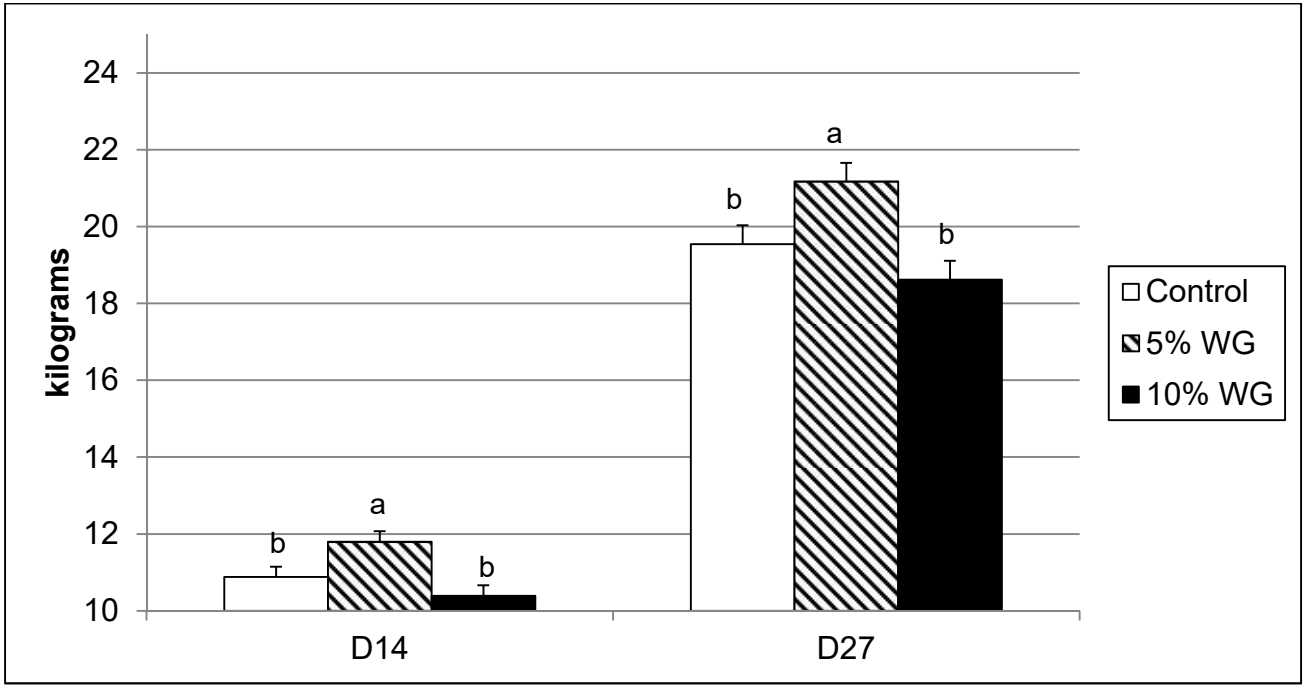

Figure A-1. Exp. 1 body weight at the end of phase 1 (d 14) and the end of phase 2 and the study (d 27). Error bars are the standard error of means (SEM). Means each age with different superscripts differ ($P < 0.05$)

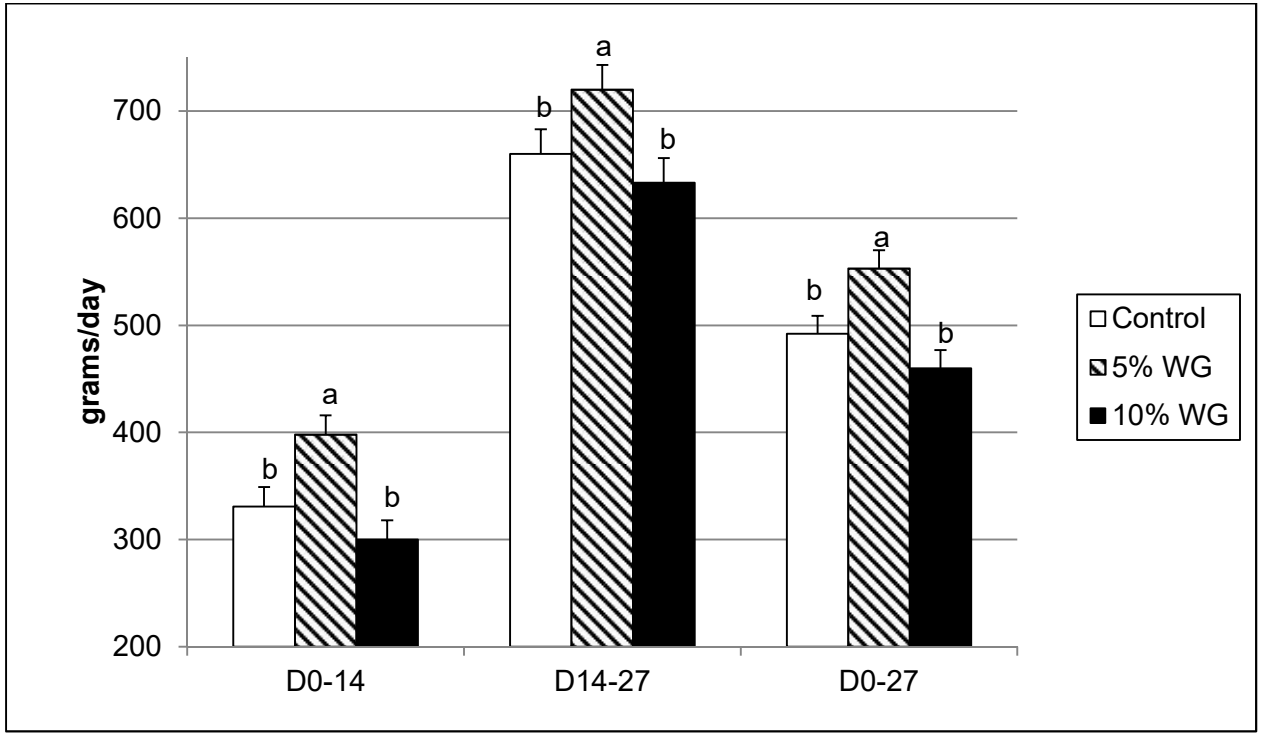

Figure A-2. Exp. 1 average daily gains for phase 1 (d 0-14), phase 2 (d 14-27) and overall (d 0-27). Error bars are the standard error of the means (SEM). Means at each phase with different superscripts differ ($P < 0.05$).

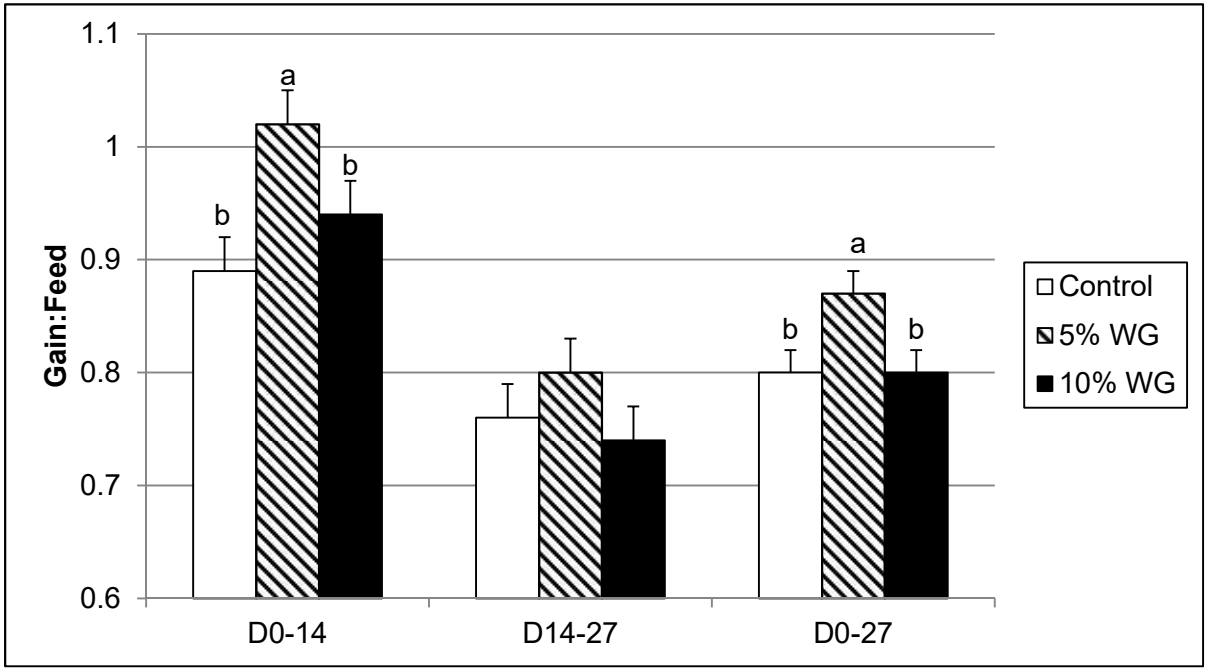

Figure A-3. Exp. 1 Gain:feed for phase 1 (d 0-14), phase 2 (d 14-27) and overall (d 0-27). Error bars are the standard error of means (SEM). Means at each phase with different superscripts differ ($P < 0.05$).

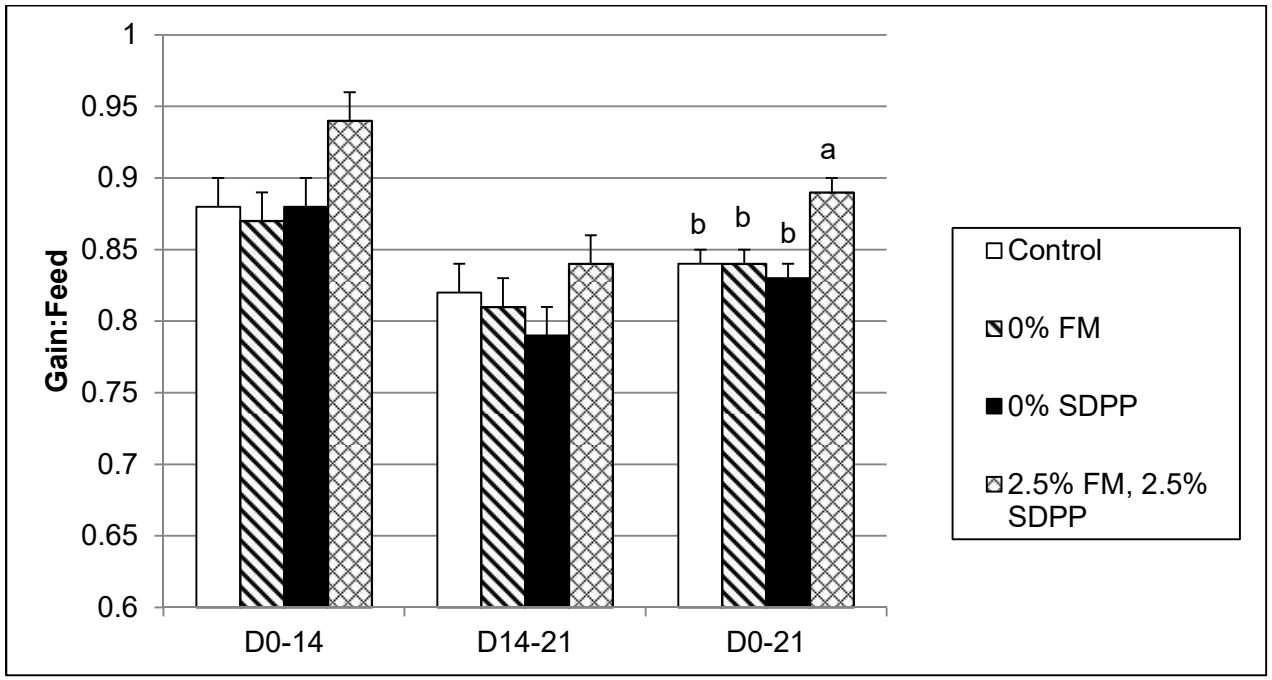

Figure A-4. Exp. 2 Gain:feed for phase 1 (d 0-14), phase 2 (d 14-21) and overall (d 0-21). Error bars are the standard error of means (SEM). Means at each phase with different superscripts differ ($P < 0.05$).

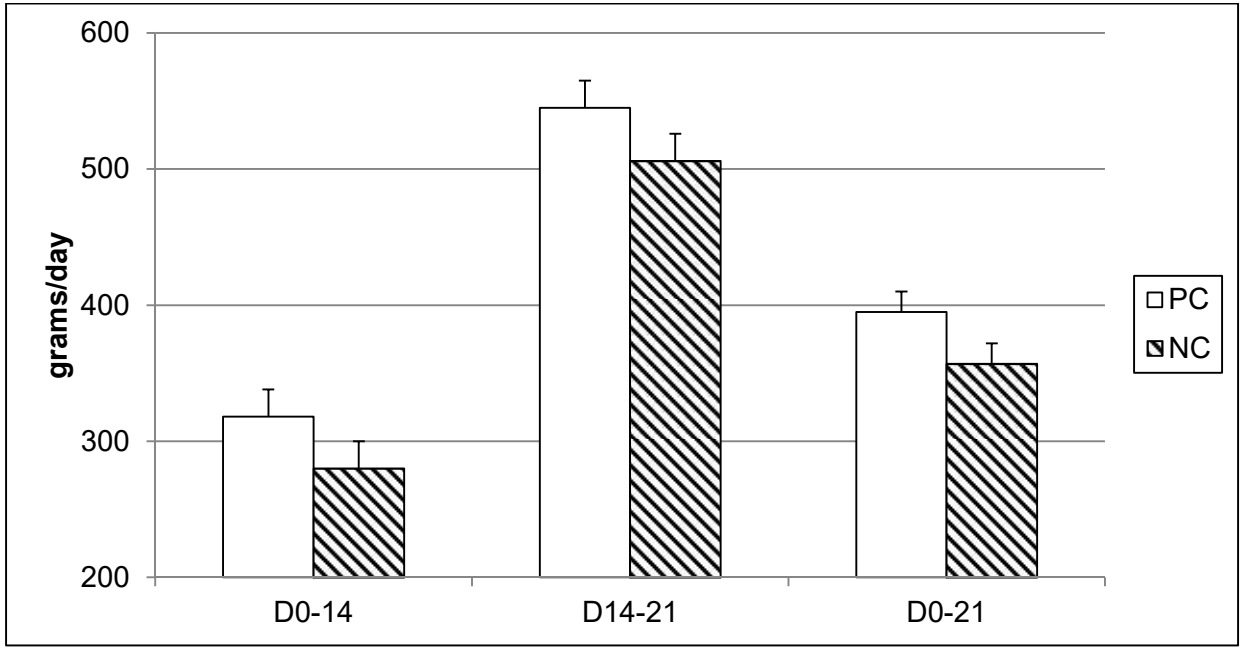

Figure A-5. Exp. 3 average daily gains for pigs in positive control treatment group and pigs in negative control treatment group during phase 1 (d 0-14), phase 2 (d 14-21) and overall (d 0 -21). Error bars are standard error of means (SEM).

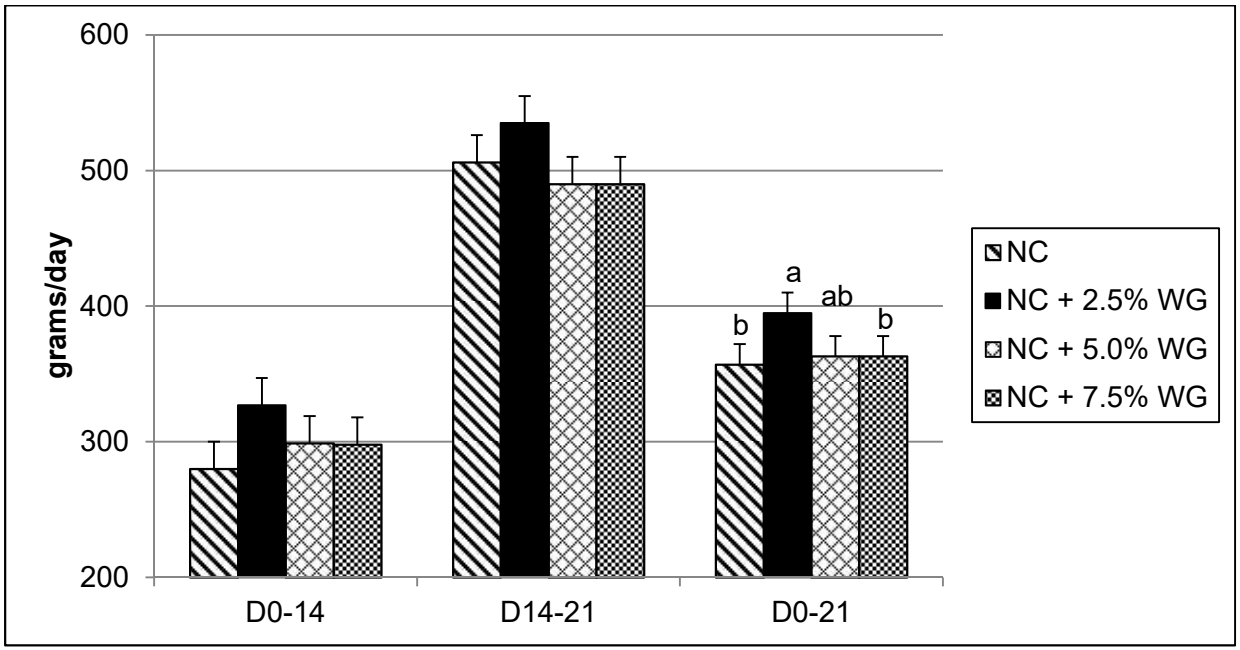

Figure A-6. Exp. 3 average daily gains for pigs fed 0, 2.5, 5.0 and 7.5% WG during phase 1 (d 0-14), phase 2 (d 14-21) and overall (d 0-21). Error bars are the standard error of the means (SEM). Means at each phase with superscripts differ (quadratic, $P < 0.05$).

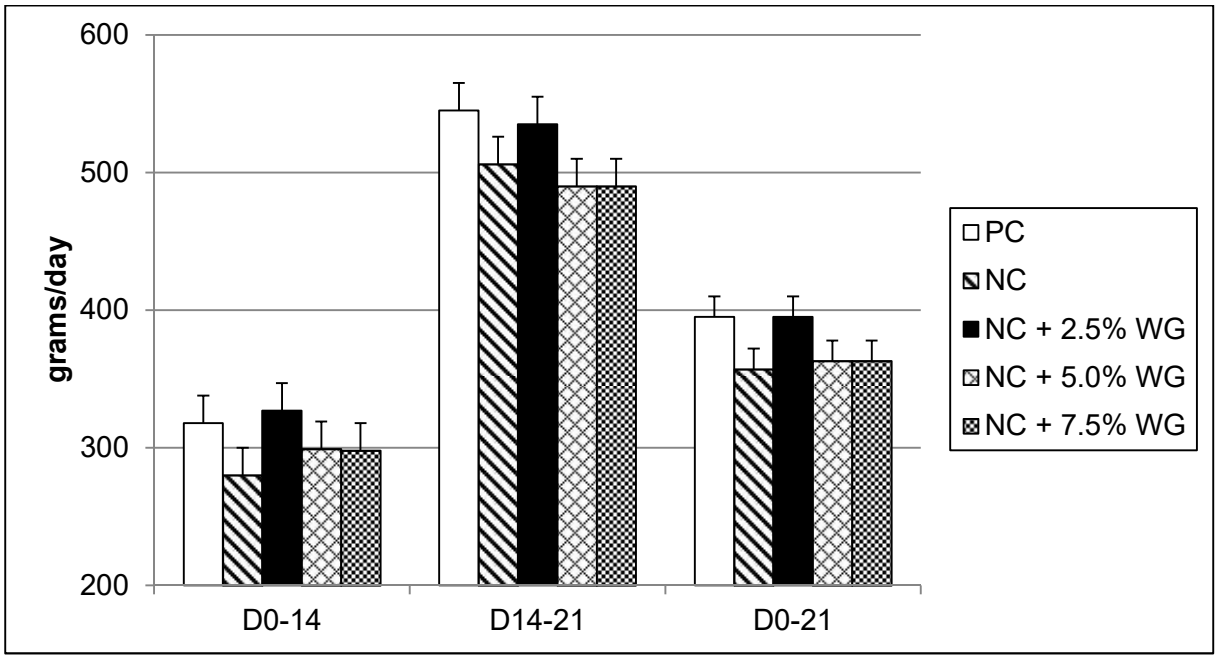

Figure A-7. Exp. 3 average daily gains for all treatment groups during phase 1 (d 0-14), phase 2 (d 14-21) and overall (d 0-21). Error bars are the standard error of the means (SEM).

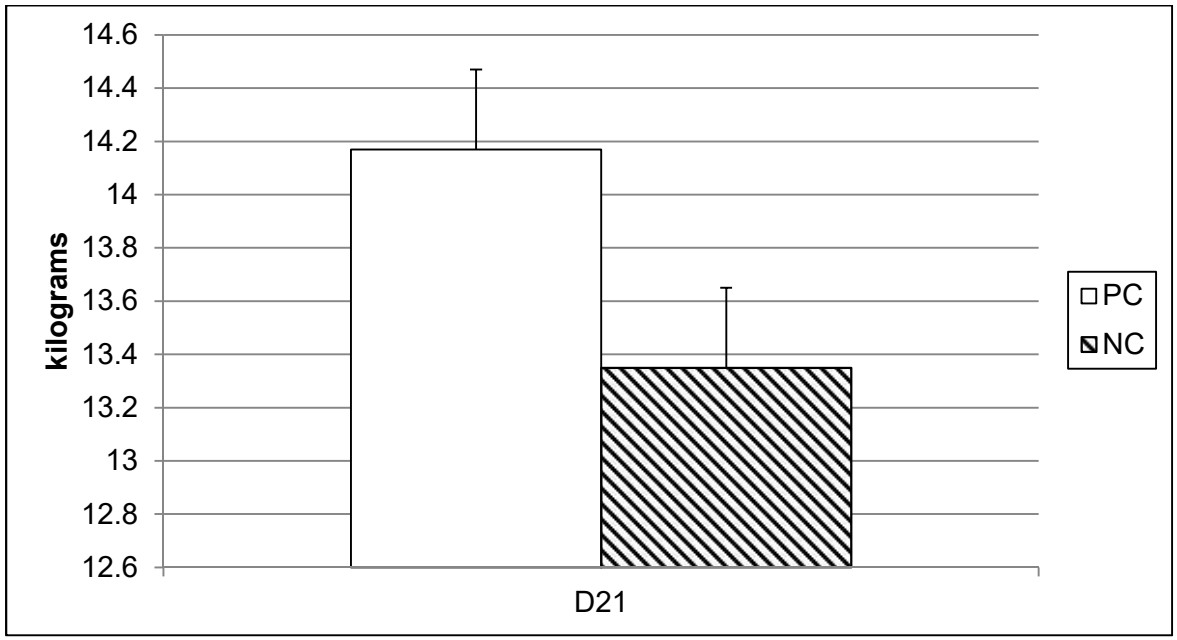

Figure A-8. Exp. 3 body weights at the end of the study (d 21) for pigs in the positive control treatment group and pigs in the negative control treatment group. Error bars are the standard error of the means (SEM).

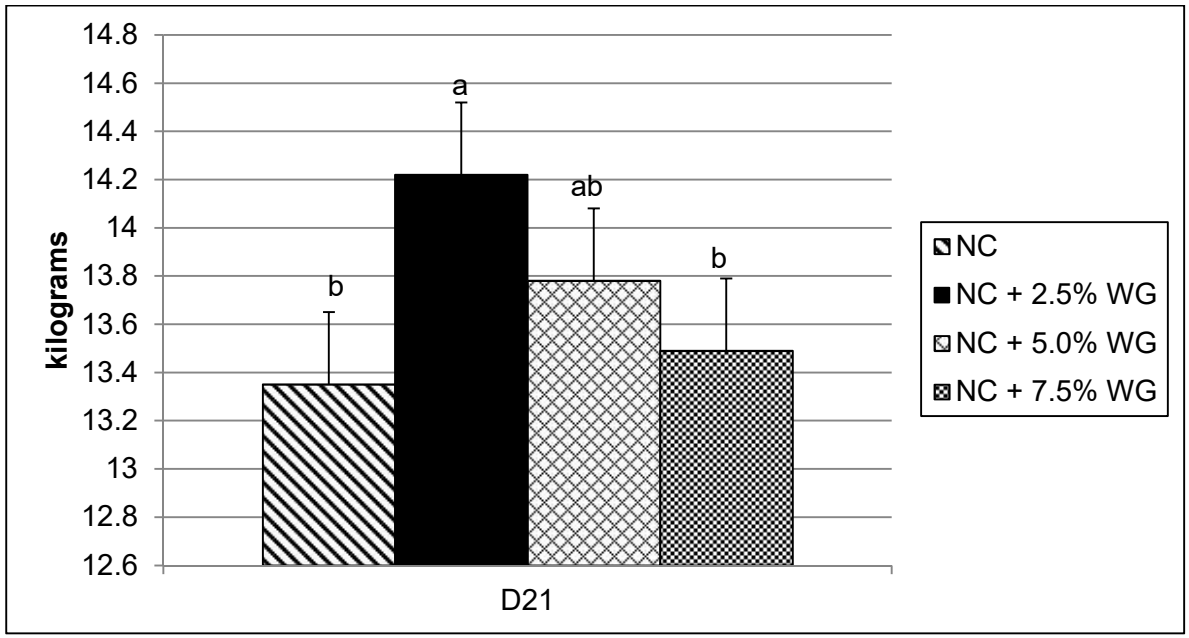

Figure A-9. Exp. 3 body weights at the end of the study (d 21) for pigs fed 0, 2.5, 5.0 and 7.5% WG. Error bars are the standard error of the means (SEM). Means with different superscripts differ (quadratic, $P < 0.05$).

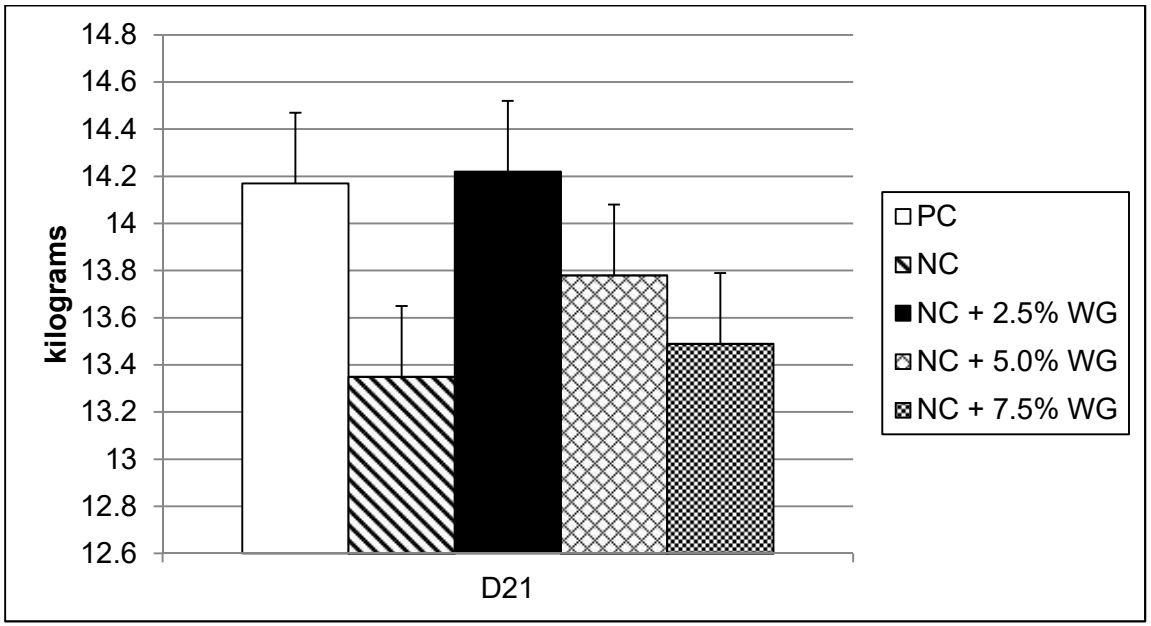

Figure A-10. Exp. 3 body weights for all treatment groups at the end of the study (d 21). Error bars are the standard error of the means.

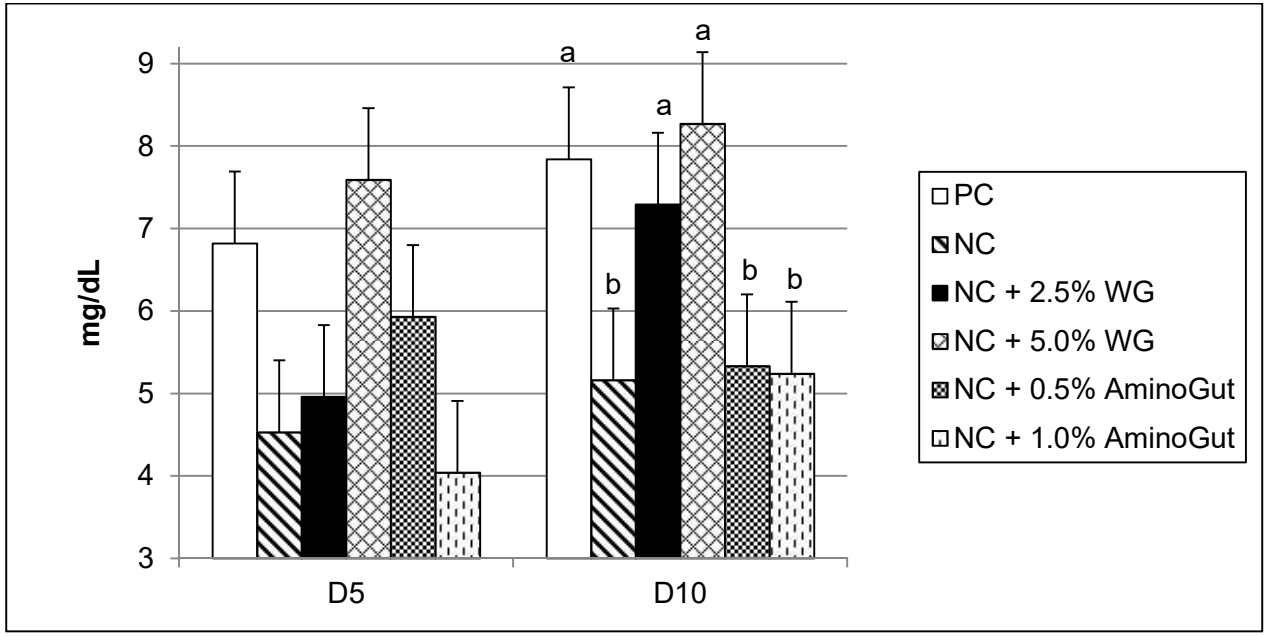

Figure A-11. Exp. 4 serum urea nitrogen (SUN) values during phase 1 (d 0-10). Error bars are the standard error the means (SEM). Means at an age with differing superscripts differ ($P < 0.05$).