**EVALUATION OF THE USE OF WHEAT IN NURSERY PIG DIETS**

By Darlene Janette Bloxham

(Under the Direction of Michael J. Azain)

**Abstract**

The objective of these experiments was to determine if wheat could substitute for corn and if wheat could be used in combination with corn dried distillers grain with and without the use a commercial enzyme in nursery pig diets. This project was done in two studies. The results of the first experiment showed that wheat could be substituted for corn with similar growth performance. A 40% wheat diet had increased body weight gain and better feed intake compared to a corn diet. Nitrogen digestibility increased with increasing amounts of wheat in the diet. Phosphorus digestibility was higher for wheat based diets than for corn diets. Experiment 2 showed that wheat can be combined with corn DDGS with an increase in body weight compared to a corn diet, however there was no effect when enzyme was added. Results indicate that wheat can be used instead of corn in phase 2 and phase 3 nursery diets. Wheat can also be used in combination and with corn DDGS in phase 2 and phase 2 nursery diets. Enzyme did not appear to be effective in phase 2 and phase 3 nursery diets.

INDEX WORDS: Nursery pigs, Wheat, Enzyme, Growth, Digestibility

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Darlene Janette Bloxham

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By

Darlene Janette Bloxham

Approved:

Major Professor: Michael Azain

Committee: C. Robert Dove
Gene Pesti

Electronic Version Approved:

Julie Coffield
Interim Dean of the Graduate School
The University of Georgia
May 2015

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# CHAPTER 1

# INTRODUCTION

Feed costs are the biggest expense when raising pigs. Corn is still the primary grain source for pigs of all growth stages in the United States. As corn prices have increased, use of corn by-products has been a common way reduce diet cost. Another way to potentially reduce the cost of swine diets is to replace corn with less expensive cereal grains. The cost of grains, including corn, can change depending on a variety of factors. Grains are harvested in a short period of time and saved the rest of the year, so during harvest there may be an excess of grain and this would temporary reduce the cost of grain while grain supplies are high. Factors that affect the price of grains include weather and other uses the crop has besides livestock feed. For example, corn is also used to make ethanol, so the price of corn is based on its use as a fuel source and less as a livestock feed.

Wheat is another commonly grown cereal grain in the United States. This makes wheat a potential grain to use for livestock feed. Most of the wheat grown in the United States is used for human food sources. Wheat has more crude protein, higher levels of essential amino acids, and better standardized ileal digestibilities of amino acids than corn. Wheat is not only an energy source, but also reduces the amount of soybean meal, or other protein sources used in the diet. When the price of wheat is cheaper than or equal to the cost of corn, wheat may be a more cost effective ingredient for livestock diets.

The concern about using wheat, in pig diets, is the higher fiber component is not digestible by the pig and this would cause decrease in performance compared to corn. Enzymes have been developed to break down the fiber components of plant material and make feedstuffs, like wheat, more digestible. Wheat contains mostly xylans, especially arabinoxylan, that can be broken down by commercially available xylanases and β-glucanases. Therefore adding commercial enzymes to feed can make the feed more digestible and in turn reduce the cost of the diet. The objective of this work is to demonstrate wheat can be substituted for corn as an energy source in nursery pig diets.

# CHAPTER 2

# LITERATURE REVIEW

## Cost of raising pigs

The most expensive component of raising pigs is the cost of feed. Feed cost can be up to 70% of the total cost of production (Bedford and Partridge, 2010). One way to reduce the cost of production is to reduce feed cost, by incorporating lower cost feed ingredients into swine diets. This is commonly done by substituting corn distillers dried grains with solubles (DDGS) into pig diets. DDGS is a by-product from ethanol production and is a cost effective way to lower the cost of livestock diets by reducing the amount of corn grain used (Yanez et al., 2011). Corn DDGS has become a common feedstuff added to swine diets since as a result of increasing ethanol production in the United States (Jones et al., 2010). Other feed ingredients that may be incorporated into swine diets instead of corn. These products can be other cereal grains like wheat and grain sorghum. These products can also include as grain by-products like wheat bran, wheat DDGS, wheat gluten, wheat middlings and other wheat by-products. Wheat is not commonly fed on the United States, but is the major feed ingredient in Canada and Europe (Woyengo et al., 2008, Rosenfelder et al., 2013). One-third of the wheat produced in the European Union is used for animal feed (Rosenfelder et al., 2013).

These products can be included when economical (USDA, 2014) (Figure 2-1). In September of 2011 wheat in Illinois was approximately two dollars cheaper per hundredweight

than corn in both central, Illinois and Chicago, Illinois. This trend stayed through until June 2012 where wheat and corn prices were within $0.25 per hundredweight of each other. Wheat became more expensive than corn from September 2012 to January 2013. The greatest difference was in November 2012 were wheat was $1.15 per hundredweight more expensive than corn. From February 2013 to August of 2013 wheat was less per hundredweight than corn. From September 2013 to present wheat has been more expensive than corn on a hundredweight basis. This is due to corn falling from twelve dollars per hundredweight to about eight dollars per hundredweight.

A similar trend was seen in the Southeast as well from January of 2012 to April of 2012 wheat was at least $1.10 less than corn on a hundredweight basis. From May 2013 to August 2013 wheat was less per hundredweight than corn. The price of wheat was $3.46 less than corn on a hundredweight in June of 2013, this was the greatest difference in dollars per hundredweight in the Southeast. Since August of 2013 wheat has become more per hundredweight than corn.

**Types of wheat**

The United States government regulates the quality of grain through the U.S. Standards Act of 1916, and by the U.S. Grain Quality Improvement Act of 1986. These acts are a way to standardize grain. These acts classify wheat on morphology, such as kernel color, and measurable characteristics such as hardness of the kernel. Wheat genetics and growing conditions may affect the wheat characteristics, making these methods of classifying wheat on nutrient content may not be informative. This can be due to cross breeding hard wheat varieties with soft wheat varieties, this causes wheat to have characteristics of both hard and soft wheat (Slaughter et al., 1992).

Winter wheat is grown more in the United States because it usually yields more bushels per acre, however it may contain less crude protein (CP) than spring wheat (Cheeke, 2005, Slaughter et al., 1992). Winter wheat is planted in the fall and harvested in the summer. Spring wheat is planted in the spring and harvested in the fall. Red is the most common kernel color of wheat grown in the United States. Kernel color also can be red, white or amber. Wheat is commonly classified according to kernel color and whether the wheat is hard or soft (Cheeke, 2005). Soft wheat has more starch than hard wheat (Rosenfelder et al., 2013). Hard wheat has a hard kernel and higher CP usually between 11-14%, and is used for bread making. Soft wheat has a soft kernel and contain less CP, usually 8-11% CP, and is used for cakes and cookies. Durum wheat is used for pastas and mostly used for human consumption and not incorporated into livestock feed (Liu et al., 1996).

The 2012 Swine National Research Council (NRC) classifies wheat as hard or soft according to CP, this is done because many studies do not say the type of wheat used. According to the NRC, wheat with more than 11% CP is hard red wheat and wheat with less than 11% CP is soft red wheat. There is less information on the nutrient content for soft red wheat. There are no standard ileal digestibilities (SID) values for any amino acids for soft red wheat, while hard red wheat has the SID amino acids based on 6-15 values used per amino acid (NRC, 2012). A study done by Rosenfelder et al. (2015) looked at eight different varieties of soft winter wheat CP of and found that the wheat CP ranged from 9.1-11.3%. This study found AA SID values for the eight different varieties of wheat and found a correlation of lower SID digestibility and higher NSP and arabinoxylan content. Standard Ileal digestibility of CP and all essential AA was lower in this study then the estimates that are reported in the Swine NRC (Rosenfelder et al., 2015, NRC, 2012).

Hardness of wheat is not directly related to crude protein. Wheat hardness is a measure of endosperm hardness. Many factors affect hardness of the endosperm like when the wheat is harvested, the variety of wheat grown, and the method of drying used before the hardness test is done. Classifying hard and soft wheat according to CP content may not be the most effective way to identify wheat (Bechtel et. al, 1996). The current NRC only reports values for red wheat, not white or amber wheat (NRC, 2012). The previous NRC (1998) reports values for hard red spring wheat, hard red winter wheat, soft red winter wheat, and soft white winter wheat. Crude protein is highest for hard red spring wheat at 14.1% and lowest for soft red winter wheat at 11.5%. Net energy values for the different values of wheat. The highest net energy was for soft red winter wheat was 2400 kcal/g and the lowest net energy values were for hard red winter wheat at 1925 kcal/g. Neutral detergent fiber was only reported for hard red winter wheat and soft white winter wheat with NDF values of 13.5 and 12.0% respectively (NRC, 1998).

A study conducted by deJong et al. (2014) compared feeding pigs hard red winter wheat (HRW) and soft white winter wheat (SWW). The CP values of both wheats were comparable at 11.8% CP for the HRW and 11.2% for the SWW. This shows that CP of wheat may not vary greatly between classes of wheat. According to the NRC both of these wheats would be considered hard red wheat (NRC, 2012). The results of this study showed that pigs fed HRW had higher average daily feed intake (ADFI) and average daily gain (ADG), but there was no differences in final body weight (BW). There were also no differences in carcass traits between the wheat sources. This shows that there is no difference in feeding HWW and SWW (deJong et al., 2014).

**Hard vs. soft wheat**

Nine studies were found with enough information to determine if the wheat used was hard or soft wheat. Wheat was determined to be hard or soft if the authors explicitly stated in the paper, if the CP of the wheat ingredient was reported in the paper, or the variety of wheat used was mentioned. Classifying hard and soft wheat was determined using NRC recommendations (NRC, 2012). From these nine studies, six studies used hard wheat and three studies used soft wheat.

All three soft wheat studies measured growth performance. Two of the studies directly compared soft wheat with corn and found no differences in overall feed efficiency when comparing corn to soft wheat from nursery age to market weight (Erickson et al., 1980, Seerley et al., 1988). Erickson et al. (1980) found that there was no difference in apparent protein digestibility between wheat and corn diets. Barrera et al. (2003) used soft wheat with four different levels of enzyme (0, 5500, 11000, 16500 units of activity/kg). The enzyme was a xylanase of fungal origin from *Aspergillus niger* and *Trichoderma longibrachiatium* from DSM Food Specialties (Delft, Netherlands). Feed efficiency was affected quadratically with 11000 units of activity/kg having the best feed efficiency. Barrera et al. (2003) found that 11000 units of activity/kg of enzyme had the best protein digestibility which agrees with the growth performance.

More studies are available using hard wheat in swine diets. A study was performed to compare twelve varieties of wheat in swine diets. All varieties of wheat used were considered hard wheat according to CP content stated in the NRC. Feeding different kinds of hard wheat showed no difference in ADG, ADFI, and feed efficiency (Jha et al., 2011). Another study by

Peterson et al. (2008) used six varieties of wheat, including transgenic, and found no differences in growth performance related to of wheat variety used. There was no difference in carcass characteristics between these wheat varieties. These diets were formulated to be isoenergetic and isonitrogenous.

A study comparing hard red winter wheat compared to grain sorghum at two different protein levels was conducted. At 15% CP the wheat diet had a lower gain to feed than the sorghum diet or the wheat-sorghum blend diet. Even when a wheat diet was formulated with 18% CP the feed efficiency was still lower than a wheat sorghum blend diet with a CP value of 16.7%. This indicates that hard wheat may be a poorer grain source than grain sorghum (Luce et al., 1972). A study conducted by Bolatinwa et al., 2012 showed that increasing wheat in the diet from 0%, 30%, to 60% linearly increased nitrogen intake, but did not change nitrogen digestibility.

A study done to compare wheat and wheat DDGS with and without a commercial xylanase (Danisco Animal Nutrition) found that there was a trend ($P<0.058$) for pigs on the wheat diet to weight more than pigs fed the wheat DDGS diet (83.9kg vs. 81.0kg) (Widyaratne, et al., 2008). Wheat diets had higher apparent energy digestibility than wheat DDGS diets (79.1% vs. 73.2%). There were no effects due to xylanase in this study.

Vahjen et al. (2007) performed a study to show the effect of hard wheat on difference enzyme products Two types of enzymes were used product A, an enzyme blend that contained activity for xylanase, mannanase, beta-galactanase, and cellulase blend made by DSM Nutritional Products. Product B a mono-enzyme that only had xylanase activity made by DSM Nutritional Products. There was no significant differences in total gain, feed intake or feed efficiency. There was no difference in CP, fat, starch, and NDF apparent ileal digestibilities. The enzymes did

decrease in viscosity in the jejunum Overall soft wheat and hard wheat can be used with little effect on growth performance.

**Variability in wheat**

Wheat is a commodity and assumed to be relatively consistent from batch to batch, year to year. However, wheat may not be as consistent as assumed. This may account for some of the variation in carbohydrase activity. This inconsistency between wheat varieties has been shown to effect metabolizable energy values content in chickens (Wiseman et al., 2000). If wheat is grown in drought conditions, the arabinoxylan has been reported to increase (Rosenfelder et al., 2013). Wiseman et al. (2000) showed that variety of wheat affected digestible nitrogen, and total tract digestibility.

Peterson et al. (2008) grew 6 different varieties of wheat grown in similar soil types and then fed these wheat varieties to pigs. Crude protein varied from 13.3% to 15.8%, crude fat varied from 1.6-2.0% fat, and NDF varied from 9.1-10.3%. Total lysine varied from 0.34-0.40%. This wheat was fed at the same level to all pigs: 70% in grower, 80% in finisher 1, and 85% in finisher 2 inclusion rates to determine if variation in wheat would affect growth performance of the animal. When the wheat was fed there was no difference in the final weight of the pigs used. This is probably due to the wheat being analyzed before the diets were formulated which allowed the investigators formulate the diets to be isocaloric and isonitrogenous. However under practical conditions nutritionist may not see every batch report for a new feedstuff so diets may not be analyzed to the feedstuffs proximate analysis. There were no significant differences in ADFI or ADG, or feed efficiency for grower phase. There was no significant difference in ADFI or ADG in finisher 1, but there was significant difference in feed efficiency even though these changes were

small. In finisher 2 phase of feeding there were no differences in ADFI, ADG, or feed efficiency. Finally overall, there were no differences ADFI, ADG, feed efficiency. To further show that different varieties of wheat do not affect pig performance carcass measurements where done, and there were no differences in backfat or lone muscle area during the end of the grower, end of the finisher 1, or end of finisher 2 (Peterson et al., 2008).

Wiseman et al. (2000) performed a study where eight varieties of wheat grown at two different sites were compared. These different varieties were fed to pigs. There was a treatment effect on varieties of wheat grown digestible energy (DE) and digestible nitrogen. There was also a trend ($P<0.10$) for the site of where the wheat was grown to effect of DE of the wheat when fed to pigs. Digestible nitrogen was significantly affected by both site and variety (Wiseman et al., 2000). Where the wheat was grown, as well as variety, can affect the nutrient content of wheat. Varieties of wheat having different nutrient contents are not abnormal. What is more of an issue for a nutritionist is that there is site to site variation on the same wheat variety.

Peterson et al. (2008) grew six different varieties of wheat and found that wheat CP varied from 13.3-15.8% and total lysine varied from 0.34-0.4%. Neutral detergent fiber varied from 9.1-10.3%. When these six varieties of wheat where fed overall feed efficiency was not different between varieties. Jha et al. (2011) performed a study were twelve different varieties of wheat were used in six different classes. The six different classes were as follows are spring white, Prairie spring red, western spring red, amber durum, western red winter, and western hard white spring. All wheats would be considered hard wheat by the NRC (NRC, 2012). The wheat varieties were also analyzed before diets were formulated so diets were to have similar CP and lysine. The twelve diets were fed to nursery pigs for 21 days. Overall there were no differences in ADG, ADFI,

and feed efficiency. There was no difference between varieties of wheat within class for ATTD. There were significant differences between classes of wheat. Amber durum and western red winter wheat had the highest ATTD (88.8%), followed by spring white, western red spring, and hard white spring (87.4%). The lowest ATTD was the Prairie spring red wheat (86.6%) ($P<0.05$), (Jha et al., 2011).

Dusel et al. (1998) performed a study was done in broilers to look at two different varieties of wheat (Ibis and Alidos) and the different enzyme products used. Product A blend that was derived from *Trichoderma longibrachiatum* and *T. viride*. Product B was derived from just *T. longibrachiatum.* The Alidos wheat had a higher viscosity in vitro, in the jejunum, and the ileum. The Alidos wheat also had a greater reduction in viscosity when both enzymes were added. Adding enzyme to the Ibis wheat did not change growth performance compared to no enzyme. Adding enzyme to the Alidos variety of wheat did improved growth performance when product B was added. Yet, there were no differences in feed efficiency within variety of wheat. From this study it was concluded that variety of wheat affects viscosity. Wheat varieties that have more viscosity be more likely to be positively affected by a mono-enzyme.

There may be reasons why many commercial enzymes do not work consistently. Wheat contains natural xylanase inhibitors (Mendis et al., 2013, Mc Lauchchlan, 1999). These xylanase inhibitors work on microbial or fungal xylanases. There appears to be three kinds of xylanase inhibiting proteins, thaumatin like xylanase inhibitor (Fierens et at., 1999), triticum aestivum xylanase inhibitor (Debyser et al., 1999), a xylanse inhibiting protein (McLauchlan et al., 1999). Having these inhibitors present may decrease the effectiveness of exogenous enzymes in diets that contain wheat. Commercial enzymes are mostly derived from microbial or fungal sources

(Bedford and Partridge, 2010). Different varieties of wheat contain different levels of these xylanase inhibitors so type of wheat that is added to the diet will affect the effectiveness of exogenous enzymes. Differing varieties of wheat can have different inhibitory xylanase activity. Xylanse activity in wheat can be as low as 0.12 mU/g to as high as 31.78 mU/g in the same variety of wheat (Mendis et al., 2013). Xylanase activity can vary depending on the location that wheat is grown. A study examined the same variety of wheat grown in three locations over the same calendar year and found that xylanase activity vary from 0.38 mU/g in one location to 6.17 mU/g in another location. This variability could be further compounded when wheat is grown in drought conditions may increasing the arabinoxylan in wheat. There may not be enough xylanase added to break down the amount of arabinoxylan present in the wheat (Barreara et al., 2004). This could be a reason why feeding trials using carbohydrase activity are so varied.

Another reason why exogenous enzymes have such varied results when fed to animals is the enzyme used may not be the best match for the xylose in the feed. Xylans have similar backbones, but vary in the modification of xylose at different carbons. These modifications groups can range from arabinose, acetic acid to glucuronic acids, even the carbon that these modifications are bonded to can vary depending on the plant the xylan is derived from. Bedford and Schulze (1998) showed that three different xylanases have different Km's that range from 2.6 to 4.2 and different Vmax that range from 650-5570. This was when the same substrate spelt was used. Further research is need to develop enzymes that work on a greater variety of substrates, or enzymes that are match with a specific substrate (Bedford and Schulze 1998). Companies have been engineering enzymes that are resistant to these inhibitors, currently the

xylanase inhibitor resistant xylanases have lower activity rates than the normal xylanases (Bedford and Partridge 2010).

The conditions of the gastrointestinal tract could affect how well enzymes work in vivo. The stomach has a pH of about 2 and the small intestine can range from 6-7.5pH. Optimal pH range for different xylanases can range greatly, as low as 3.5pH units of activity to as high as 6.5pH. This pH range still is in between the pH values of the stomach and the small intestine. This gives the enzymes a limited time frame to work when the stomach contents are being transitioned to the small intestine. Few studies have been performed to confirm this. A study had been done measuring xylanse activity in wheat bran using a stomach contains of pigs. Compared to a control, in vitro, xylanase analysis both the stomach conditions had lower xylanase activity. The activity however was not zero. The xylanase activity of the stomach was 57% of the control. This shows that the enzymes added to feed are not at their optimal pH to work fully and xylanase cannot be broken down as was. This is important to consider when using exogenous enzymes in feeds (Inborr et al., 1996).

Adding exogenous enzymes to livestock diets will become more common due to increasing feed prices, more byproducts feeds being used, and less common cereal grains being used. Commercial enzymes will need to become more tailored to the needs of the animals that they are intended for, and the feed ingredient that they intend to break down.

**Comparing wheat to other cereal grains**

Corn and soybean have been the most used grain and protein sources in swine diets in the United States for many years (Pond et al., 2005, Hongtrakul et al., 1998). Studies need to determine if cereal grains, such as wheat, are a viable substitute for corn. However there are

limited studies that compare feeding corn to other cereal grains. Wheat is commonly grown in the United States, Canada, and Europe (Pond, 2005, Rosenfielder et al., 2013). However, in the United States, wheat is not commonly added to livestock feed. Wheat is primarily added to the diet as an energy source, however, the protein content of wheat cannot be ignored. Hard wheat has 14.46% CP, compared to corn which has 8.24% CP. Wheat also has better standard ileal digestibility (SID) (88% SID for wheat vs. 80% SID for corn) for protein and other amino acids than corn (NRC, 2012) (Table 2-1). Wheat can be used as the primarily energy source for swine diets, and the protein content of wheat can provide the majority of protein to a growing pig. For example, a diet containing 70% percent wheat can account for 60% of total protein and supply approximately 70% of the essential amino acids that a growing pig would need (Rosenfielder et al., 2013). The protein in wheat can be used to reduce the amount of soybean meal or other protein source used in a diet, and thus reduce cost even further.

A study was done comparing soft wheat to yellow corn during all growth stages to determine if there were growth and carcass differences that due to different feed ingredient compositions (Erickson et al., 1980). Wheat and corn diets were formulated to have the same metabolizable energy (ME), CP, and total lysine within phase throughout the whole experiment. There were no differences in nursery and grower pig performance for ADG, or gain to feed ratio (G:F). Finisher pigs on the corn diet had a better ADG and G:F than pigs on the wheat diet. Overall, there was no differences on growth performance between wheat and corn based diets in this study, suggesting that using wheat as a complete replacement of corn did not affect overall pig performance. There were no differences in the apparent protein balance or the apparent biological value between the wheat and corn diets. There were also no differences in carcass

yield, backfat, or combined ham and loin weight (Erickson et al., 1980). A similar study was performed by Seerley et al. (1988). This study compared soft red winter wheat to corn. This study fed three diets in three phases a nursery, a growing, and a finisher. Treatments within phase were a control corn diet, a fine wheat diet (3.18 mm hammer mill) and a course wheat diet (4mm roller mill). Grower and finisher diets had a control corn diet with a fine wheat (3.18 mm hammer mill), medium wheat (6.35mm hammer mill, and course wheat (4mm roller mill) diets. In trial 1 of the nursery study fine wheat had significantly higher ADG than corn, but no differences were observed in trial two. There were no differences in corn and wheat diet for ADG, ADFI, and feed efficiency in the grower study. The finisher study had the course wheat diet and the corn diet perform statically the same, however there was a decrease in ADG with fine and course wheat diet. Finely ground diets may increase ADG in nursery phase, however feeding finely ground and medium ground decrease ADG in the finisher phase, but not the grower phase. This study confirms the Erikson et al. (1980) of findings that soft wheat can be fed to all stages of pigs without a lost in growth performance compared to corn, depending on how the wheat is ground. Hongtrakul et al. (1998) compared different grain sources, including wheat flour, with different feed processing techniques in weaning diets and found that ADG, ADFI, and G:F were not affected by any diet that was fed, or feed processing method, including a standard corn diet.

Luce et al. (1972) directly compared hard wheat to grain sorghum in grower and finisher pigs. They found that there were no differences in ADG or ADFI in pigs fed a grain sorghum diet or a 50:50 blend of wheat and grain sorghum, but there a decrease in G:F when wheat was the sole grain source fed. Pelleted wheat diets containing wheat had increased ADG, decreased ADFI, and higher G:F compared to meal grain sorghum diet (Luce et al., 1972). This indicated that wheat

would be better suited for pelleted diets than grain sorghum. Rosenfielder et al. (2013) reported wheat diets that are pelleted, extruded, or finely ground wheat diets will improved crude protein digestibility. Seerley et al. (1988) found that coarse ground wheat had better ADG than fine and medium ground wheat when fed to finisher pigs. Erickson et al. (1980) compared pelleted wheat and corn diets to meal wheat and corn diets and found no interaction between grain source and diet processing. These data would suggest that wheat can replace corn in all growth phases (Erikson et al., 1980, Seerley et al, 1970) Wheat would be best in a 50:50 blend with grain sorghum in swine diets of all growth phases (Luce et al., 1972). Wheat can also be pelleted and extruded without changing the performance in swine diets, and if wheat is finely ground may even help improve protein digestibility (Rosenfielder et al., 1972). Adding wheat to diets can be done when economically feasible (Pond et al., 2005). Studies that show are direct comparison of wheat to other cereal grains are limited, however, these studies show that wheat performs similar to other cereal grains. Research is needed to show how wheat compares to other cereal grains in modern genetic lines of pigs. The only factor that would limit wheat inclusion in swine diets would be the cost.

**Dietary fiber**

The term dietary fiber is a term for anything that cannot be broken down by the digestive enzymes of an animal (NRC, 2012). This usually refers to carbohydrates, but fiber commonly includes lignin, a non-carbohydrate compound that is commonly classified in the fiber component. Carbohydrate fiber components include oligosaccharides, celluloses, hemicelluloses, and pectins (NRC, 2012). Fiber is also commonly called nonstarch polysaccharides (NSP). Microbes can ferment these NSP from plants to produce volatile fatty acids (VFA), that can

be used for energy by the animal's own microbes or can be absorbed though the lumen of the large intestine, and be used as an energy source (Pond, 2005). Fiber is sometimes classified as an antinutritional factor (ANF). Antinutritional factors like fiber can decrease digestibility of protein, phosphorus, calcium, and other minerals (Bedford and Schulze, 1998). High fiber feed ingredients are avoided because these feedstuffs decrease growth performance in nonruminants (Bedford and Partridge, 2001). Using feed ingredients with higher NSP has been increasing over the past decade because common feed ingredients like corn and soybeans are being used less as feedstuffs for livestock, because corn and soybeans are being used as biofuels (deVries et al., 2012).

### *Oligosaccharides*

Oligosaccharides are medium chain polysaccharides consisting of three to ten monosaccharide units. The short chain length of oligosaccharides makes these ideal for fermentation by microbes in large intestine. Common oligosaccharides include fructo-oligosaccharides, inulins, or levans, and galacto-oligosaccharides raffinose, stachyose, and verbascose (NRC, 2012). Oligosaccharides are considered prebiotics and the may help establish healthily microbial gut populations (Bedford and Partridge, 2010).

### *Cellulose*

Cellulose is the most abundant compound in plants and is major component of cell walls (Scheller and Ulvskov, 2010). Cellulose is repeating units of β-(1, 4) linkages of glucose molecules. This is what gives plants its structural integrity. Cellulose is considered insoluble fiber. The β-(1, 4) linkages cannot be broken down by the animal's digestive enzymes (Bedford and Partridge, 2001).

### *Hemicellulose*

Hemicellulose only is second to cellulose in abundance in the cell walls of plants. Hemicelluloses are not made up of one single compound like cellulose, but many different kinds of hexoses and pentoses, which include xylans, mannans, xyloglucans, glucomannans, and arabinoxylans. These sugars are linked by β-(1, 4) linkages. There are no digestive enzymes in the animals that can breakdown these bonds (Scheller and Ulvskov, 2010). Common hemicelluloses that are present in cereal grains is xylan and arabinoxylan. Xylan has repeated unites of xylose which form a backbone. This backbone can stay linear or can be branched with sugars like mannose, galactose, glucose, or arabinose (NRC, 2012).

Hemicellulose, in cereal grains, can be in the cell walls of seeds but can also act as a way for the seed to store carbohydrates (Scheller and Ulvskov, 2010). Xylans combined with arabinose are commonly referred to as arabinoxylans. These molecules are the most common NSP in feed ingredients like wheat (Barreara et al., 2004). Xylans are a common target for carbohydrases added to swine or poultry diets in an attempt to reduce the negative effects of fiber (Bedford and Schulze, 1998).

### *Pectins*

Pectins, like hemicellulose, are made of several types of polysaccharides. Pectins are easily fermented by microbes (Scheller and Ulvskov, 2010, Metzler et al., 2008). Pectins are a class of NSP, but not part of the cell wall like cell celluloses and hemicelluloses. Unlike most other NSPs, pectins are α-(1, 4) linkages (NRC, 2012). Pectins are a soluble fiber and form gels in the intestine of animals (Rosenfelder et al., 2013). This can increase the viscosity of the digesta and reduce the absorption of nutrients (Bedford and Partridge, 2010).

## Fiber degrading enzymes

### *Mode of action for enzymes*

The exact mechanism of how enzymes work remains unclear. The mechanism of how enzymes work could be different depending on the enzyme used and the substrate that is being broken down (Bedford and Schulze, 1998). Nonstarch polysaccharides are thought to be anti-nutritional because the cell wall components block the animal's digestive enzymes from breaking down digestible components like protein, fat, and starch (Bedford and Schulze, 1998, Adeola and Cowieson, 2010, deVries et al., 2012). Pigs fed diets high in NSP result in an increase in digesta viscosity in the small intestine (Bedford and Partridge, 2001). Commercial exogenous enzymes may breakdown the cell wall or the NSP to allow nutrients to be digested that would not normally be exposed to digestive enzymes. This would increase the digestibility of the feedstuff (Bedford and Schulze, 1998). However, this may not fully explain the decrease in viscosity of digesta that is normally seen when carbohydrases are fed (deVries et al., 2012). Yet an overall decrease in viscosity may not be as important especially in the pig where the digesta viscosity is already low, unlike the chicken were viscosity is already higher (Bedford and Schulze, 1998). Carbohydrases may work to breakdown the long polysaccharide chains and allow the endogenous enzymes to move more effectively throughout the digesta. This would increase the digestibly of the diet (deVries et al., 2012).

Another theory on how enzymes work is by breaking down long polysaccharide chains to easily fermentable oligomers that will increase the fermentation capacity of the animal. Therefore the animal will absorb more VFA that can be used as substrate for energy. For this to work the outer cell wall must be already broken to a sufficient degree to allow enzymes to work

and breakdown exposed NSP's (Bedford and Partridge, 2010). Vahjen et al. (2007) measured VFA in the stomach, jejunum, and colon and found no difference in VFA production when enzymes was included in a wheat based diet. The enzyme treatments were a multi-enzyme blend with xylanase, mannanase, beta-galactanase, and cellulase and a mono-enzyme with only xylanase activity. This was compared to a wheat based diet with no added enzymes.

Nonstructural polysaccharides may affect the pig and chicken intestinal tracts differently. In the chicken and pig viscosity measurements are usually taken in the jejunum small intestine. When fiber degrading enzymes are added a reduction of viscosity is commonly seen in the small intestine (Bedford and Partridge, 2010). Pigs however, may have a more beneficial reduction in viscosity in the stomach. Pigs have a stomach that allows more dense particles to sink and get exposed to stomach acid for a longer time frame, and get broken down by stomach acid before going into the small intestine. This study further proposed that the gel formed would even coat proteins and starches, so they would not be exposed to stomach acid so chemical breakdown of feedstuffs could not occur (Ellis et al. 1996). Carbohydrases may need to be engineered specifically for a pig's digestive tract.

## Carbohydrase use in swine diets

### *Digestibility with enzymes*

Energy digestibility decreases with increasing fiber components in swine diets (deVries et al., 2012). Adding carbohydrases to the feed would increase the energy value, and reduce the anti-nutritional effects of the fiber (NRC, 2012). The use of commercially available carbohydrases has increased in recent years due to the increased incorporation of higher fiber feedstuffs in swine diets (Bedford and Partridge, 2010). Exogenous enzymes are added to nonruminant diets

as a way to break down components of feedstuffs that cannot be broken down by the animal's endogenous enzymes. Nonstructural polysaccharides that are most common target for exogenous enzymes these molecules arabinoxylan and β-glucans. Other less common enzymes used are α-galactosidase, galactomannanase, pectinases, galactosidases, amylases, and mannanases (Adeola and Cowieson, 2011, Jones et al., 2010).

Several companies (Dupont, BASF, and DSM) all make exogenous enzymes that break down NSPs that can be included in swine diets. Dupont makes axtra XB® a xylanase and β-glucanase blend. Danisco Xylanase is also made by Dupont and is a 1, 4-β-xylanase that is produced by the bacteria *Trichoderma reesei.* BASF makes an exogenous enzyme blend called natugrain® TS. This carbohydrase is an endo-1, 4-β-xylanase and endo-1, 4-β-glucanase purified from BASF strain of Aspergillus. DSM produces a Roxazyme® G2 is a combination of beta-glucanases, cellulases, and xylanases. DSM also makes Ronozyme® that has xylanase, β-glucanases, and other "side activities".

Wheat has more NSP than corn (Table 2-1) (10.60% NDF of wheat vs. 9.11% NDF of corn). Wheat also has less energy dense than corn. Wheat has a net energy (NE) value of 2472 kcal/kg while corn has an NE value of 2672 kcal/kg (NRC, 2012). Adding carbohydrases could be a way to increase the energy value of wheat to make it more comparable to the energy level of corn (Bedford and Partridge 2010, Bedford and Schulze, 1998, deVries et al., 2012). Wheat has more arabinoxylans than corn. There are commercial enzymes available to breakdown these arabinoxylans and other NSP. Arabinoxylan can bind water and form gels this increases viscosity. When xylanases are added to a diet, arabinoxylans are broken down, so there is no decrease in

digestibility and therefore no decrease in growth performance (Barrera et al., 2004, Bedford and Partridge, 2010).

For enzymes to be used in practical diets they must be proven effective. The amount of enzyme in the diet can change the effectiveness of that enzyme. There has been one study to try and show that amount of enzyme in the diet can determine the effectiveness of enzyme. In this study wheat was added as the only protein source to the diet. A commercial carbohydrases was added to the diets at 0, 5500, 11000, and 16500 units of activity/kg. Apparent ileal crude protein digestibility was increased linearly until 11000 units of activity /kg. This was also seen for all amino acids, essential and nonessential (Barrera et al., 2004). This study would suggest that xylanase would improve protein availability in wheat up to 11000 units of activity /kg. Unfortunately energy values were not measured so the effect of energy digestibility could not be determined. Widyaratne et al. (2008) fed wheat based diets with and without enzyme to pigs that had ileal cannula inserted at 29 kg. This study found that the apparent ileal digestibility (AID) for energy and threonine was greater when the enzyme was added. There was no difference in AID for lysine. There was also no difference in apparent total tract digestibility (ATTD) for energy or phosphorus. Oryschak et al. (2002) found that the adding a carbohydrase blend of xylanase and β-glucanase increased nitrogen digestibility, but did not change nitrogen retention. Adding this carbohydrase complex did increase energy digestibility, and dry matter digestibility.

Mavromichalis et al. (2000) compared particle size and enzyme effectiveness in pigs from weaning to finishing. In the nursery stage the addition of a carbohydrases (Porzyme 9300, Finnfeeds international, Schaumburg, IL) increased feed efficiency with the diet that had a particle size of 1,300 µm. However, this was not seen in the other feeding stages. Enzyme

addition in this study did not affect dressing percentage, fat free lean, and last rib fat thickness. No differences in digestive viscosity were seen when the enzyme was added.

Nortey et al. (2008) inserted T-cannula in 32.5 kg pigs to compare ileal digestibilities of wheat diets with and without a xylanase, and found no significant differences in digestibility. Total tract digestibilities were greater than the ileal digestibilities suggesting that there is digestion happening in the hind gut, and this would mostly due to microbial breakdown of the NSP. This study contradicts a similar study done by Owusu-Asiedu et al. (2012) that showed a wheat-barley blend diet with a xylanase and a β-glucanase blend to ileal cannulated pigs to determine AID. It was found that ileal dry matter (DM), ileal gross energy (GE), and ileal CP digestibility all increase linearly with increasing enzyme. Average daily gain and ADFI decrease linearly while feed efficiency increased linearly with increasing enzyme. This study shows that then enzyme improves digestibility in the small intestine, but this does not always translate to improved performance.

Studies suggest that carbohydrases improve feed efficiency more in diets with wheat by-products than those with grain wheat (Adeola and Cowieson, 2011). This was also supported by Nortey et al. (2008) who fed a diet with five wheat by-products with and without enzyme. Xylanse increased total tract digestibility for diets with wheat middlings, wheat shorts, wheat bran, and wheat millrun. Ileal digestibility of the wheat grain was not effected by addition of the enzyme. However grain wheat was not affected by the inclusion enzyme. This suggests that the increase in digestibility happens in the hind gut and this would most likely be due to microbial breakdown (Adeola and Cowieson, 2011).

Diebold et al. (2004) found adding enzyme to the diet had no effect on total tract digestibility or ileal digestibility of CP, crude fat, NDF, or ADF. Individual amino acid digestibilities were also analyzed, and no significant differences were found. Volatile fatty acids were also analyzed in the ileal digesta and feces as a way to possibly indicate microbial fermentation. There were no differences in VFAs at any location. This would indicate in xylanase has no effect on VFA production or microbial fermentation. A study also tested VFAs in the jejunum and colon and found that enzymes did not change the concentration of acetate, propionate, and butyrate (Vahjen et al., 2007).

Not having an increase in ADF digestibility is not unexpected. This along with an increase in digestibility in NDF may indicate that the hemicellulose portion of the fiber component are getting broken down, which is excepted when adding xylanase or β-glucanase to the diet. This indicates that these fiber components get broken down in the small intestine, because there were no changes in total tract digestibilities (Diebold et al., 2004). This would suggest that gut microbes are unaffected by carbohydrases.

Swine studies done observe the effects of enzymes on performacne has been mixed (Nortey et al., 2008, Owusu-Asiedu et al., 2011). This is further reinforced by Rosenfelder et al. (2013) which summarized 24 studies that looked at the effect of carbohydrases on digestibility. The studies used wheat or wheat by-products like wheat DDGS, wheat middlings, and wheat millrun. Of these studies, 13 had found an increase in digestibility when a carbohydrase was added. The remaining studies showed the enzyme had no effect. Sixteen studies used wheat as the grain and energy source with 7 having an increase in digestibility when a carbohydrase was used. The remaining nine studies showed that no improvement of digestibility with inclusion of

enzyme. This may be because pigs are not as affected by the negative effects of fiber as poultry are. Pigs have a slower passage rate of feed than chickens, and lower digestive viscosities. Exogenous enzymes in pigs may not work as well in the swine digestive tract even though the enzyme has a longer time in the digestive tract to work (Bedford and Partridge, 2001).

### *Carbohydrase and Phytase*

Oryschak et al. (2002) found that adding a carbohydrase and a phytase together may improve dry matter digestibility slightly but from significantly 82%, a diet with no added enzymes to 83% with a carbohydrase and phytase. This conflicts with Rosenfelder et al. (2013) who reported an adverse effect between a carbohydrase and phytase. Yanez et al. (2010) found that carbohydrase and phytase do not interact. This agrees with Woyengo et al. (2008) that directly compared the use of xylanase and phytase in wheat based diets. There was no xylanase phytase interaction observed in the study. There was no effect of xylanase on DM digestibility, calcium, or phosphorus digestibly. There was a trend for increased CP digestibility. The effects of phytase and carbohydrases are not well studied and the current literature is mixed on the effects of these two enzymes.

A study was done in layer hens to look at potential interactions between xylanase and phytase. This study found that phytase had no affect when xylanase was already present in the diet, this would suggest that xylanase may somehow release enough phosphorus that the effects of phytase are not observable. There was no differences in the feed conversation ratio due to diets fed. These studies shows that xylanase and phytase can be used together or separately without affecting growth performance (Silversides et al., 2006). The use of phytase with

commercial xylanase and xylanase blends is mixed, and it is an area of further investigation in the swine nutrition industry.

### *Growth performance with carbohydrases*

There are many different commercial enzymes on the market. These enzymes can be a singular enzyme, like xylanase, or a combination of enzymes like a xylanase and β-glucanase combination. Vahjen et al. (2007) preformed a study with no enzyme, mono-enzyme, which was just xylanase, and a multi-enzyme, which was a xylanase, mannase, β-galactanase, and a cellulase. This study showed that were no significant difference among feed consumption and feed efficiency. Jones et al. (2010) compared the effect of three different enzymes products in swine diets. The first product had galactomannanse, β-glucanase, and xylanse activity. The second product had galactomannanse and xylanse activity, and the third product had only xylanse activity. The second and the third product had significantly lower ADG than the control diet, with no enzyme added, and feed efficiency was not affected. Widyaratne et al. 2008 found similar results with wheat based diets with enzyme had significantly lower ADFI. There was no effect on BW gain, ADG, G: F when compared to diets without enzyme added. There was no difference between treatments of ADG, and feed efficiency.

Willamil et al. (2012) fed 36 pigs fed four diets in a 2x2 factorial design. A corn diet, with and without enzyme, and a wheat, barley, and rye combination diet (WBR) with and without enzyme. The enzyme used was a xylanase and β-glucanase combination. At the end of the study there was no significant differences in BW, ADG, ADFI, and feed efficiency. There was a significant interaction between enzyme and grain type used. Pigs fed WBR diet with enzyme had increased BW, higher ADG, and lower ADFI than pigs on a corn diet with no enzyme.

Barrera et al. (2004) fed xylanase in four levels 0, 5500, 11000, and 16500 units of activity/kg in diets where wheat was the only protein source and found that 11000 unit of activity/kg had the highest feed efficiency. Feeding a commercial enzymes can increase feed efficiency when it was the only protein source fed. Adding more enzyme did not further increase feed efficiency but did make feed efficiency numerically lower.

Overall wheat can be used in swine diets of all phases without effecting growth performance compared to corn (Erikson et al., 1980, Seerely et al., 1988). The results of adding enzymes to swine diets have mixed results (Rosenfelder et al, 2013). Wheat may be used with wheat DDGS, this however indicates a decrease in growth performance (Widyaratne et al., 2008). Wheat is a versatile feed ingredient in the swine industry.

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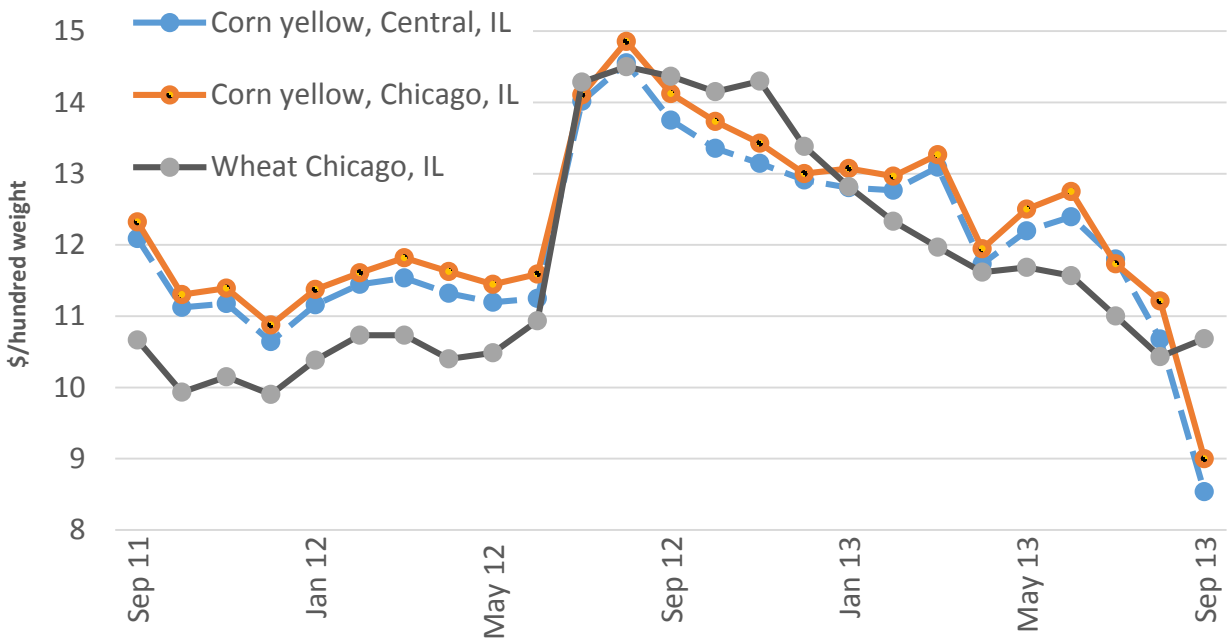
**Table 2-1.** Comparison of wheat, corn and DDGS adapted from NRC 2012

| Nutrient % | Corn | SID % | Wheat | SID% | DDGS | SID% | SBM | SID% |
|---|---|---|---|---|---|---|---|---|
| DM | 88.31 | | 88.67 | | 89.35 | | 89.89 | |
| Crude protein | 8.24 | 80 | 14.46 | 88 | 27.36 | 74 | 47.73 | 87 |
| Arg | 0.37 | 87 | 0.60 | 91 | 1.23 | 81 | 3.45 | 94 |
| His | 0.24 | 83 | 0.34 | 88 | 0.74 | 78 | 1.28 | 90 |
| Ile | 0.28 | 82 | 0.47 | 89 | 1.06 | 76 | 2.14 | 89 |
| Leu | 0.96 | 87 | 0.91 | 89 | 3.25 | 84 | 3.62 | 88 |
| Lys | 0.25 | 74 | 0.39 | 82 | 0.90 | 61 | 2.96 | 89 |
| Met | 0.18 | 83 | 0.22 | 88 | 0.57 | 82 | 0.66 | 90 |
| Phe | 0.39 | 85 | 0.64 | 90 | 1.37 | 81 | 2.40 | 88 |
| Thr | 0.28 | 77 | 0.40 | 84 | 0.99 | 71 | 1.86 | 85 |
| Trp | 0.06 | 80 | 0.17 | 88 | 0.20 | 71 | 0.66 | 91 |
| Val | 0.38 | 82 | 0.58 | 88 | 1.39 | 75 | 2.23 | 87 |
| Ether extract | 3.48 | | 1.82 | | 8.90 | | 1.52 | |
| Ash | 1.3 | | 1.98 | | 4.04 | | 6.27 | |
| Net Energy | 1747 | | 2595 | | 2343 | | 2087 | |
| NDF | 9.11 | | 10.60 | | 30.46 | | 8.21 | |
| ADF | 2.88 | | 3.55 | | 12.02 | | 5.28 | |




Adapted from USDA, Economic Research Service, wheat data and feed grains data.

**Figure 2-1. Price of wheat and corn in Chicago, and central Illinois**

# CHAPTER 3

# EVALUATION OF THE USE OF WHEAT IN NURSERY PIG DIETS

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Bloxham, D. J., C. R. Dove, and M. J. Azain. To be submitted to *Journal of Animal Science.*

**Abstract**

Two studies were conducted to determine if in nursery diet 1) corn can be replaced by wheat, as an energy source, and if there was an optimal wheat corn blend, and 2) to determine if wheat can be combined with corn distillers dried grains with solubles (DDGS) and a commercial carbohydrase enzyme in nursery diets. Experiment 1, 144 pigs were sorted by weight and randomly allotted within block to six dietary treatments (0%, 20%, 40%, 60%, 80%, and 100% wheat) replacing corn. In experiment 2, 210 pigs were blocked by weight and randomly allotted to five dietary treatments (control diet (C), wheat diet (W), wheat diet with enzyme (W +enz), and wheat diet with corn DDGS (WCD), wheat diet with corn DDGS with enzyme (WCD +enz)). Pig weights and feed disappearance were determined weekly for both experiments. Fecal samples were collected for both experiments. Titanium dioxide was used as an indigestible marker at 0.3% to determine apparent digestibility of nitrogen, fat, phosphorus, NDF, and ADF in both experiments. In experiment 1, there was a quadratic effect of increasing wheat on body weight at 35 d (20.8, 21.5, 22.0, 21.8, 21.1, 21.3 kg, $P<0.05$). There was a quadratic effect of increasing wheat on ADG (483, 502, 529, 516, 491, 496 g/d, $P<0.05$). There was quadratic effect of increasing wheat on G:F (0.68, 0.68, 0.71, 0.71, 0.70, 0.70, $P<0.05$). Overall changes in ADFI were not different. Nitrogen and phosphorus digestibility increased with increasing wheat in phase 2 ($P<0.05$). Nitrogen, fat, and phosphorus increased linearly with increasing wheat in phase 3 ($P<0.05$). In experiment 2, there was a treatment effect on body weight on 35 d (21.1 C, 21.6 W, 20.6 W +enz, 22.5 WCD, 21.4 WCD +enz, $P<0.05$). There was a treatment effect on ADG (499 C, 519 W, 481 W +enz, 549 WCD, 511 WCD +enz, g/d, $P<0.05$. There was no DDGS affects or enzyme effects on ADFI (729 C, 717 W, 740 W +enz, 789 WCD, 707 WCD +enz, g/d, $P<0.05$). There

was no enzyme effect on G:F, but there was a DDGS effect on G:F (0.69 C, 0.72 W, 0.65 W +enz, 0.70 WCD, 0.72 WCD +enz, $P<0.05$). There were treatment effects on nitrogen, fat, and phosphorus digestibility in phase 2 and 3 ($P<0.05$). Overall wheat can be fully substituted for corn without effecting growth performance. A wheat corn blend of 40% can increase growth performance compared to corn. Wheat can be fed with corn DDGS without affecting growth performance. The results demonstrate that wheat can be fully or partially substituted for corn in nursery diets.

## Introduction

Feed costs can be up to 70% of the total cost of live production when raising pigs (Bedford and Partridge, 2010). Corn is the major energy source for swine diets in the United States, however Canada and Europe use wheat as the major energy source (Hongtrakul et al., 1998, Rosenfielder et al., 2013). The price of wheat and corn vary, by season and region, so there are times when wheat would be a more economical energy source than corn in swine diets. Few studies have been shown to directly compare wheat to corn. Studies that have been performed that shows that wheat can give similar growth performance to corn of pigs from weaning to market weight (Erikson et al, 1980, Seerley et al., 1988). There have been few studies to show how much wheat can be substituted for corn without affecting growth performance in nursery diet.

Exogenous enzymes called carbohydrases have been commonly added to swine diets in recent years to increase digestibility of fiber components, commonly xylans and β-glucans, of feed ingredients that contain high fiber content (Bedford and Partridge, 2001). Wheat has a NDF component of 10.60% while corn has an NDF component of 9.11%, while the difference in the

NDF fraction between wheat and corn is not large, there are still concerns that using wheat instead of corn will decrease growth performance, because the wheat has more non-starch polysaccharides (NSP) than corn (NRC, 2012). Fiber or NSP can decrease the absorption of other nutrients. Exogenous enzymes, commonly xylanases and β-glucanases, are added to feeds to break down part of the NSP fraction. The benefit of carbohydrases in swine diets is variable (Rosenfielder et al., 2013). These studies were conducted to find a suitable wheat corn ratio, and to combine wheat with corn DDGS and a commercially available carbohydrase to observe growth performance and digestibility in nursery aged pigs.

## Material and methods

Experimental protocols were approved by the University of Georgia (UGA) Institutional Animal Care and Use Committee (UGA Animal Care and Use, A2012 02-022-Y1-A0) (Athens, Ga). All diets were fed as a pellet. Diets were pelleted at 65.6˚C and never exceeded 71.1˚C.

### *Experiment 1*

The objective of this study was to determine if wheat could substitute for corn, and if there was an optimal inclusion rate for wheat in nursery diets. One hundred forty four commercial crossbreed barrows and gilts (PIC C29 x PIC 380) were allotted to 24 pens in two trials for a total 48 pens for the experiment. Pigs were weaned at approximately 21 d of age then moved to the nursery where a common diet was fed 0-7 d post weaning (Table 3-1). Pigs (6.20± 0.20kg; 78 barrows and 66 gilts) were allotted to pens and blocked by weight and sex with 3 pigs per pen on day 0. Gender was balanced within block. Pens were 0.94m x 1.83m woven wire flooring and pits. Pigs were fed ad libitum. The room was keep at a consent temperature with continuous lighting. Water was supplied at all times with a nipple waterer. The pen was the

experimental unit. On day 7 the common diet was removed and phase 2 test diet was fed d 7-21. Phase 3 test diet was fed 21-35 d. Pigs were weighed and feed disappearance was measured weekly. Wheat for the study was obtained by a commercial feed mill (Godfery's Feed Mill, Madison, Ga). Wheat was purchased and ground with a hammer mill. Two diets were made one that contained corn as the energy source and another with wheat as the energy source. Diets were formulated to be isoenergetic, have the same SID lysine (Table 3-2). The two diets were blended to make the six treatments diets in 0, 20, 40, 60, 80, 100% corn replaced with wheat (Table 3-2). $TiO_2$ was added to all experimental diets at 0.3% as an indigestible marker to determine apparent digestibility of nitrogen, crude fat (CF), total phosphorus, NDF, and ADF digestibilities.

***Experiment 2***

Two hundred ten commercial crossbreed barrows and gilts (PIC C29 x PIC 380) were allotted to 20 pens in two trials for a total 40 pens for the experiment. Pigs were weaned at approximately 21 d of age then moved to the nursery where a common diet was fed 0-7 d post weaning (Table 3-1). Pigs (6.40± 0.11kg; 95 barrows and 115 gilts) were allotted to pens at weaning and blocked by weight and sex with 4-6 pigs per pen at day 0. Gender was balanced with block. Pens were 1.83m x 1.68m with plastic mesh floors and pits. Pigs were fed ad libitum. The room was environmentally controlled with continuous lighting. Water was supplied at all times with a pan waterer. The pen was the experimental unit. On day 7 the common diet was removed and phase 2 test diet was fed 7-21 d. Phase 3 test diet was fed 21-35 d. Pigs were weighed and feed disappearance was measured weekly. Wheat was obtained by a commercial feed mill (Godfery's Feed Mill, Madison, Ga). Commercial carbohydrase enzyme used was Axtra® XB, which

had xylanase and β-glucanase activity (DuPont, Marlborough, Wiltshire, UK). Five diets were made: control diet (C), wheat diet (W), wheat diet with enzyme (W +enz), and wheat diet with corn DDGS (WCD), wheat diet with corn DDGS with enzyme (WCD +enz) (Table 3-3 and 3-4). $TiO_2$ was added to all experimental diets at 0.3% as an indigestible marker to determine apparent digestibility of nitrogen, CF, total phosphorus, NDF, and ADF digestibilities.

***Sample analysis***

Fecal samples were collected on days 17-21 d for phase 2 and on days 31-35 d for phase 3 for both experiments. Fecal samples were frozen and then oven dried at 65 ˚C (SA-350 Grieve, The Grieve Cooperation, Round Lake, IL) until constant weight was reached. The samples were then stored at room temperature until ground. Fecal samples and diets were ground through a 2mm screen (Model 4, Wiley mill, Thomas Scientific, Swedesboro, NJ). Dried fecal samples were stored at room temperature until analyzed. Ground diets were stored at 4˚C.

Diets and fecal samples were analyzed for crude fat (AnkomX15, Method 2, Ankom, Macedonia, NY), crude protein (FP 628 LECO, LECO Corp., St. Joseph, MI), titanium (Myers et al., 2004), phosphorus (DU 600 Beckman-Coulter, Fullerton, CA), neutral detergent fiber (NDF) (Ankom 200 and Ankom 2000, Method 13, Ankom, Macedonia, NY), and acid detergent fiber (ADF) (Ankom 200 and 2000, method 12, Ankom, Macedonia, NY).

Experimental diets and wheat used were analyzed for amino acids profile (University of Missouri – Columbia, Office of the Missouri State Chemist, Analytical Services) (Table 3-6, Table 3-7, Table 3-8, and Table 3-9). Diets for phase 2 were analyzed for enzyme activity (DuPont Industrial Biosciences / Danisco Animal Nutrition (St. Louis, MO)), (Table 3-5). Wheat was analyzed for vomitoxin and zearalenone (Table 3-6), (University of Missouri- Columbia,

Veterinary Medical Diagnostic Lab). Due to the high mycotoxin content of the wheat in exp. 2 wheat was only added to diets 2-5 at 30%. This was done so mycotoxin values would be fed at safe levels (Diekman et al, 2005).

## Statistical analysis

Data was analyzed using the General Linear Model procedure (PROC GLM) of SAS (SAS Institute, Inc., Cary, NC). Exp. 1 was dose model of 20% increments. Model included trial, block, treatment day 7 BW, and trial x diet. Body weights were co-varied for day 7 Exp. 2 was a 2x2 factorial with enzyme and DDGS as main effects and a positive control treatment. Model included trial, block, treatment day 7 BW, and trial x diet. A preplanned contrast statements were used in exp. 2 to compare the effect of DDGS and enzyme on BW, ADG, ADFI and G:F. In both experiments the pen was the experimental unit. Differences were considered significant at $p<0.05$, while trends were considered at $P <0.10$.

## Results

### *Wheat analysis*

The wheats for these experiments were purchased at two different times from the same commercial feed mill (Goddfery's Feed Mill, Madison, Ga) and was purchased under the assumption that both batches were hard red winter wheat. Diets were formulated as hard red wheat according to the NRC (NRC, 2012). Both wheats differed from the NRC value of hard red wheat for CP, NDF, and ADF (Table 2-1 and Table 3-12). Crude protein of the wheat used in exp. 1 was 10.19%, whereas the wheat used in exp. 2 was 11.5% CP. Neutral detergent fiber for the wheat in exp. 1 was 9.59%. Neutral detergent fiber for the wheat used in exp. 2 was 14.22% (Table 3-12) which is higher than the 10.60% reported in the NRC (NRC, 2012). Both ADF values

(3.79 exp. 1 and 4.73 exp. 2) were higher than the 3.55% ADF in the NRC for both hard and soft wheat. The amino acid profile for wheat is reported in table 3-7, generally the wheat used in exp. 2 had greater amino acid values than the wheat used in exp. 1.

***Experiment 1***

There was no effect of initial 0 d BW, 7 d BW, or trial*diet interactions. At the end of phase 2, BW, ADG, or G:F, however there was cubic effect on ADFI with increasing wheat in phase 2 (494, 498, 513, 479, 451, 489, g/d, $P<0.05$) receptivity. At day 35 there was a quadratic effect on body weight with increasing wheat (20.78, 21.54, 22.00, 21.84, 21.09, 21.30, kg, $P<0.05$), respectively. Pigs fed the 40% wheat diet were significantly heavier at day 35 than pigs fed the 0% wheat ($P<0.05$). At 35 d 0% wheat diet and the 100% wheat diet (20.78 vs 21.3kg) performed the same (SEM 0.56, NS). Average daily gain was affected quadratically with increasing wheat in phase 3 (649, 662, 721, 702, 687, 651, g/d, $P<0.01$) respectively with 40% wheat have significantly higher ADG than the 0% wheat diet ($P<0.05$). Average daily feed intake had the same trend as ADG with 40% wheat have a higher ADFI than the 0% wheat diet (938, 976, 990, 973, 960, 900, g/d, $P<0.03$) respectively. Feed efficiency increased linearly with increasing wheat in phase 3 (0.69, 0.68, 0.73, 0.72, 0.72, 0.73, $P<0.02$) respectively. Overall ADG was greater for the 40% wheat diet than the 0% wheat diet, and ADG was effected quadratically with increasing wheat (483, 502, 529, 516, 491, 496, g/d, $P<0.04$) respectively. Overall ADFI was not different over the experiment (708, 744, 745, 730, 705, 707, g/d, $P>0.10$) respectively. Overall feed efficiency was increased linearly with increasing wheat (0.68, 0.38, 0.71, 0.71, 0.70, 0.70, $P<0.02$) respectively (Table 3-7).

Nitrogen in the fecal samples decreased with increasing wheat in the diet (4.62, 4.62, 4.53, 4.49, 4.22, 4.02, %, P<0.0001) respectively in phase 2 and phase 3 (4.17, 4.19, 4.01, 3.97, 3.97, 3.97, %, P<0.005) respectively. Crude fat in the fecal samples increased linearly with increasing wheat in the diet (5.88, 7.03, 7.42, 7.49, 9.23, 9.91, %, P<0.0001) respectively in phase 2 and phase 3 (8.45, 8.82, 9.08, 8.74, 9.97, 9.20, %, P<0.05). The neutral detergent fiber fraction in fecal samples decreased quadratically with increasing wheat (30.0, 28.0, 27.9, 27.9, 28.7, 29.8, %, P<0.0001) respectively in phase 2 and was not different in phase 3 (33.2, 34.1, 33.6, 35.8, 34.2, 34.5, %, P>0.10) respectively. Acid detergent fiber in the fecal samples increased with increasing wheat (11.1, 11.2, 11.5, 11.7, 13.0, 13.8, %, P<0.0001) respectively in phase 2 and 3 (11.9, 12.6, 13.8, 14.8, 15.0, 15.9, %, P<0.0001) respectively (Table 3- 12).

In phase 2, digestibility of nitrogen increased linearly with increasing wheat (68.8, 71.2, 73.7, 74.9, 79.4, 83.7, %, P<0.05) respectively. Phosphorus digestibility for the 100% diet was higher than all other diets (51.0, 52.8, 52.9, 55.5, 54.5, 60.7 %, P<0.0003) respectively. There was a trend for increasing NDF digestibility with increasing wheat inclusion (42.0, 37.0, 49.1, 42.9, 42.5, 48.1, %, P<0.10) respectively. There was a decrease in ADF digestibility with increasing wheat (36.1, 23.1, 30.8, 26.7, 23.2, 25.3, %, P<0.04) respectively. There were no differences in crude fat digestibility with increasing wheat (60.2, 57.8, 56.9, 58.9, 55.5, 59.4, %, P>0.10) respectively. In phase 3, digestibility of nitrogen increased linearly with increasing wheat (72.5, 73.5, 74.2, 79.1, 83.1, 83.9, %, P<0.0001) respectively. Crude fat digestibility increased with increasing wheat (44.5, 45.4, 43.5, 53.9, 57.8, 63.1, %, P<0.0001) respectively. Phosphorus digestibility was higher for the 80% and 100% wheat diets than all other diets (55.1, 56.3, 53.7, 54.6, 66.7, 65.5 %, P<0.0001) respectively. Neutral detergent fiber digestibility was affected

quadratically by increasing wheat (50.5, 49.5, 48.2, 46.9, 53.5, 58.4, %, P<0.0001). Acid detergent fiber digestibility was affected quadratically with increasing wheat (46.3, 45.3, 34.6, 36.5, 40.2, 43.9, %, P<0.0001).

***Experiment 2***

The presence of xylanase for experiment 2 was confirmed (Table 3-5). One pig died for unknown reasons during the study.

At the end of phase 2 there were treatment effects on BW (12.4 C, 12.6 W, 11.7 W +enz, 13.1 WCD, 12.9 WCD +enz, kg, P<0.0001). There was ingredient effects on BW, with pigs on the cDDGS diets having increased body weights (P<0.0001). There was also enzyme effects on body weight with pigs on the enzyme treatments having decrease body weights (P<0.01). There was an enzyme effect on AGD on day 21 with the pigs fed the enzyme diets gaining less per day than pigs not fed an enzyme (P<0.05). There was an enzyme effect on ADFI in phase 2 with the pigs fed the enzyme having lower ADFI. In phase 3 there was an ingredient effect on ADFI with pigs in the cDDGS treatments having higher ADFI than the wheat treatments. There was no overall effect of ingredient on ADFI (P>0.10). However there was an overall ingredient*enzyme interaction with enzyme increasing ADFI in the wheat diet but enzyme decreased ADFI in the DDGS diet (P<0.05), however, there was no enzyme effect on feed efficiency for phase 2, phase 3, and overall. Feed efficiency was affected by ingredient in phase 2 and phase 3 with the pigs on the cDDGS diets having higher feed efficiency than the wheat diets. Final BW was affected by treatment (21.1 C, 21.6 W, 20.6 W +enz, 22.5 WCD, 21.4 WCD +enz, kg, P<0.002). There was ingredients effects, with the pigs on the cDDGS diets having increase BW overall. There was enzyme effects with pigs

on the enzyme treatments having decrease in BW, however, there was no interaction of ingredient by enzyme on body weight (Table 3-14).

In phase 2, enzyme had no effect on nitrogen, CF, NDF, or phosphorus concentration in the fecal samples, however there was an enzyme effect on fecal ADF ($P<0.05$). There was an ingredient effect on nitrogen, fat, NDF, and phosphorus in phase 2 ($P<0.05$). There was an ingredient by enzyme interaction for NDF and phosphorus in phase 2 ($P<0.05$). In phase 3 there was an ingredient effect for nitrogen, fat, NDF, ADF, and phosphorus ($P<0.05$). Nitrogen, fat, and phosphorus decreased when cDDGS was fed. Fiber components NDF and ADF increase when cDDGS was in the diet (Table 3-15).

In phase 2 there was ingredient effects for nitrogen and phosphorus digestibility. Nitrogen and phosphorus digestibility increased when cDDGS was added to the diet. When enzyme was present there was an increase in nitrogen, fat, NDF, and ADF digestibilities in phase 2 ($P<0.05$, Table 3-16). There was an ingredient by enzyme interaction for phosphorus in phase 2 enzyme decreased phosphorus digestibility when DDGS was present but increased phosphorous digestibility when was present ($P<0.05$).

Nitrogen digestibility was about 7% lower for the control diet in phase 2 than the wheat diets in phase 2 (74.0 C vs. 77.2 W, 81.4 W +enz, %, $P<0.0001$) and 14% lower than the DDGS treatments (84.3 WCD, 85.5 WCD +enz, %, $P<0.0001$) compared to the control. In phase 2, phosphorus digestibility was higher for the DDGS treatments than the control and the wheat treatments (58.1 C, 53.5 W, 58.2 W +enz, 70.3 WCD, 66.6 WCD +enz, $P<0.0002$). In phase 3, phosphorous digestibility was greater for the W +enz diet and the DDGS than the control (59.8 C, 62.4 W, 64.7 W +enz, 70.7 WCD, 68.6 WCD +enz, %, $P<0.0001$). In phase 3 there was an increase

in ADF digestibility when the enzyme was used compared to the diets without enzyme (38.7 W and 40.1 WCD% vs. 46.3 W +enz and 46.5 WCD +enz $P<0.05$), however this was not seen in phase 2 ADF digestibility (30.1 C, 21.3 W, 23.8 W +enz, 19.4 WCD, 32.6 WCD +enz, %, $P<0.0015$). Gross energy (GE) digestibility decreased with the inclusion of DDGS in both phase 2 and phase 3. There was a trend ($P=0.06$) for enzyme to increase GE digestibility. Wheat had the same GE digestibility as corn in both phase 2 and 3 (Table 3-16).

**Discussion**

Wheat can replace corn and achieve similar growth rates. This agrees with studies done by Erikson et al. (1980) and Seerley et al. (1988) that replaced wheat with corn, but did use wheat corn blends. Blending wheat with cDDGS increases growth rate compared to a corn diet. A wheat: corn blend of 40% wheat increases growth performance more than a standard corn diet. The increase in bodyweight from feeding the WCD may, but these gains may no longer be significant once the animals reach market weight do to more variation between animals (Skinner et al. 2014).

The use of enzymes did not improve growth performance in this study, however there was an increase in digestibility of ADF with the inclusion of enzyme to the diet. The effectiveness of carbohydrase enzymes in pig diets is mixed (Rosenfelder et al., 2013). Kiarie et al. (2012) used the same enzyme as the current study (Axtra® XB, Danisco Animal Nutrition, Malborough, Wilshire, UK) and found the enzyme was did not change growth performance, but digestibilities of nitrogen, dry matter, and gross energy increased with inclusion of enzyme. Widyaratne et al. (2008) used enzymes in wheat diets and wheat DDGS diets had a trend ($P<0.058$) for lower body weights for the diets that contained enzymes. Similar results were found in the current study.

Jones et al. (2010) compared three different kinds of carbohydrase enzymes two of the three products had significantly lower ADG compared to the control diet that did not have an enzyme added. These studies show similar results with the current study, that carbohydrases are not always affective. This further shows that the inclusion of carbohydrases remains inconsistent on growth performance in swine diets. The enzyme activity was determined to in the diets (Table 3-5), and all diets had more enzyme activity than expected. Increasing the level of enzyme may not however improve performance. A study done by Barrera et al, 2004 showed a quadratic effect of enzyme efficacy. Growth performance and protein digestibility decreased after 11,000 units of activity/ kg. This decrease in performance was observed for CP, all essential amino acids, ADG, ADFI, and feed efficiency.

Cost of gain (COG) can be an important factor when feeding diets to pigs. Cost of gain analysis was done for June of 2013 when wheat was $3.46/hundredweight cheaper than corn, this was greatest difference in wheat and corn prices since June of 2011. This would show the largest COG differences. Cost of gain for the wheat ($0.873/kg) diet in phase 2 was $0.05 less than the corn diet ($0.923/kg) and the pigs performed the same for the 0% wheat and the 100% corn diet. In phase 3 the wheat diet ($0.668/ kg) was a $0.14 cheaper than the corn diet ($0.810/kg). The 40% wheat diet COG in phase 2 was $0.880/kg which had less than $0.01 higher COG than the wheat diet in phase 2. In phase 3, COG of the 40% wheat diet was intermediate of the 0% and the 100% wheat diet (0.81 0%, 0.733 40%, and 0.668 100%). The price of wheat and corn were the same price per bushel as they were in August 2013, at $6.6 a bushel ($11.00/hundredweight and $11.785/hundredweight, respectively). In the phase 2 diets there was a $5 difference per ton in the diets ($557.0/ton corn and 551.9 wheat), but COG was only

$0.007/kg less in the wheat diet than the corn diet. In the phase 3 diet the wheat diet cost $7.90 less per ton than the corn diet ($414.2/ton corn and $406.3/ton wheat), and the COG of $0.075 less for wheat than the corn diet ($0.722/kg corn and $0.647/kg). For the 40% wheat diet in phase 2 was $0.838/kg which was cheaper than either the 0% corn diet or the 100% wheat diet. In phase 3 the COG of the 40% wheat diet had an intermediate COG of $0.675/kg.

**Implications**

These studies determine that wheat can replace corn in phase 2 and 3 nursery phase diets and growth performance is not decreased. Wheat can be used in combination with cDDGS to further reduce the cost of diets and increase gains. The use of enzyme in this study was not effective. When wheat is cheaper than corn on a bushel or hundredweight basis wheat would be a more economical feeding choice for nursery pigs.

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**Table 3-1.** Common diet composition 0-7 days post weaning (Exp. 1 and 2)

| Ingredient | Percent |
|---|---|
| Corn | 38.36 |
| Soybean meal | 18.75 |
| Whey | 27.50 |
| Fish meal | 5.00 |
| Plasma protein | 5.00 |
| Fat | 2.00 |
| Limestone | 0.83 |
| Dicalcium phosphate | 0.23 |
| Salt | 0.20 |
| Vitamin premix | 0.25 |
| Mineral premix | 0.15 |
| Lysine HCl | 0.23 |
| Methionine | 0.12 |
| Antibiotic (Mecadox) | 1.00 |
| Zinc Oxide | 0.38 |
| | |
| Calculated Analysis | |
| ME, Mcal/kg | 3.42 |
| CP% | 22.84 |
| Lysine% | 1.70 |
| SID Lysine% | 1.53 |
| TSAA% | 0.93 |
| Thr% | 1.02 |
| Ca% | 0.85 |
| Total P,% | 0.65 |
| Available P% (ATTD) | 0.45 |

* The vitamin premix (ADM, Quincy, IL) provided the following per kilogram of complete diet: 1100 IU vitamin A, 1376 IU vitamin D3, 44 IU vitamin E, 4.4 mg vitamin K, 8.3 mg riboflavin, 50 mg niacin, 28 mg pantothenic acid, 23 µg vitamin $B_{12}$.

**The trace mineral premix (ADM, Quincy, IL) provided the following per kilogram of complete diet: 165 mg Fe ($FeSO_4 \cdot H_20$), 16.5 mg Cu (CuSO4·5H20), 36 mg Mn ($MnSO_4$), 165 mg Zn (ZnO), .3mg I ($Ca(IO_3)_2$), and .3 mg Se ($Na_2SeO_3$).

**Table 3-2.** Diet composition and calculated analysis of 0:100 and 100:0 for phase 2 and 3(Exp. 1)

| | Phase II | | Phase III | |
|---|---|---|---|---|
| | Corn | Wheat | Corn | Wheat |
| Corn | 53.568 | - | 64.518 | - |
| Soybean meal | 27.49 | 24.80 | 30.77 | 27.45 |
| Wheat | - | 54.178 | - | 65.438 |
| Whey | 10.00 | 10.00 | - | - |
| Fish Meal | 2.50 | 2.50 | - | - |
| Blood Cells | 2.50 | 2.50 | - | - |
| Fat | 0.32 | 2.42 | 0.45 | 3.00 |
| Limestone | 1.06 | 1.04 | 0.97 | .96 |
| Dicalcium phosphate | - | - | 0.64 | 0.56 |
| Salt | 0.25 | 0.25 | 0.35 | 0.35 |
| Vitamin Premix* | 0.25 | 0.25 | 0.25 | 0.25 |
| Mineral Premix** | 0.15 | 0.15 | 0.15 | 0.15 |
| Lysine | 0.20 | 0.20 | 0.40 | 0.40 |
| Methionine | 0.15 | 0.14 | 0.13 | 0.05 |
| Threonine | - | 0.01 | 0.06 | 0.08 |
| Titanium dioxide | 0.30 | 0.30 | 0.30 | 0.30 |
| Phytase | 0.012 | 0.012 | 0.012 | 0.012 |
| Antibiotic | 1.00 | 1.00 | 1.00 | 1.00 |
| Zinc Oxide | 0.25 | 0.25 | - | - |
| Calculated Analysis | | | | |
| ME, Mcal/kg | 3.30 | 3.30 | 3.30 | 3.30 |
| Lysine % | 1.52 | 1.51 | 1.40 | 1.39 |
| SID lysine, % | 1.35 | 1.35 | 1.26 | 1.25 |
| TSAA, % | 0.87 | 0.87 | 0.79 | 0.79 |
| Thr, % | 0.96 | 0.95 | 0.87 | 0.87 |
| Ca, % | 0.68 | 0.68 | 0.60 | 0.60 |
| Total P, % | 0.49 | 0.53 | 0.51 | 0.44 |
| Available P% | 0.24 | 0.25 | 0.22 | 0.22 |

* The vitamin premix (ADM, Quincy, IL) provided the following per kilogram of complete diet: 1100 IU vitamin A, 1376 IU vitamin D3, 44 IU vitamin E, 4.4 mg vitamin K, 8.3 mg riboflavin, 50 mg niacin, 28 mg pantothenic acid, 23 µg vitamin $B_{12}$.

**The trace mineral premix (ADM, Quincy, IL) provided the following per kilogram of complete diet: 165 mg Fe ($FeSO_4 \cdot H_20$), 16.5 mg Cu (CuSO4·5H20), 36 mg Mn ($MnSO_4$), 165 mg Zn (ZnO), .3mg I ($Ca(IO_3)_2$), and .3 mg Se ($Na_2SeO_3$).

**Table 3-3.** Diet composition and calculated analysis for phase 2 (Exp. 2)

| | Control | Wheat | | DDGS | |
|---|---|---|---|---|---|
| Enzyme | | - | + | - | + |
| Corn | 53.568 | 23.928 | 23.906 | 2.108 | 2.086 |
| SBM | 27.49 | 25.98 | 25.98 | 16.54 | 16.54 |
| Wheat | - | 30.00 | 30.00 | 30.00 | 30.00 |
| DDGS | - | - | - | 30.00 | 30.00 |
| Axtra® XB | - | - | 0.022 | - | 0.022 |
| Whey | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| Fish meal | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| Blood cells | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| Fat | 0.32 | 1.49 | 1.49 | 2.68 | 2.68 |
| Limestone | 1.06 | 1.05 | 1.05 | 1.03 | 1.03 |
| Salt | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Vitamin premix* | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Mineral premix** | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| Lysine HCl | 0.20 | 0.20 | 0.20 | 0.40 | 0.40 |
| Methionine | 0.15 | 0.14 | 0.14 | 0.03 | 0.03 |
| Titanium dioxide | 0.30 | 0.30 | 0.30 | 0.3 | 0.3 |
| Phytase | 0.012 | 0.012 | 0.012 | 0.012 | 0.012 |
| Mecadox | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Zinc Oxide | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Calculated Analysis | | | | | |
| ME, Mcal/kg | 3.40 | 3.30 | 3.30 | 3.30 | 3.30 |
| Crude protein, % | 22.73 | 24.71 | 24.71 | 25.08 | 25.08 |
| Lysine, % | 1.51 | 1.51 | 1.51 | 1.60 | 1.60 |
| SID lysine, % | 1.35 | 1.35 | 1.35 | 1.38 | 1.38 |
| TSAA, % | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 |
| Thr, % | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| Ca, % | 0.68 | 0.68 | 0.68 | 0.68 | 0.68 |
| Total P, % | 0.47 | 0.53 | 0.53 | 0.60 | 0.60 |
| Available P% | 0.23 | 0.25 | 0.25 | 0.33 | 0.33 |

* The vitamin premix (ADM, Quincy, IL) provided the following per kilogram of complete diet: 1100 IU vitamin A, 1376 IU vitamin D3, 44 IU vitamin E, 4.4 mg vitamin K, 8.3 mg riboflavin, 50 mg niacin, 28 mg pantothenic acid, 23 µg vitamin $B_{12}$.

**The trace mineral premix (ADM, Quincy, IL) provided the following per kilogram of complete diet: 165 mg Fe ($FeSO_4 \cdot H_20$), 16.5 mg Cu ($CuSO4 \cdot 5H20$), 36 mg Mn ($MnSO_4$), 165 mg Zn (ZnO), .3mg I ($Ca(IO_3)_2$), and .3 mg Se ($Na_2SeO_3$).

**Table 3-4.** Diet composition and calculated analysis for phase 3 (Exp. 2)

| | Control | Wheat | | DDGS | |
|---|---|---|---|---|---|
| | Enzyme | - | + | - | + |
| Corn | 64.518 | 35.528 | 35.506 | 9.948 | 9.926 |
| SBM | 30.77 | 28.66 | 28.66 | 25.14 | 25.14 |
| Wheat | - | 30.00 | 30.00 | 30.00 | 30.00 |
| DDGS | - | - | - | 30.00 | 30.00 |
| Axtra® XB | - | - | 0.022 | - | 0.022 |
| Fat | 0.45 | 1.61 | 1.61 | 1.20 | 1.20 |
| Limestone | 0.97 | 0.97 | 0.97 | 1.25 | 1.25 |
| Dicalcium phosphate | 0.64 | 0.60 | 0.60 | - | - |
| Salt | 0.35 | 0.35 | 0.35 | 0.35 | 0.35 |
| Vitamin premix* | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Mineral premix** | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| Lysine HCl | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Methionine | 0.13 | 0.09 | 0.09 | - | - |
| Threonine | 0.06 | 0.08 | 0.08 | - | - |
| Titanium dioxide | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 |
| Phytase | 0.012 | 0.012 | 0.012 | 0.012 | 0.012 |
| Mecadox | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Calculated Analysis | | | | | |
| ME, Mcal/kg | 3.40 | 3.30 | 3.30 | 3.30 | 3.30 |
| Crude protein, % | 21.08 | 23.31 | 23.31 | 26.03 | 26.03 |
| Lysine, % | 1.40 | 1.38 | 1.38 | 1.48 | 1.48 |
| SID lysine, % | 1.26 | 1.24 | 1.24 | 1.26 | 1.26 |
| TSAA, % | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 |
| Thr, % | 0.87 | 0.87 | 0.87 | 0.87 | 0.87 |
| Ca, % | 0.60 | 0.60 | 0.60 | 0.60 | 0.60 |
| Total P, % | 0.50 | 0.45 | 0.45 | 0.48 | 0.48 |
| Available P% | 0.22 | 0.22 | 0.22 | 0.24 | 0.24 |

* The vitamin premix (ADM, Quincy, IL) provided the following per kilogram of complete diet: 1100 IU vitamin A, 1376 IU vitamin D3, 44 IU vitamin E, 4.4 mg vitamin K, 8.3 mg riboflavin, 50 mg niacin, 28 mg pantothenic acid, 23 µg vitamin $B_{12}$.

**The trace mineral premix (ADM, Quincy, IL) provided the following per kilogram of complete diet: 165 mg Fe ($FeSO_4 \cdot H_20$), 16.5 mg Cu (CuSO4·5H20), 36 mg Mn ($MnSO_4$), 165 mg Zn (ZnO), .3mg I ($Ca(IO_3)_2$), and .3 mg Se ($Na_2SeO_3$).

**Table 3-5.** Enzyme activities for xylanase and phytase in phase 2 and 3 diets (Exp. 2)[ab]

| Diet | Expected Activity Xylanase | Assayed activity Xylanse | Expected Activity Phytase | Assayed activity Phytase |
|---|---|---|---|---|
| Phase 2 | | | | |
| Corn | 0 | <133 | 500 | 503 |
| Wheat | 0 | 381 | 500 | 630 |
| Wheat +enz | 1830 | 1990 | 500 | 588 |
| DDGS | 0 | <133 | 500 | 685 |
| DDGS +enz | 1830 | 2690 | 500 | 611 |
| Phase 3 | | | | |
| Corn | 0 | 444 | 500 | 457 |
| Wheat | 0 | 310 | 500 | 570 |
| Wheat +enz | 1830 | 3300 | 500 | 381 |
| DDGS | 0 | 431 | 500 | 448 |
| DDGS +enz | 1830 | 2990 | 500 | 573 |

[a] Units for activity test are expressed in units of activity/ kg of feed

[a] Analysis was performed by DuPont Industrial Biosciences, Danisco Animal Nutrition, St. Louis, MO

**Table 3-6.** Mycotoxin for wheat and diets (Exp. 1 and 2)[a]

| Sample | Aflatoxin | Ochratoxin | Zearalenone | Vomitoxin |
|---|---|---|---|---|
| Exp. 1 wheat | None detected | None detected | None detected | 750 |
| Exp. 2 wheat | None detected | None detected | 2341 | 1900 |
| Exp. 1 0% phase 3 | None detected | None detected | None detected | None detected |
| Exp. 1 100% phase 3 | None detected | None detected | None detected | 650 |
| Exp. 2 Control | None detected | None detected | None detected | 250 |
| Exp. 2 Wheat | None detected | None detected | 1000 | 700 |
| Exp. 2 WCD | None detected | None detected | 875 | 1050 |

[a] reports are in parts per billion

**Table 3-7.** Calculated analysis of wheat (Exp. 1 and 2)[a]

| | Exp. 1 | Exp. 2 |
|---|---|---|
| Crude protein | 10.19 | 11.50 |
| Aspartic acid | 0.52 | 0.65 |
| Threonine | 0.29 | 0.35 |
| Serine | 0.43 | 0.49 |
| Glutamic acid | 2.54 | 2.99 |
| Proline | 0.85 | 1.06 |
| Glycine | 0.41 | 0.51 |
| Alanine | 0.38 | 0.45 |
| Cysteine | 0.23 | 0.25 |
| Valine | 0.43 | 0.52 |
| Methionine | 0.17 | 0.19 |
| Isoleucine | 0.35 | 0.42 |
| Leucine | 0.65 | 0.79 |
| Tyrosine | 0.26 | 0.31 |
| Phenylalanine | 0.42 | 0.52 |
| Lysine | 0.35 | 0.38 |
| Histidine | 0.23 | 0.28 |
| Arginine | 0.48 | 0.61 |
| Tryptophan | 0.15 | 0.16 |
| Fat | 1.58 | 1.29 |
| NDF | 9.59 | 14.22 |
| ADF | 3.79 | 4.73 |

[a] Analysis performed by University of Missouri – Columbia, Office of the Missouri State Chemist, Analytical Services

**Table 3-8.** Calculated analysis of phase 2 and 3 diets (Exp. 1)[a]

| | Phase 2 | | Phase 3 | |
|---|---|---|---|---|
| | 0:100 (corn) | 100:0 (wheat) | 0:100 (corn) | 100:0 (wheat) |
| Crude Protein | 22.96 | 23.36 | 19.18 | 20.19 |
| Aspartic acid | 12.19 | 2.14 | 1.96 | 1.76 |
| Threonine | 0.87 | 0.86 | 0.77 | 0.72 |
| Serine | 0.94 | 0.96 | 0.85 | 0.83 |
| Glutamic acid | 3.52 | 4.03 | 3.42 | 3.86 |
| Proline | 1.16 | 1.27 | 1.12 | 1.19 |
| Glycine | 0.94 | 0.98 | 0.81 | 0.81 |
| Alanine | 1.16 | 1.09 | 0.97 | 0.80 |
| Cysteine | 0.29 | 0.32 | 0.28 | 0.31 |
| Valine | 1.16 | 1.19 | 0.95 | 0.92 |
| Methionine | 0.45 | 0.42 | 0.38 | 0.32 |
| Isoleucine | 0.89 | 0.91 | 0.86 | 0.83 |
| Leucine | 1.95 | 1.84 | 1.66 | 1.41 |
| Tyrosine | 0.66 | 0.65 | 0.61 | 0.59 |
| Phenylalanine | 1.10 | 1.12 | 0.97 | 0.93 |
| Lysine | 1.49 | 1.50 | 1.40 | 1.47 |
| Histidine | 0.66 | 0.66 | 0.52 | 0.48 |
| Arginine | 1.31 | 1.34 | 1.27 | 1.22 |
| Tryptophan | 0.28 | 0.29 | 0.26 | 0.23 |
| Fat | 2.58 | 3.52 | 2.22 | 2.98 |
| NDF | 7.67 | 8.17 | 8.97 | 10.11 |
| ADF | 2.71 | 2.64 | 3.23 | 3.44 |
| Total phosphorus | 0.57 | 0.64 | 0.56 | 0.56 |

[a] Analysis performed by University of Missouri – Columbia, Office of the Missouri State Chemist, Analytical Services

**Table 3-9.** Calculated analysis of phase 2 diets (Exp. 2)[a]

| | Control | Wheat | | DDGS | |
|---|---|---|---|---|---|
| Enzyme | - | - | + | - | + |
| Crude protein | 22.90 | 23.74 | 23.37 | 24.83 | 25.51 |
| Aspartic acid | 2.24 | 2.14 | 2.32 | 2.05 | 2.13 |
| Threonine | 0.88 | 0.85 | 0.91 | 0.92 | 0.96 |
| Serine | 0.96 | 0.95 | 1.00 | 1.02 | 1.08 |
| Glutamic acid | 3.58 | 3.83 | 4.06 | 3.87 | 3.98 |
| Proline | 1.19 | 1.26 | 0.91 | 1.49 | 1.59 |
| Glycine | 0.97 | 0.98 | 1.03 | 1.02 | 1.06 |
| Alanine | 1.19 | 1.13 | 1.18 | 1.33 | 1.42 |
| Cysteine | 0.30 | 0.30 | 0.32 | 0.34 | 0.38 |
| Valine | 1.19 | 1.19 | 1.27 | 1.27 | 1.33 |
| Methionine | 0.45 | 0.44 | 0.41 | 0.40 | 0.43 |
| Isoleucine | 0.90 | 0.88 | 0.95 | 0.92 | 0.97 |
| Leucine | 1.97 | 1.88 | 2.00 | 2.21 | 2.38 |
| Tyrosine | 0.67 | 0.67 | 0.66 | 0.75 | 0.79 |
| Phenylalanine | 1.12 | 1.12 | 1.20 | 1.18 | 1.25 |
| Lysine | 1.53 | 1.50 | 1.55 | 1.53 | 1.58 |
| Histidine | 0.67 | 0.67 | 0.71 | 0.70 | 0.74 |
| Arginine | 1.35 | 1.32 | 1.41 | 1.27 | 1.32 |
| Tryptophan | 0.29 | 0.39 | 0.28 | 0.27 | 0.29 |
| Fat | 2.80 | 3.39 | 3.5 | 5.55 | 5.90 |
| NDF | 7.24 | 7.67 | 7.82 | 12.97 | 13.45 |
| ADF | 2.61 | 3.53 | 3.24 | 4.08 | 4.53 |
| Total phosphorus | 0.57 | 0.55 | 0.59 | 0.69 | 0.71 |

[a] Analysis performed by University of Missouri – Columbia, Office of the Missouri State Chemist, Analytical Services

**Table 3-10.** Calculated analysis of phase 3 diets (Exp. 2)[a]

| | Control | Wheat | | DDGS | |
|---|---|---|---|---|---|
| Enzyme | - | - | + | - | + |
| Crude protein | 20.58 | 20.02 | 20.29 | 24.30 | 24.36 |
| Aspartic acid | 1.96 | 1.91 | 1.92 | 2.19 | 2.06 |
| Threonine | 0.79 | 0.79 | 0.79 | 0.94 | 0.89 |
| Serine | 0.87 | 0.88 | 0.89 | 1.22 | 1.08 |
| Glutamic acid | 3.42 | 3.74 | 3.77 | 4.56 | 4.17 |
| Proline | 1.10 | 1.19 | 1.21 | 1.63 | 1.58 |
| Glycine | 0.82 | 0.85 | 0.85 | 1.03 | 0.98 |
| Alanine | 0.98 | 0.92 | 0.93 | 1.30 | 1.23 |
| Cysteine | 0.28 | 0.30 | 0.30 | 0.41 | 0.37 |
| Valine | 0.93 | 0.94 | 0.95 | 1.16 | 1.12 |
| Methionine | 0.37 | 0.37 | 0.35 | 0.41 | 0.37 |
| Isoleucine | 0.85 | 0.85 | 0.85 | 1.01 | 0.98 |
| Leucine | 1.65 | 1.57 | 1.59 | 2.19 | 2.11 |
| Tyrosine | 0.60 | 0.63 | 0.62 | 0.79 | 0.77 |
| Phenylalanine | 0.97 | 0.97 | 0.98 | 1.21 | 1.17 |
| Lysine | 1.38 | 1.35 | 1.38 | 1.49 | 1.40 |
| Histidine | 0.52 | 0.52 | 0.52 | 0.64 | 0.61 |
| Arginine | 1.28 | 1.31 | 1.31 | 1.46 | 1.39 |
| Tryptophan | 0.25 | 0.24 | 0.26 | 0.26 | 0.26 |
| Fat | 3.61 | 3.75 | 3.95 | 4.31 | 4.43 |
| NDF | 8.61 | 9.33 | 9.87 | 15.16 | 15.92 |
| ADF | 2.81 | 3.13 | 3.48 | 4.77 | 5.14 |
| Total phosphorus | 0.56 | 0.58 | 0.58 | 0.62 | 0.63 |

[a] Analysis performed by University of Missouri – Columbia, Office of the Missouri State Chemist, Analytical Services

**Table 3-11.** Growth performance of pigs (Exp. 1)

| | 0 | 20 | 40 | 60 | 80 | 100 | SEM | P | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | L | Q | C |
| Body weight, kg | | | | | | | | | | |
| d 0 | 6.19 | 6.15 | 6.21 | 6.19 | 6.22 | 6.25 | 0.20 | 0.65 | 0.86 | 0.95 |
| d 7 | 7.51 | 7.74 | 7.46 | 7.67 | 7.59 | 7.69 | 0.20 | 0.67 | 0.92 | 0.64 |
| d 21 | 12.45 | 12.84 | 12.70 | 12.68 | 12.17 | 12.57 | 0.39 | 0.21 | 0.40 | 0.18 |
| d 35 | 20.78$^{a}$ | 21.54$^{ab}$ | 22.00$^{b}$ | 21.84$^{ab}$ | 21.09$^{ab}$ | 21.3$^{ab}$ | 0.56 | 0.98 | 0.04 | 0.40 |
| ADG, g/d | | | | | | | | | | |
| Phase 2 | 370 | 373 | 394 | 369 | 341 | 361 | 17 | 0.25 | 0.51 | 0.24 |
| Phase 3 | 649$^{a}$ | 662$^{ab}$ | 721$^{b}$ | 702$^{b}$ | 687$^{ab}$ | 651$^{ab}$ | 22 | 0.72 | 0.01 | 0.78 |
| Overall | 483$^{a}$ | 502$^{ab}$ | 529$^{b}$ | 516$^{ab}$ | 491$^{ab}$ | 496$^{ab}$ | 16 | 0.97 | 0.04 | 0.44 |
| ADFI, g/d | | | | | | | | | | |
| Phase 2 | 491$^{ab}$ | 499$^{a}$ | 513$^{a}$ | 480$^{ab}$ | 452$^{b}$ | 488$^{ab}$ | 15 | 0.12 | 0.99 | 0.04 |
| Phase 3 | 938$^{a}$ | 976$^{b}$ | 990$^{b}$ | 973$^{b}$ | 960$^{b}$ | 900$^{a}$ | 31 | 0.30 | 0.03 | 0.99 |
| Overall | 708 | 744 | 745 | 730 | 705 | 707 | 22 | 0.32 | 0.14 | 0.31 |
| G:F | | | | | | | | | | |
| Phase 2 | 0.70 | 0.69 | 0.73 | 0.72 | 0.69 | 0.70 | 0.02 | 0.89 | 0.37 | 0.79 |
| Phase 3 | 0.69$^{ab}$ | 0.68$^{a}$ | 0.73$^{b}$ | 0.72$^{bc}$ | 0.72$^{bc}$ | 0.73$^{b}$ | 0.01 | 0.02 | 0.39 | 0.65 |
| Overall | 0.68$^{a}$ | 0.68$^{a}$ | 0.71$^{b}$ | 0.71$^{b}$ | 0.70$^{ab}$ | 0.70$^{ab}$ | 0.01 | 0.02 | 0.12 | 0.61 |

Means within a row with different superscripts differ ($P < 0.05$).

**Table 3-12.** Nutrient composition of fecal samples (Exp. 1)

| | 0% | 20% | 40% | 60% | 80% | 100% | SEM | P | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | L | Q | C |
| Phase 2 | | | | | | | | | | |
| Nitrogen % | 4.62$^{a}$ | 4.62$^{a}$ | 4.53$^{a}$ | 4.49$^{ab}$ | 4.22$^{bc}$ | 4.02$^{c}$ | 0.101 | <0.0001 | .076 | 0.97 |
| Fat % | 5.88$^{a}$ | 7.03$^{ab}$ | 7.42$^{b}$ | 7.49$^{b}$ | 9.23$^{c}$ | 9.91$^{c}$ | 0.482 | <0.0001 | .4923 | 0.49 |
| NDF % | 30.0$^{a}$ | 28.0$^{b}$ | 27.9$^{b}$ | 27.9$^{b}$ | 28.7$^{ab}$ | 29.8$^{a}$ | 0.602 | 0.84 | 0.0016 | 0.45 |
| ADF % | 11.1$^{a}$ | 11.2$^{a}$ | 11.5$^{a}$ | 11.7$^{a}$ | 13.0$^{b}$ | 13.8$^{b}$ | 0.330 | <0.0001 | 0.015 | 0.92 |
| Phosphorus % | 1.79 | 1.69 | 1.79 | 1.72 | 1.75 | 1.75 | 0.052 | 0.79 | 0.64 | 0.65 |
| Phase 3 | | | | | | | | | | |
| Nitrogen % | 4.17$^{a}$ | 4.19$^{a}$ | 4.01$^{ab}$ | 3.97$^{b}$ | 3.97$^{b}$ | 3.97$^{b}$ | 0.067 | 0.0051 | 0.33 | 0.39 |
| Fat % | 8.45$^{a}$ | 8.82$^{ab}$ | 9.08$^{ab}$ | 8.74$^{a}$ | 9.97$^{b}$ | 9.20$^{ab}$ | 0.398 | 0.0488 | 0.62 | 0.59 |
| NDF % | 33.2 | 34.1 | 33.6 | 35.8 | 34.2 | 34.5 | 0.668 | 0.12 | 0.24 | 0.69 |
| ADF % | 11.9$^{a}$ | 12.6$^{a}$ | 13.8$^{b}$ | 14.8$^{c}$ | 15.0$^{c}$ | 15.9$^{d}$ | 0.285 | <0.0001 | 0.19 | 0.87 |
| Phosphorus % | 1.88$^{a}$ | 1.78$^{ab}$ | 1.80$^{ab}$ | 1.68$^{bc}$ | 1.62$^{c}$ | 1.59$^{c}$ | 0.043 | <0.0001 | 0.9508 | 0.78 |

Means within a row with different superscripts differ ($P < 0.05$).

**Table 3-13.** Nutrient digestibility of pigs in exp. 1

| | 0% | 20% | 40% | 60% | 80% | 100% | SEM | P | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | L | Q | C |
| Phase 2 | | | | | | | | | | |
| Nitrogen % | 68.8$^{a}$ | 71.2$^{ab}$ | 73.7$^{bc}$ | 74.9$^{c}$ | 79.4$^{d}$ | 83.7$^{e}$ | 1.23 | <0.0001 | 0.1268 | 0.4602 |
| Fat % | 60.2 | 57.8 | 56.9 | 58.9 | 55.5 | 59.4 | 2.69 | 0.69 | 0.39 | 0.09097 |
| NDF | 42.0 | 37.0 | 49.1 | 42.9 | 42.5 | 48.1 | 2.90 | 0.0991 | 0.93 | 0.66 |
| ADF % | 36.1$^{a}$ | 23.1$^{b}$ | 30.8$^{ab}$ | 26.7$^{ab}$ | 23.2$^{b}$ | 25.3$^{b}$ | 3.27 | 0.0442 | 0.33 | 0.39 |
| Phosphorus % | 51.0$^{a}$ | 52.8$^{a}$ | 52.9$^{a}$ | 55.5$^{a}$ | 54.5$^{a}$ | 60.7$^{b}$ | 1.63 | 0.0003 | 0.2571 | 0.25 |
| Phase 3 | | | | | | | | | | |
| Nitrogen % | 72.5$^{a}$ | 73.5$^{a}$ | 74.2$^{a}$ | 79.1$^{b}$ | 83.1$^{c}$ | 83.9$^{c}$ | .729 | <0.0001 | 0.0902 | 0.0051 |
| Fat % | 44.5$^{a}$ | 45.4$^{a}$ | 43.5$^{a}$ | 53.9$^{b}$ | 57.8$^{b}$ | 63.1$^{c}$ | 1.69 | <0.0001 | 0.0069 | 0.1303 |
| NDF % | 50.5$^{bc}$ | 49.5$^{cd}$ | 48.2$^{cd}$ | 46.9$^{d}$ | 53.5$^{b}$ | 58.4$^{a}$ | 1.15 | <0.0001 | <0.0001 | 0.27 |
| ADF % | 46.3$^{a}$ | 45.3$^{a}$ | 34.6$^{d}$ | 36.5$^{cd}$ | 40.2$^{bc}$ | 43.9$^{ab}$ | 1.66 | 0.0726 | <0.0001 | 0.48 |
| Phosphorus % | 55.1$^{a}$ | 56.5$^{a}$ | 53.7$^{a}$ | 54.6$^{a}$ | 66.7$^{b}$ | 65.5$^{b}$ | 1.18 | <0.0001 | 0.0002 | 0.17 |

Means within a row with different superscripts differ ($P < 0.05$).

**Table 3-14.** Growth performance of pigs (Exp. 2)

| | Control | Wheat | | DDGS | | SEM | P | | | Ingredient vs |
|---|---|---|---|---|---|---|---|---|---|---|
| | Enz | - | + | - | + | | | Ingredient | Enz | Enz |
| BW, kg | | | | | | | | | | |
| d 0 | 6.40 | 6.40 | 6.50 | 6.40 | 6.40 | 0.11 | 0.99 | 0.99 | 0.94 | 0.5613 |
| d 7 | 7.0 | 7.1 | 7.2 | 7.2 | 7.0 | 0.16 | 0.86 | 0.79 | 0.63 | 0.30 |
| d 21 | 12.4$^{bc}$ | 12.6$^{ab}$ | 11.7$^{c}$ | 13.1$^{a}$ | 12.9$^{ab}$ | 0.17 | <0.0001 | <0.0001 | 0.0021 | 0.05 |
| d 35 | 21.1$^{a}$ | 21.6$^{ab}$ | 20.6$^{a}$ | 22.5$^{b}$ | 21.4$^{ab}$ | 0.29 | 0.002 | 0.0080 | 0.0013 | 0.99 |
| ADG, g/d | | | | | | | | | | |
| Phase 2 | 379$^{a}$ | 396$^{a}$ | 326$^{c}$ | 430$^{b}$ | 413$^{ab}$ | 12.1 | <0.0001 | <0.0001 | 0.0020 | 0.0488 |
| Phase 3 | 617$^{a}$ | 642$^{ab}$ | 637$^{ab}$ | 670$^{b}$ | 602$^{a}$ | 14.4 | 0.03 | 0.82 | 0.0186 | 0.1290 |
| Overall | 499$^{ab}$ | 519$^{a}$ | 481$^{b}$ | 549$^{c}$ | 511$^{ab}$ | 10.5 | 0.002 | 0.0081 | 0.0012 | 0.99 |
| ADFI g/d | | | | | | | | | | |
| Phase 2 | 566$^{a}$ | 564$^{a}$ | 563$^{a}$ | 577$^{a}$ | 495$^{b}$ | 18.1 | <0.0001 | 0.1443 | 0.0284 | 0.0534 |
| Phase 3 | 892$^{a}$ | 870$^{a}$ | 923$^{ab}$ | 1000$^{b}$ | 918$^{ab}$ | 30.2 | <0.0001 | 0.0433 | 0.59 | 0.0554 |
| Overall | 729$^{a}$ | 717$^{a}$ | 740$^{ab}$ | 789$^{b}$ | 707$^{a}$ | 17.3 | <0.0001 | 0.28 | 0.1022 | 0.0108 |
| G:F | | | | | | | | | | |
| Phase 2 | 0.67$^{b}$ | 0.70$^{bc}$ | 0.58$^{a}$ | 0.76$^{cd}$ | 0.83$^{d}$ | 0.023 | <0.0001 | <0.0001 | 0.3165 | 0.0014 |
| Phase 3 | 0.70$^{ab}$ | 0.74$^{a}$ | 0.70$^{ab}$ | 0.67$^{a}$ | 0.66$^{a}$ | 0.021 | 0.0815 | 0.0149 | 0.25 | 0.27 |
| Overall | 0.69$^{ab}$ | 0.72$^{a}$ | 0.65$^{b}$ | 0.70$^{a}$ | 0.72$^{a}$ | 0.014 | 0.005 | 0.12 | 0.1098 | 0.0029 |

Means within a row with different superscripts differ ($P < 0.05$).

**Table 3-15.** Nutrient composition of fecal samples (Exp. 2)

| | Control | Wheat | | DDGS | | SEM | P | | | Ingredient vs |
|---|---|---|---|---|---|---|---|---|---|---|
| Enzyme | - | - | + | - | + | | | Ingredient | Enz | Enz |
| Phase 2 | | | | | | | | | | |
| Nitrogen % | 4.85[a] | 4.49[b] | 4.43[b] | 4.18[c] | 4.12[c] | 0.068 | <0.0001 | 0.0001 | 0.3960 | 0.5285 |
| Fat % | 6.33[a] | 6.86[ab] | 6.46[a] | 7.50[bc] | 7.85[c] | 0.293 | 0.0042 | 0.0020 | 0.93 | 0.25 |
| NDF % | 30.8[a] | 31.8[ab] | 32.6[b] | 41.2[c] | 40.1[c] | 0.448 | <0.0001 | <0.0001 | 0.69 | <0.0001 |
| ADF % | 11.9[a] | 14.5[b] | 15.0[bc] | 15.9[c] | 14.8[bc] | 0.398 | <0.0001 | 0.14 | 0.044 | 0.0834 |
| Phosphorus % | 1.60[a] | 1.57[a] | 1.67[a] | 1.00[b] | 1.15[b] | 0.080 | <0.0001 | <0.0001 | 0.12 | <0.0001 |
| GE, kcal/kg | 4273 | 4276 | 4224 | 4451 | 4208 | 118 | 0.62 | 0.51 | 0.22 | 0.48 |
| Phase 3 | | | | | | | | | | |
| Nitrogen % | 4.11[a] | 3.98[b] | 3.93[b] | 3.58[c] | 3.70[c] | 0.0434 | <0.0001 | <0.0001 | 0.48 | 0.0007 |
| Fat % | 8.56[a] | 8.74[a] | 8.78[a] | 7.41[b] | 7.69[b] | 0.238 | 0.0006 | <0.0001 | 0.51 | 0.0201 |
| NDF % | 33.6[a] | 35.1[b] | 36.6[b] | 45.2[c] | 43.8[c] | 0.533 | <0.0001 | <0.0001 | 0.99 | <0.0001 |
| ADF % | 11.7[a] | 14.4[b] | 14.8[b] | 15.9[c] | 16.7[c] | 0.214 | <0.0001 | <0.0001 | 0.82 | 0.0660 |
| Phosphorus % | 1.87[a] | 1.63[b] | 1.64[b] | 1.01[b] | 1.11[b] | 0.051 | <.00001 | <0.0001 | 0.32 | <0.0001 |
| GE, kcal/kg | 4233[2] | 4360[b] | 4383[b] | 4388[b] | 4427[b] | 30.8 | 0.0079 | 0.27 | 0.34 | 0.68 |

Means within a row with different superscripts differ ($P < 0.05$).

**Table 3-16.** Nutrient digestibility of pigs (Exp. 2)

| | Control | Wheat | | DDGS | | | P | | | Ingredient vs |
|---|---|---|---|---|---|---|---|---|---|---|
| Enzyme | - | - | + | - | + | SEM | | Ingredient | Enz | Enz |
| Phase 2 | | | | | | | | | | |
| Nitrogen % | 74.0$^{a}$ | 77.2$^{c}$ | 81.4$^{c}$ | 84.3$^{d}$ | 85.5$^{d}$ | 0.559 | <0.0001 | <0.0001 | <0.0001 | 0.3626 |
| Fat % | 66.4$^{a}$ | 66.1$^{a}$ | 72.9$^{b}$ | 71.9$^{b}$ | 72.4$^{b}$ | 1.31 | 0.001 | 0.0567 | 0.0110 | 0.0533 |
| NDF % | 37.3$^{a}$ | 32.4$^{c}$ | 38.5$^{a}$ | 33.7$^{c}$ | 40.4$^{ab}$ | 1.45 | 0.0036 | 0.28 | 0.0002 | 0.1011 |
| ADF % | 30.1$^{ab}$ | 21.3$^{c}$ | 23.8$^{c}$ | 19.4$^{c}$ | 32.6$^{a}$ | 2.29 | 0.0015 | 0.15 | 0.0022 | 0.0798 |
| Phosphorus % | 58.1$^{a}$ | 53.5$^{a}$ | 58.2$^{a}$ | 70.3$^{b}$ | 66.6$^{b}$ | 2.35 | 0.0002 | <0.0001 | 0.85 | 0.0037 |
| GE % | 83.90$^{a}$ | 82.47$^{a}$ | 84.15$^{a}$ | 78.42$^{b}$ | 79.57$^{b}$ | 0.737 | <0.0001 | <0.0001 | 0.0646 | 0.75 |
| Phase 3 | | | | | | | | | | |
| Nitrogen % | 86.1 | 85.6 | 87.7 | 86.6 | 85.2 | 0.308 | 0.0741 | 0.0246 | 0.17 | 0.0275 |
| Fat % | 71.2$^{abc}$ | 68.8$^{c}$ | 72.7$^{a}$ | 72.3$^{ab}$ | 69.4$^{bc}$ | 1.12 | <0.0001 | 0.92 | 0.67 | 0.0977 |
| NDF % | 53.4$^{a}$ | 49.8$^{b}$ | 53.2$^{a}$ | 46.0$^{c}$ | 51.4$^{ab}$ | 0.726 | <0.0001 | 0.0008 | 0.0001 | 0.0011 |
| ADF % | 49.4$^{a}$ | 38.7$^{c}$ | 46.3$^{b}$ | 40.1$^{c}$ | 46.5$^{b}$ | 0.751 | <0.0001 | 0.30 | <0.0001 | <0.0001 |
| Phosphorus % | 59.8$^{a}$ | 62.4$^{ab}$ | 64.7$^{b}$ | 70.7$^{c}$ | 68.6$^{d}$ | 1.27 | <0.0001 | <0.0001 | 0.95 | 0.0694 |
| GE % | 87.75$^{a}$ | 87.77$^{a}$ | 86.05$^{a}$ | 81.37$^{b}$ | 82.27$^{b}$ | 0.286 | <0.0001 | <0.0001 | 0.18 | 0.0018 |

Means within a row with different superscripts differ ($P < 0.05$).

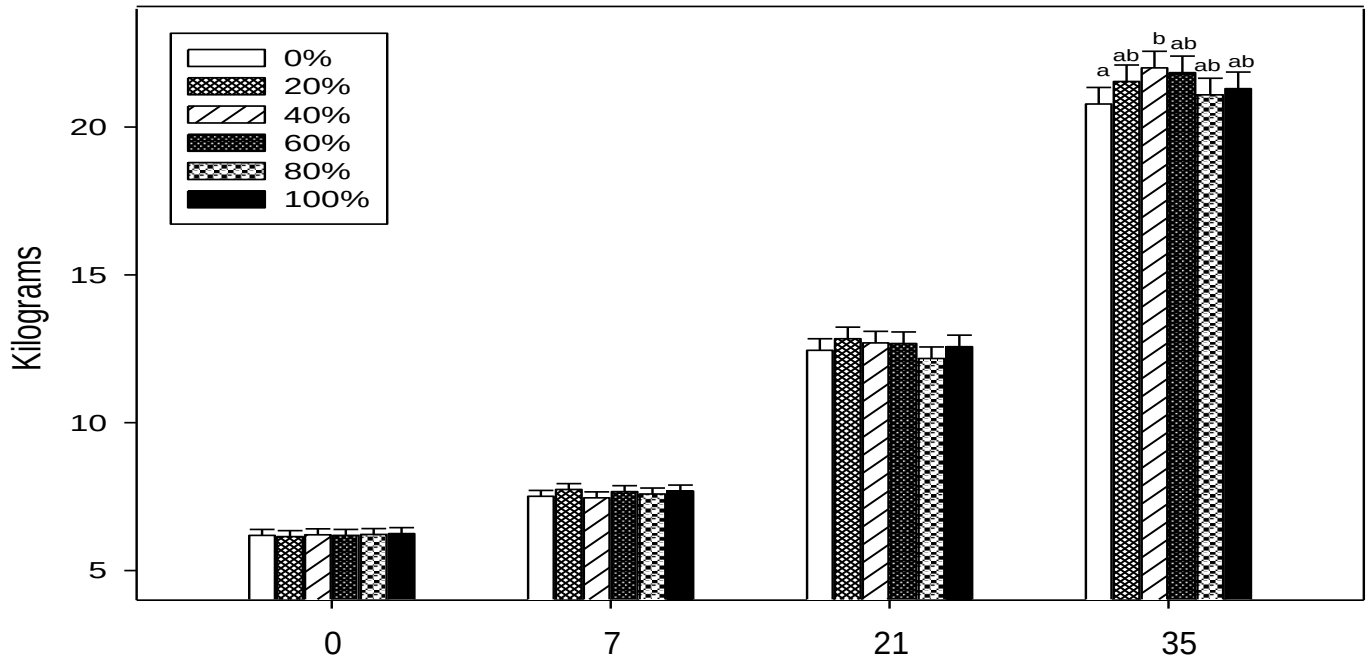


**Figure 3-1.** Exp. 1 body gains at weaning (day 0), the start of phase 2 feeding (day 7), the end of phase 2 feeding, and the start of phase 3 (day 21), and the end of phase 3 and the end of the study (35 day). Error bars are the standard error of means (SEM). Means each age with different superscripts differ ($P < 0.05$).

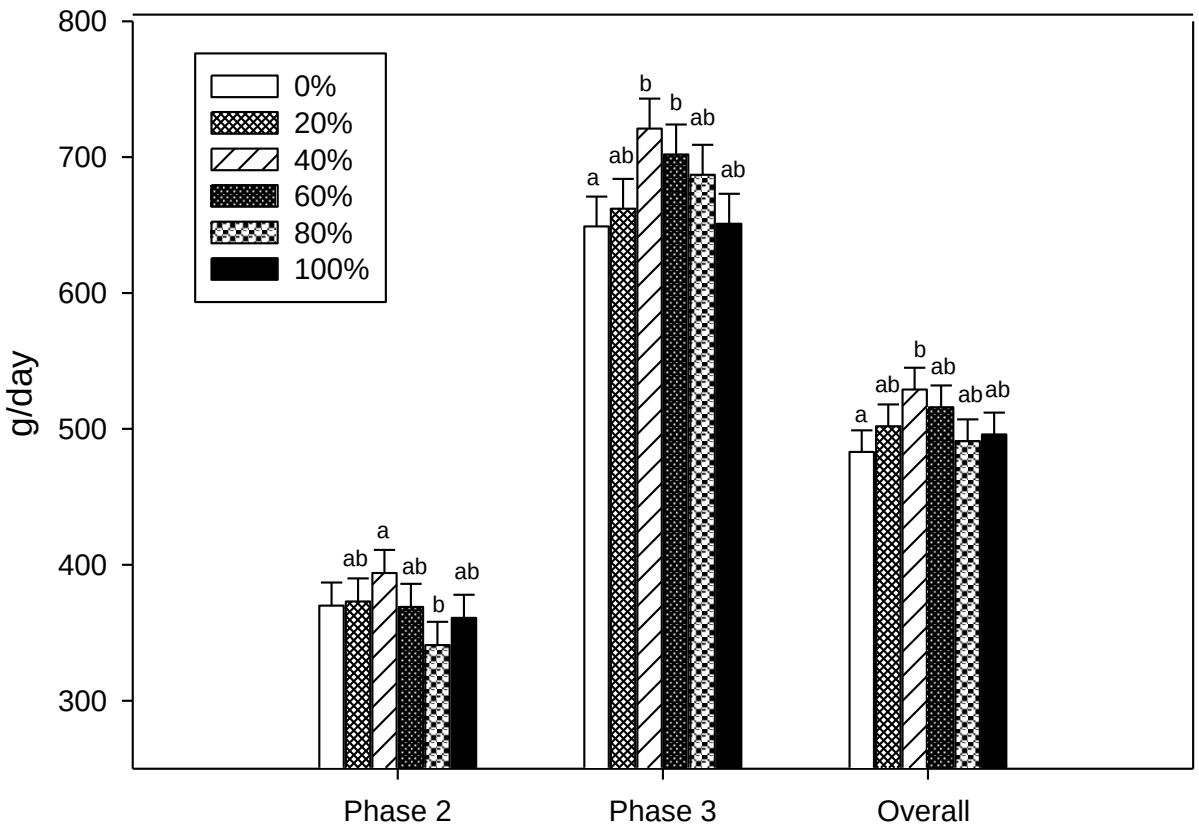


**Figure 3-2**. Exp. 1 average daily gains for phase 2 (7-21 d) and phase 3 (21-35 d) and phase 2 and phase 3 combined (P<0.05). Error bars are the standard error of means (SEM). Means at each phase with different superscripts differ (P < 0.05).

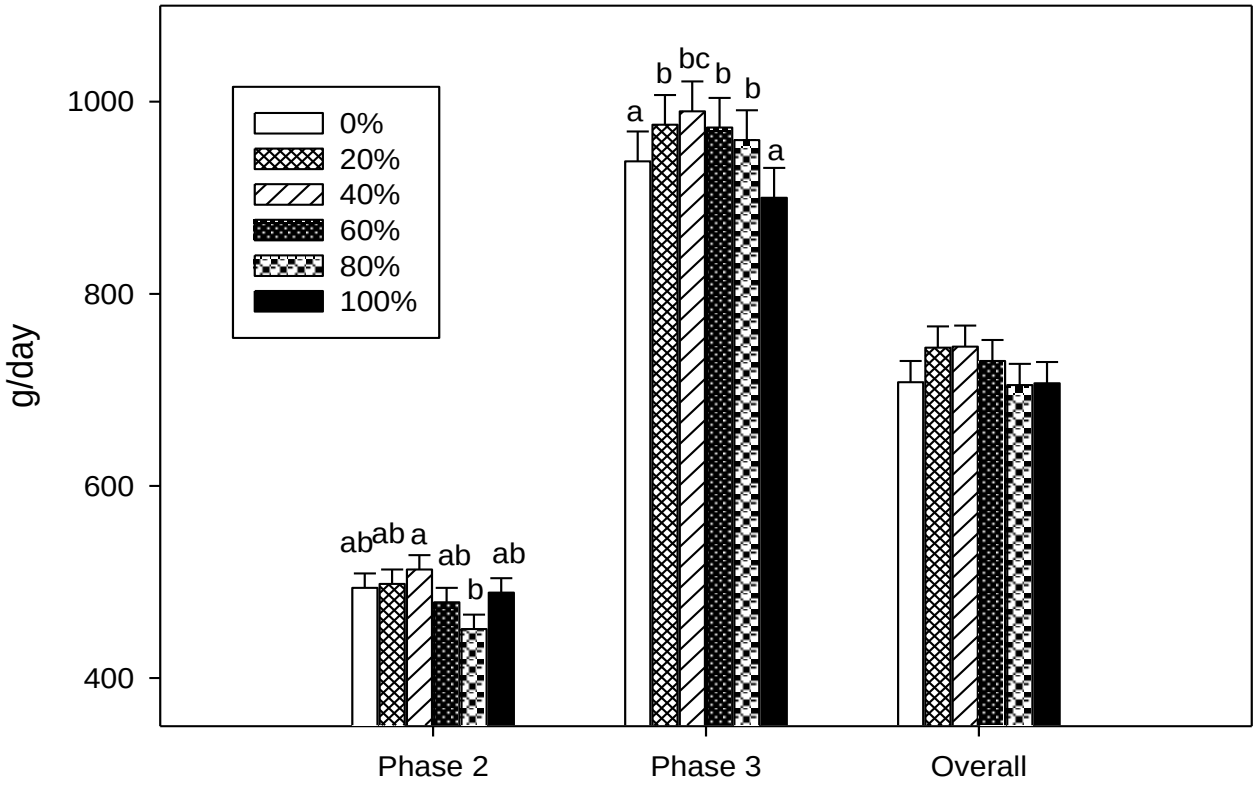


**Figure 3-3**. Average daily feed intake for phase 2 (7-21 d) and phase 3 (21-35 d) and over the test diet period (7-35) ($P<0.05$) Error bars are the standard error of means (SEM). Means at each phase with different superscripts differ ($P < 0.05$).

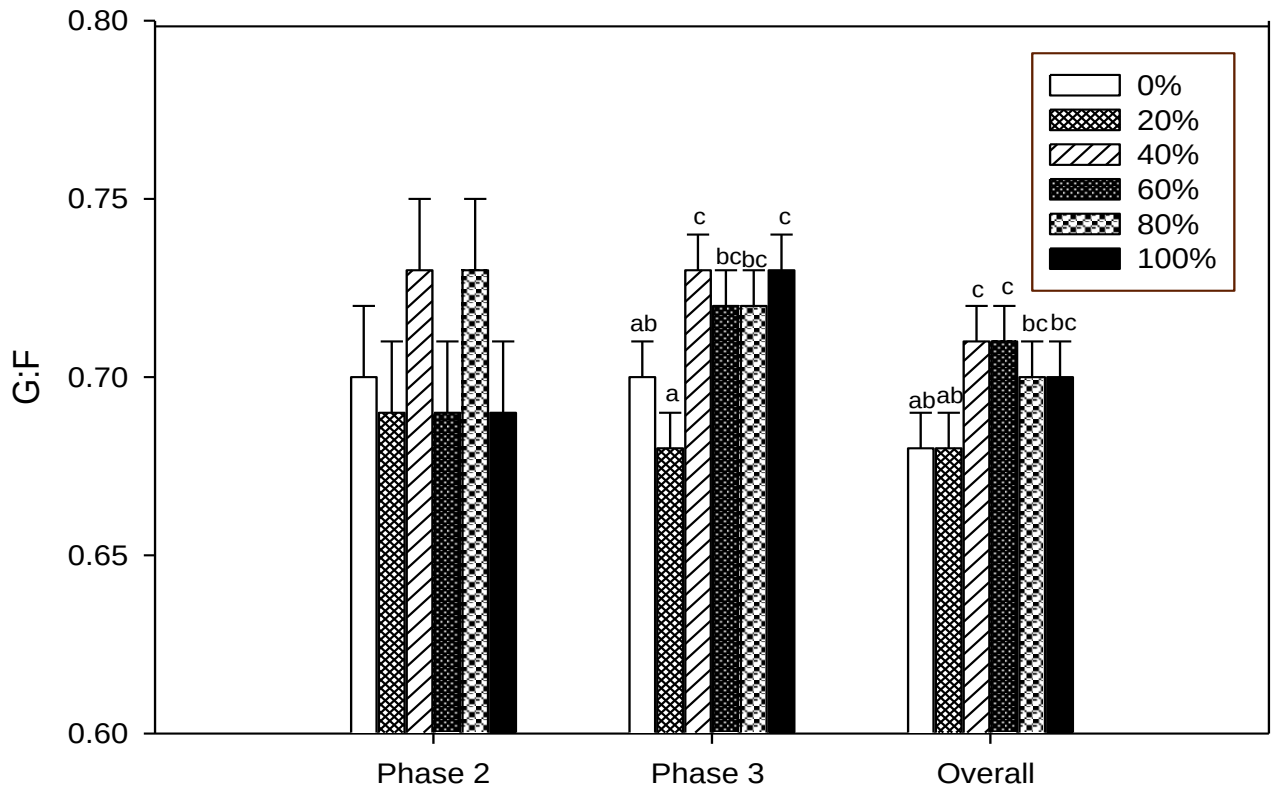


**Figure 3-4**. Exp. 1 Gain: feed for phase 2 (7-21 d) and phase 3 (21-35 d) and over the test diet period (7-35) ($P<0.05$) Error bars are the standard error of means (SEM). Means at each phase with different superscripts differ ($P < 0.05$).

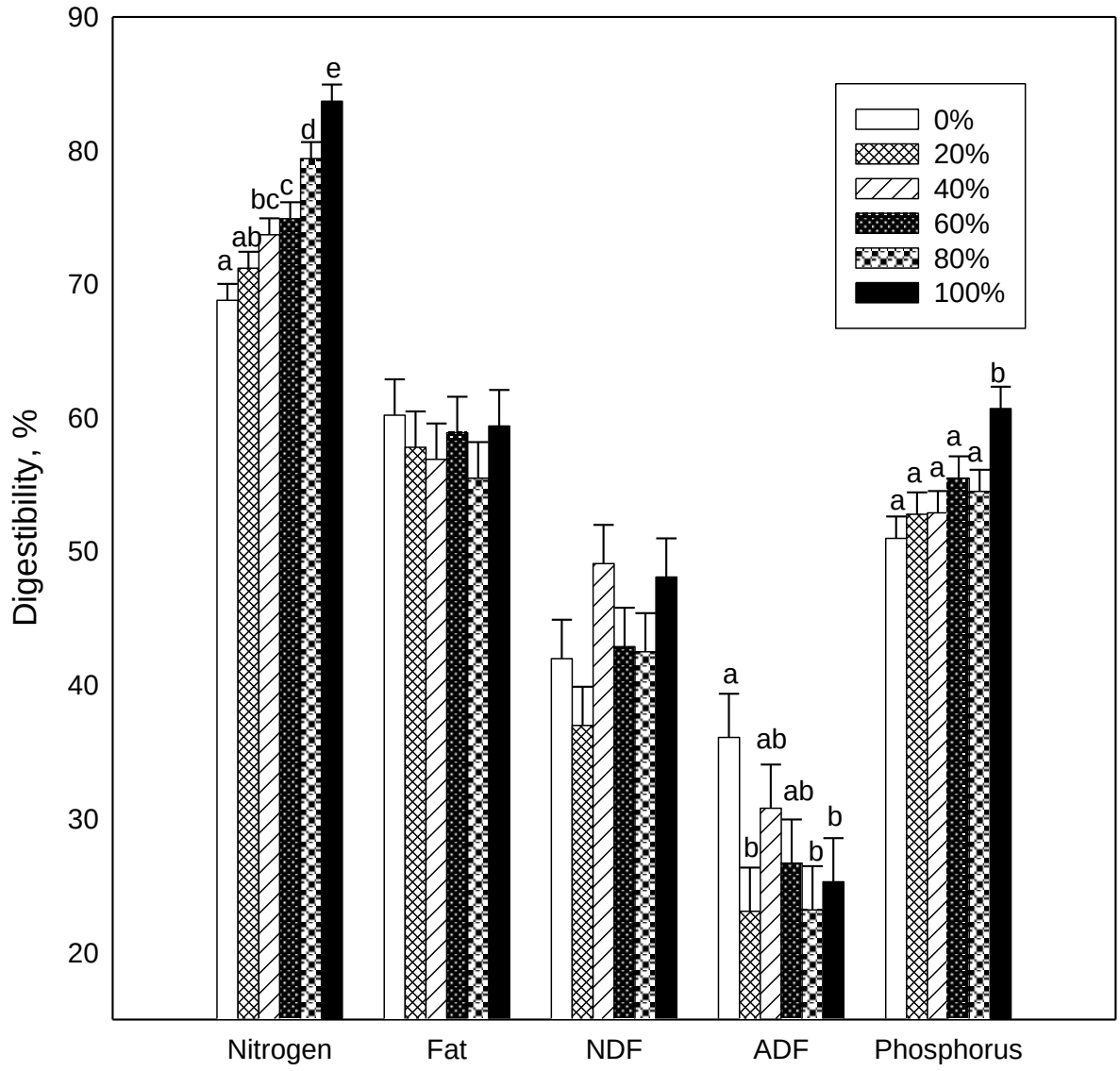


**Figure 3-5**. Digestibilities for exp. 1 were determined for the phase 2 diets between 17-21 days of the experiment. Significance values were determined between nitrogen, fat, NDF, ADF, and phosphorus ($P < 0.05$).

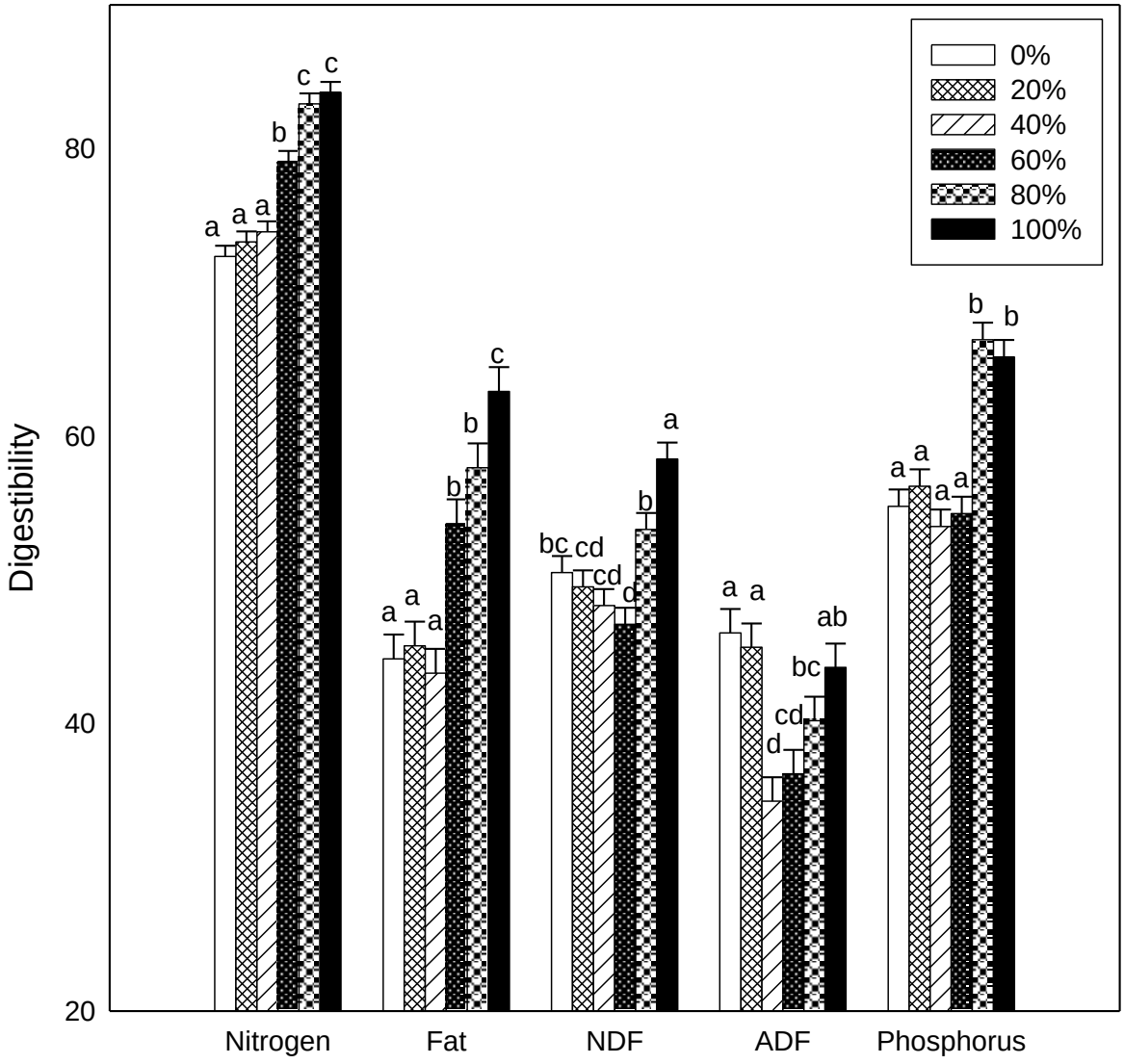


**Figure 3-6**. Digestibilities for exp. 1 were determined for the phase 3 diets between 30-35 days of the experiment. Means within a graph different superscripts differ between nitrogen, fat, NDF, ADF, and phosphorus ($P < 0.05$).

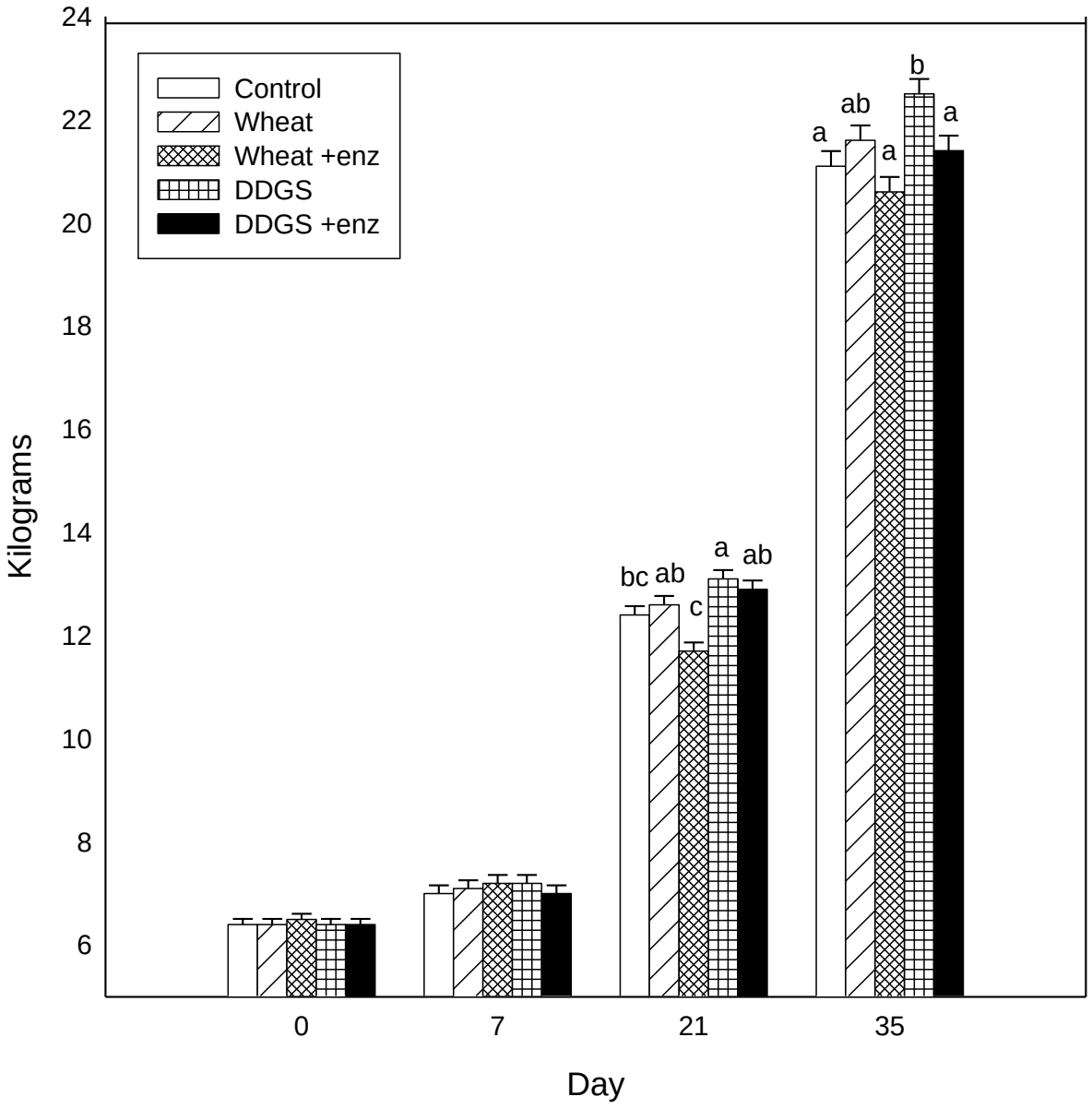


**Figure 3-7**. Exp. 2 body gains at weaning (day 0), the start of phase 2 feeding (day 7), the end of phase 2 feeding, and the start of phase 3 (day 21), and the end of phase 3 and the end of the study (35 day). Error bars are the standard error of means (SEM). Means each age with different superscripts differ ($P < 0.05$).

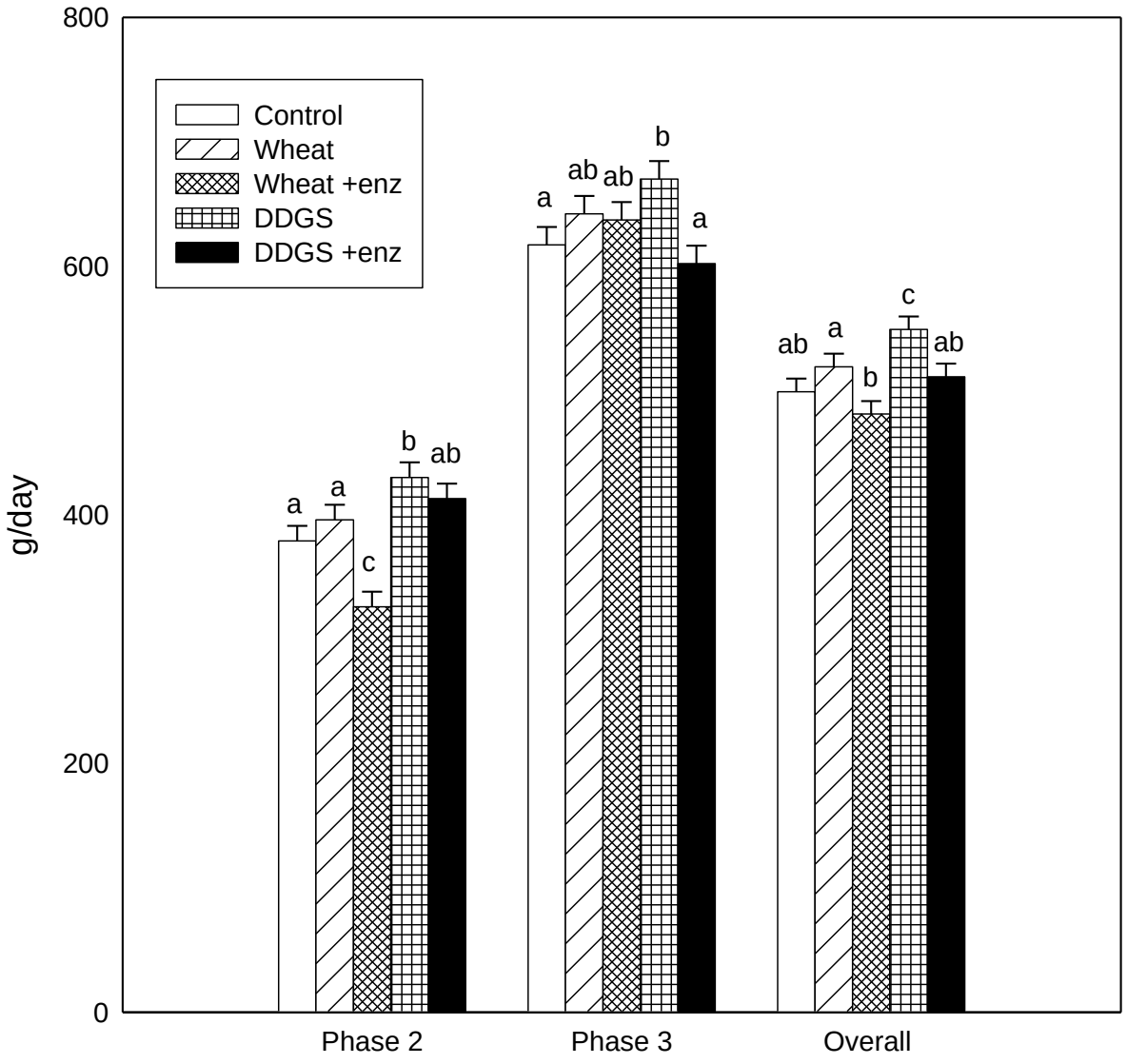


**Figure 3-8.** Exp. 2 average daily gains for phase 2 (7-21 d) and phase 3 (21-35 d) and phase 2 and phase 3 combined. Error bars are the standard error of means (SEM). Means at each phase with different superscripts differ ($P < 0.05$).

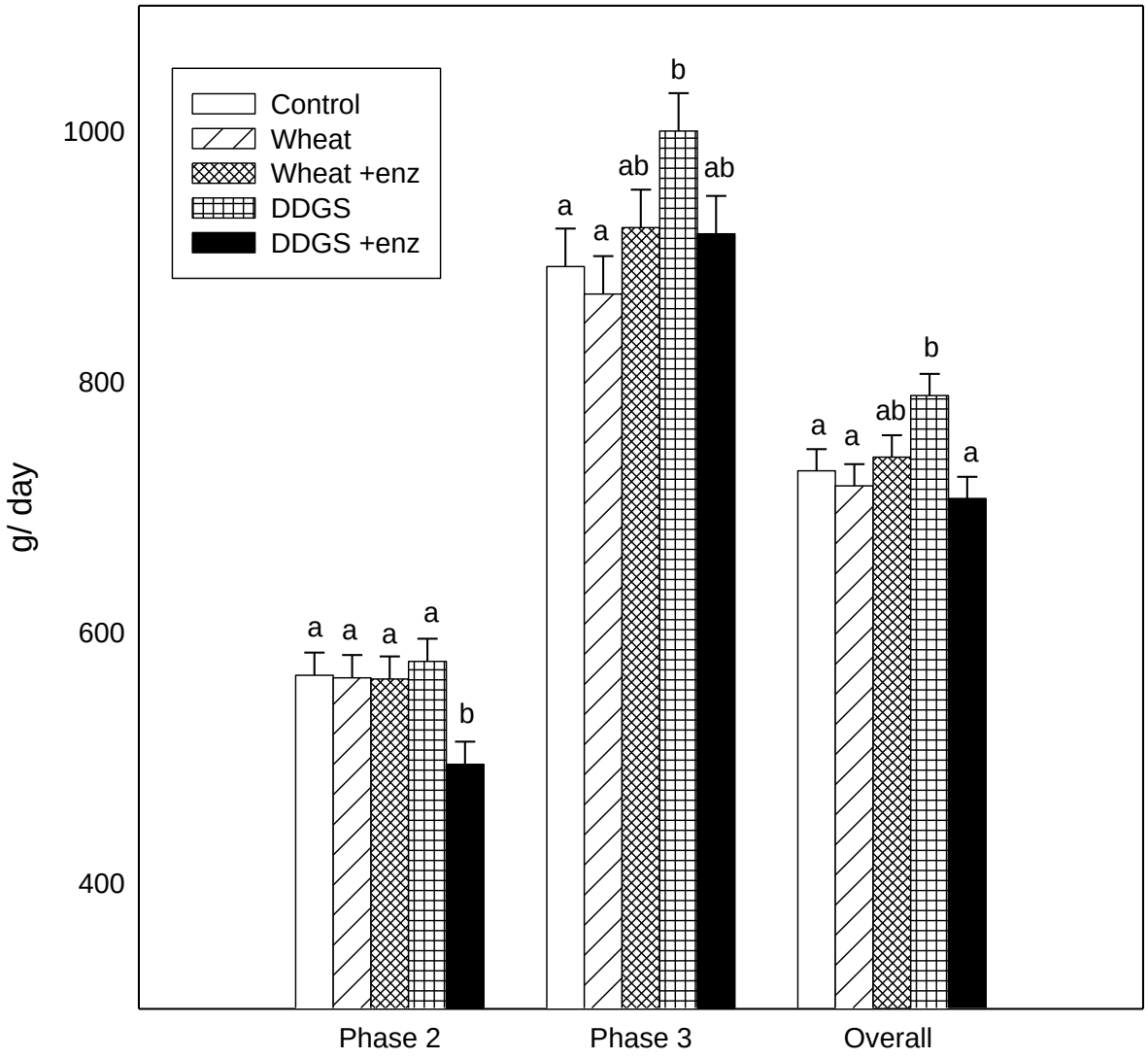


**Figure 3-9.** Average daily feed intake for phase 2 (7-21 d) and phase 3 (21-35 d) and over the test diet period (7-35) ($P<0.05$) Error bars are the standard error of means (SEM). Means at each phase with different superscripts differ ($P < 0.05$).

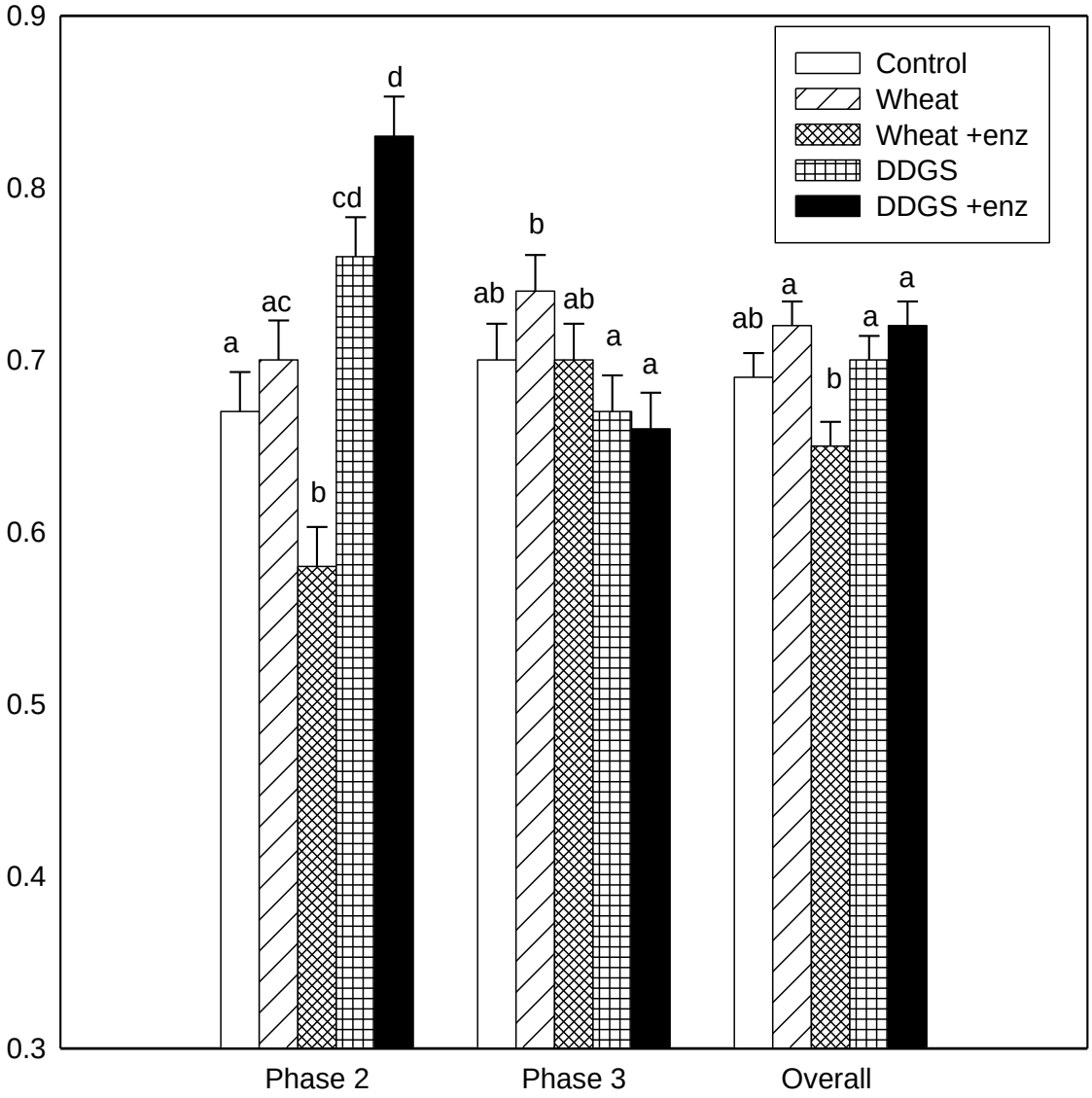


**Figure 3-10.** Exp. 2 Gain: feed for phase 2 (7-21 d) and phase 3 (21-35 d) and over the test diet period (7-35) ($P<0.05$) Error bars are the standard error of means (SEM). Means at each phase with different superscripts differ ($P < 0.05$).

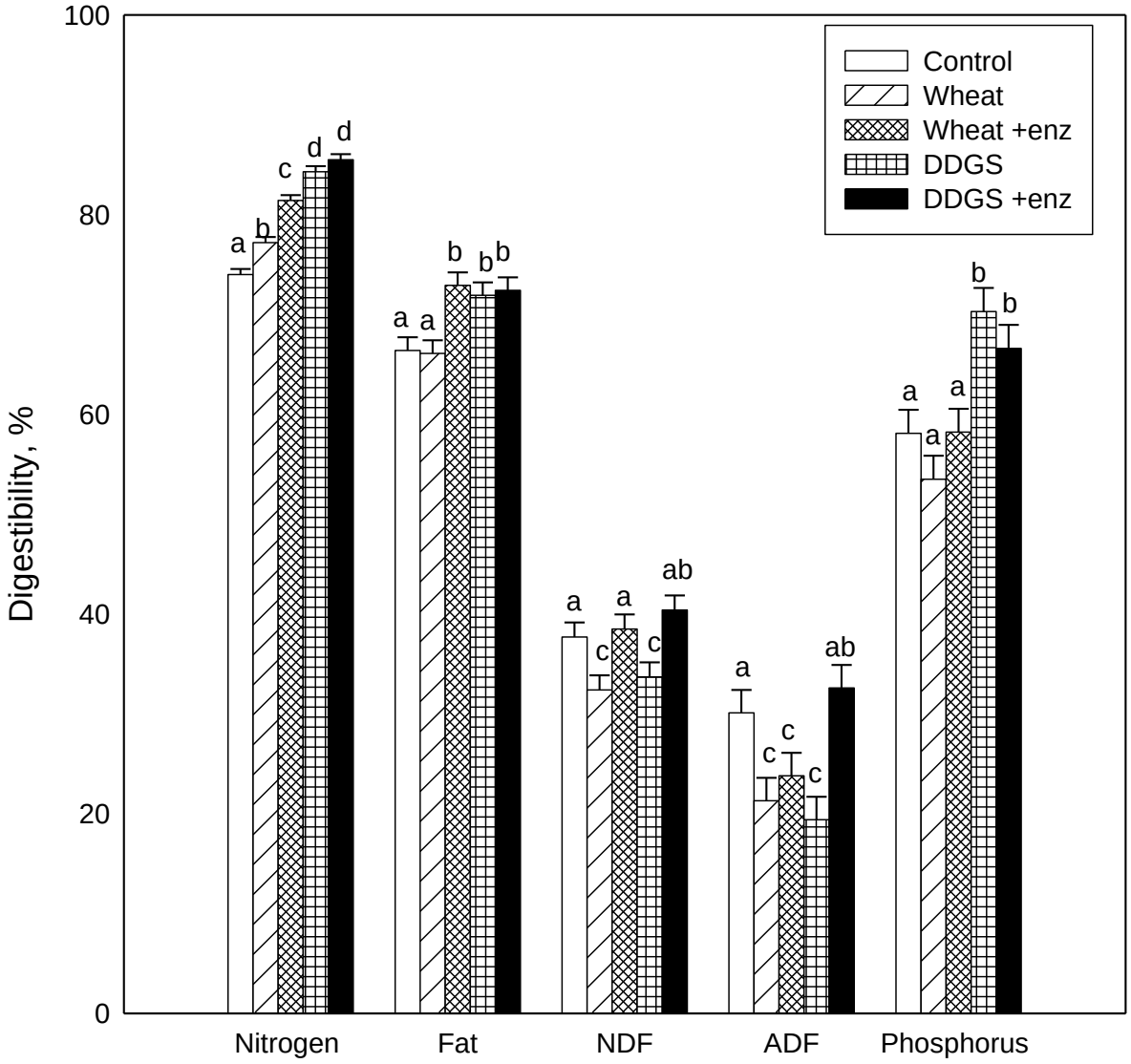


**Figure 3-11.** Digestibilities for exp. 2 were determined for the phase 2 diets between 17-21 days of the experiment. Means within a graph different superscripts differ between nitrogen, fat, NDF, ADF, and phosphorus ($P < 0.05$).

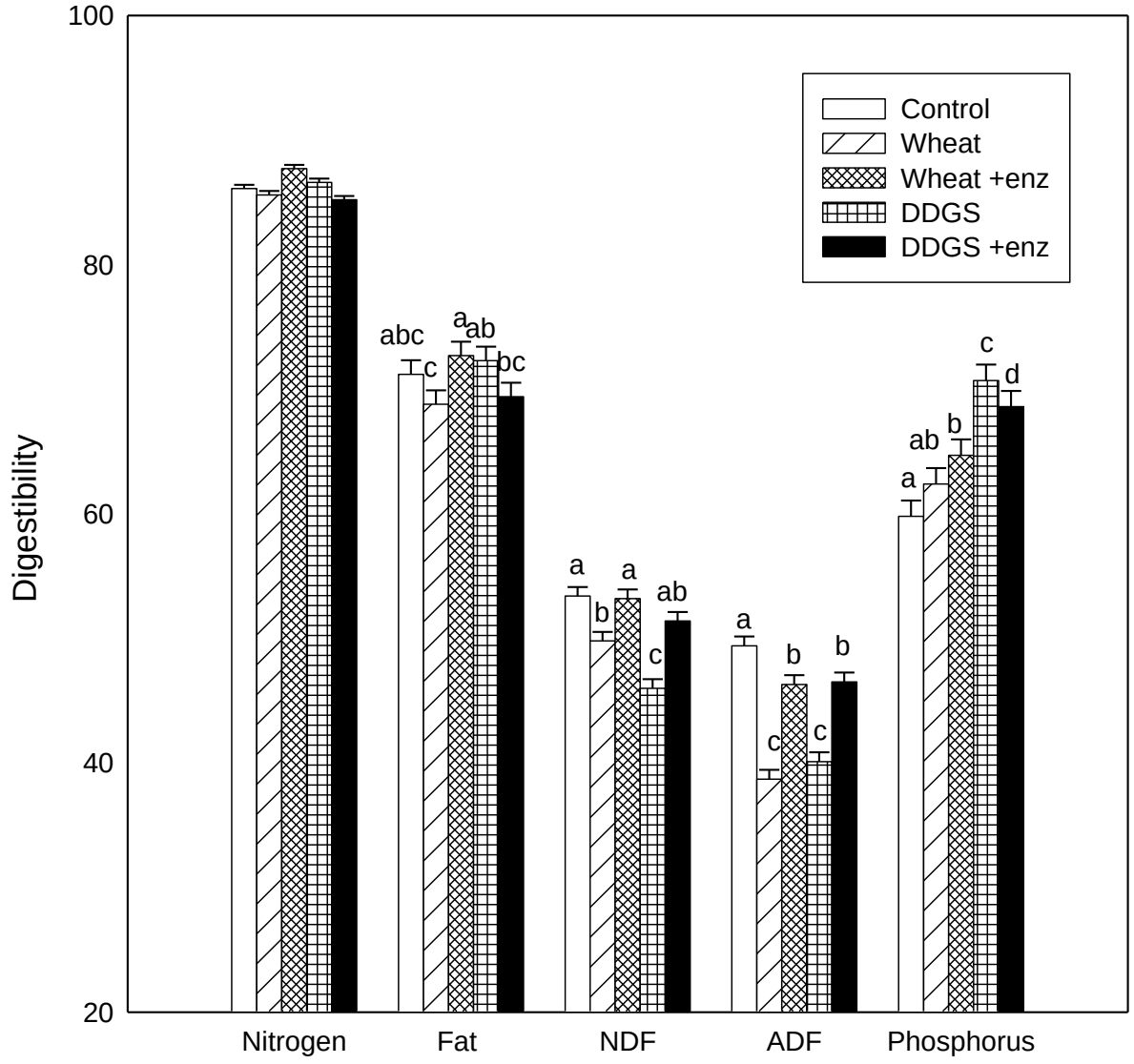


**Figure 3-12.** Digestibilities for exp. 1 were determined for the phase 3 diets between 17-21 days of the experiment. Means within a graph different superscripts differ between nitrogen, fat, NDF, ADF, and phosphorus ($P < 0.05$).

# CHAPTER 4

# CONCLUSIONS

Two experiments were performed to determine how well wheat can substitute corn in nursery diets of pigs. Wheat can be incorporated into nursery phase 2 and 3 diets with no decrease in final body weight. A wheat inclusion of about 40% may be the wheat: corn blend to maximize growth performance. Nitrogen digestibility increases with increasing wheat. This may be due to wheat having higher standardized ileal digestibilities for protein than corn. Phosphorous digestibility is higher in diets with wheat than in diets with corn. Fat digestibility increases with increasing wheat in phase 3, however, this was not seen in phase 2. Gross energy digestibility was not affected by the inclusion of wheat. Including cDDGS did decrease gross energy digestibility in phase 2 and phase 3.

Wheat can also be combined with corn DDGS in a nursery diets to improve growth performance compared to a typically fed corn diet. Adding carbohydrase enzyme to diets containing wheat does not appear to change growth performance. Carbohydrase did increase NDF and ADF digestibility in phase 2 and phase 3 nursery diets. Wheat can replace corn in nursery diets, and be just as cost effective as well, with lower cost of gain when wheat and corn are similar prices per hundredweight.