ABSTRACT

ERCEG, JAKE ANTHONY. Growth Performance, Carcass Traits and Nutrient Digestibility of Low and High Fiber Diet Selection Lines of Pigs Fed either a Low or High Fiber Diet. (Under the direction of Dr. Eric van Heugten.)

The objectives were to determine the impact of high fiber diet and genetic line, developed using either a high or low fiber diet, on growing pig nutrient digestibility, grow-finish pig performance and carcass characteristics. Two experiments used a 2x2 factorial design with genetic line (selected high fiber and selected control lines) and diet (control or fiber) as factors. Pigs were selected for lean growth while consuming fiber or control (low fiber) diets for 3 generations. fiber diets were formulated to include 15% each of DDGS, soybean hulls, and wheat middlings and control diets were corn-soybean meal based. In Exp. 1, barrows (n=175; 45.8 ± 6.5 kg) were used in a 3-phase feeding program, diets were formulated to contain equal SID lysine to net energy ratios between treatments and within phase. Pigs were marketed by two BW blocks, with the heavy block marketed on d 64 and light block on d 78 (BW 118 ±10.8kg). No interactions were detected ($P>0.11$) between diet and genetic line. Genetic line did not impact ADG, ADFI, Gain:Feed, or caloric efficiency (Gain:NE intake), but decreased carcass yield (71.7 vs. 72.6%) . Pigs fed fiber diets had lower ($P<0.05$) ADG for phase 1, 2, and overall, higher ADFI for phase 3 ($P=0.01$), lower Gain:Feed for phase 2, 3, and overall ($P<0.05$) and increased ($P<0.05$) caloric efficiency for phase 1 and 2. Pigs fed fiber diets had reduced ($P<0.05$) HCW (81.4 vs. 88.8, kg), LEA (16.9 vs. 18.2 cm^2), BF (1.66 vs. 1.98 cm), yield (70.8 vs. 73.5%), daily lean gain (0.36 vs. 0.39 kg/d). In Exp. 2, barrows (n=32; 50.4±3 kg) were separated into 2 replicate groups of 16 pigs each, consisting of 4 littermate pairs from each genetic line, for a 14d metabolism study. Diets were formulated to contain equal SID lysine to net energy ratios and were randomly assigned within littermate pair. Pigs had ad libitum access to feed for a 9d adaptation period and were restricted to 90% ad libitum on d 12, 13, and 14 while fecal samples were collected to determine digestibility of ADF, NDF, N, and energy, using titanium dioxide as indigestible marker. Transit time was measured by feeding a color marker (chromic oxide) and recording time until first fecal appearance of marker. Pigs were euthanized on d 14, pH was measured in the ileum, cecum, and colon along with cecum weights. Ileal digesta samples were collected to determine the apparent ileal digestibility (AID) of ADF and NDF. There were no interactions between diet and genetic line ($P>0.05$). Digesta transit time, cecal and colon pH were not impacted by diet. No effects of genetic line on digesta pH or digestibility were observed. High fiber genetic selection tended ($P=0.09$) to increase digesta transit time (1,704 vs. 1,521 ±75.5 min). Pigs fed fiber diets had increased ($P<0.05$) ileal pH (6.61 vs. 6.32), ATTD ADF (56.3 vs. 41.7%) and NDF digestibility (61.0 vs. 41.6%), AID of NDF and had decreased ($P<0.05$) N (77.8 vs. 84.5%) and gross energy (GE) digestibility (78.3 vs. 84.2%). In conclusion, genetic selection for lean gain while feeding high fiber diets did not improve digestibility of fiber, energy utilization of fiber diets or digestive tract characteristics, but increased total transit time. Furthermore, genetic selection did not improve performance or carcass characteristics, regardless of diet type, but did decrease yield. Lack of positive responses may be attributed to the indirect method of selection for lean gain, rather than direct selection for improved energy and nutrient utilization. Selection of pigs for lean gain when fed high fiber diets should be carefully considered because it reduced yield after only 3 generations of selection.

Growth Performance, Carcass Traits and Nutrient Digestibility of Low and High Fiber Diet Selection Lines of Pigs Fed either a Low or High Fiber Diet

by
Jake Anthony Erceg

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Masters of Science

Animal Science

Raleigh, North Carolina

2017

APPROVED BY:

Dr. Eric van Heugten
Chair of Advisory Committee

Dr. Mark Knauer

Dr. Jack Odle

Dr. Miles See

BIOGRAPHY

Jake Anthony Erceg was born on August 28th, 1992 in Ashland, Oregon to John Erceg and Valarie Erceg. Jake developed a passion for agriculture through showing pigs in his local FFA chapter. After high school, he attended his first year of college at Oregon State University focusing on animal sciences. After dedicating his focus on swine, he moved to Kansas and finished a bachelor's degree at Kansas State University. While there, he participated in undergraduate research, summer internships, and collegiate livestock judging. After graduation, Jake began attending North Carolina State University, for a Masters in Animal Science with a focus on swine nutrition. Jake completed two personal research projects, coached the NCSU livestock judging team and volunteered with state level 4H programs. In June of 2016 Jake was married to his wife Nicole Erceg. In the following June, Jake completed his masters of animal science at North Carolina State University.

ACKNOWLEDGMENTS

I would like to acknowledge my advisor Dr. Eric van Heugten. Not only has he been an extremely understanding, supporting and encouraging advisor, he has become a lifelong friend and mentor. I have greatly enjoyed our long talks and philosophical conversation that stimulated many ideas and questions throughout my graduate program. I would also like to thank Dr. Mark Knuaer for all his help, guidance and direction with my research trials as well as my graduate program. If I had a second advisor it would be Dr. Knauer. I would also like to thank Dr. Todd See and Dr. Jack Odle for serving as my committee members. Dr. Odle you have been a great instructor and resource for any questions I have had. Dr. See, thank you for being the ultimate guide and taking the time to personally invest yourself in my success.

I would like to thank the staff the swine research and education unit for all of their help and assistance with research projects. You were all there in times of need and went out of your own way to make these research projects possible. Thank you for all of your help.

I would further like to thank my cohort of graduate students that helped with projects in the early hours of the morning and late hours of the evening. Jeff Weigert, Garrett See, Roel Becerra, Kory Moran and Petra Chang. You all have supported me through this process and gave your time to contribute to my success.

Finally, I would like to thank my wife Nicole Erceg. Without your love and support I would not be the man that I am today. Thank you for everything.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER II

CHAPTER III

LIST OF FIGURES

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER I: Review of Literature

Introduction

Feed costs are the largest production cost, up to 70%, associated with modern pork production (Niemi et al., 2010). Traditionally, corn and soybean meal (SBM) are the most common ingredients used in modern U.S. swine diets. Corn constitutes the main energy source providing mostly dietary starch and fat (NRC 2012). Corn, however, is relatively low in fat and crude protein and lacks sufficient amounts of essential amino acids, including lysine, the first limiting amino acid in swine diets (Easter and Baker 1980). To correct for this, SBM is added into diets to increase and balance amino acid profiles and total amino acid concentrations (NRC 2012). However, due to recent increases in ethanol production and increased demand for corn and SBM based products, the cost of these dietary ingredients has greatly increased (Tyner and Taheripour 2007). Thus, large recent increases in feed costs have driven the use of alternative feed ingredients that may lower diet costs (Schmit et al., 2009). Furthermore, inclusion of feedstuffs such as corn dried distiller grains with solubles (DDGS), wheat middlings, and soybean hulls have shown to be cost competitive when fed to growing-finishing pigs (Woyengo et al., 2014)

Often, alternative feed ingredients are byproducts of ethanol or other food manufacturing industries. For example, DDGS, a byproduct of corn ethanol production, corn starch from the endosperm is converted enzymatically to sugars to be subsequently fermented into ethanol (Ye Sung and Cheng 2002). Furthermore, post-ethanol processing, DDGS have a changed nutrient profile compared to corn having increased fiber, protein, and P content, and have lower concentrations of starch (Srinivasan et al., 2005). Similarly, soybean hulls, a byproduct of soy oil production, are high in fiber content and serve as a viable feed ingredient with a changed nutrient profile from soybeans (Hsu et al., 1987). Wheat middlings, a byproduct of flour production, are a high fiber ingredient commonly included in swine diets to decrease diets costs (Woyengo et al., 2014), Due to larger dietary inclusions of fibrous byproducts in pig diets, a deeper understanding of fiber and its role in swine diets is needed.

Fiber

Dietary fiber is the sum of all plant derived carbohydrates that are indigestible to digestive enzymes in the gastrointestinal tract of mammalians (Gutierrez et al., 2014). This may include but is not limited to fructans, β-glucans, pectin, hemicellulose, cellulose, and lignin. The carbohydrates in plants are divided into two categories based on the location of those carbohydrates, the cell contents and the cell wall. Sub-categories are then proposed to show what classification each component is divided into. In the instance of fiber, cell wall components are the focus in defining fiber. Below (Figure 1) are common classifications used for fiber based on the assay used to measure that specific component of the cell wall (NRC 2012).

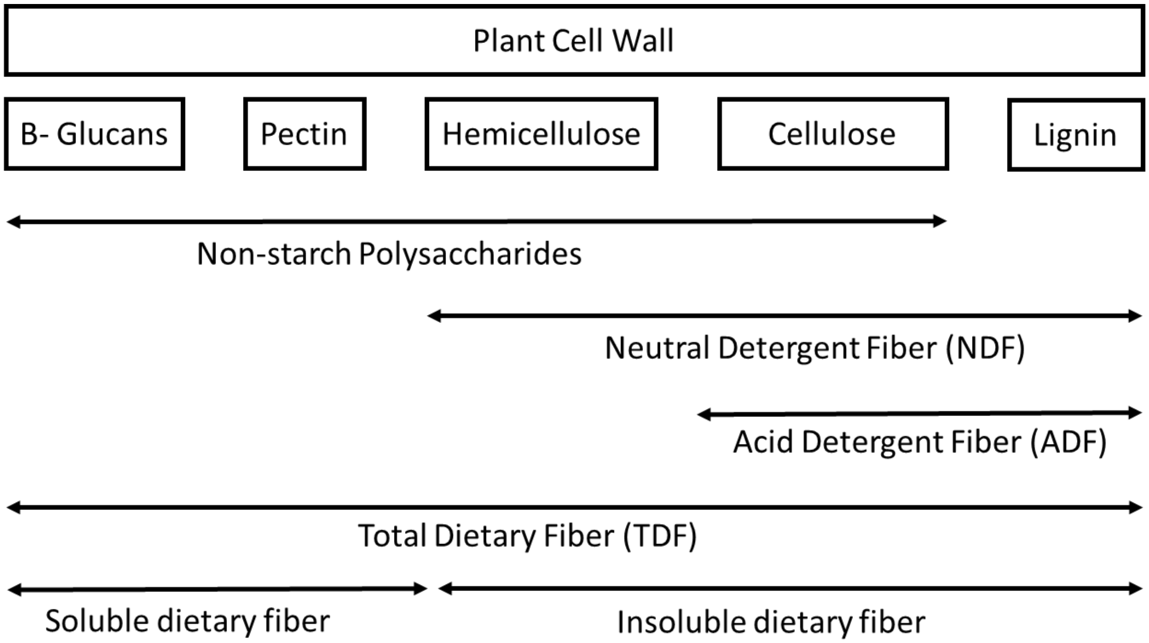

Figure 1. Classification of dietary fiber. Adapted from NRC (2012).

Non-starch polysaccharides (NSP) account for total polysaccharide content with the exception of starch (alpha linked glucans). Furthermore, NSP encompasses beta linked glucans, pectin and gums, hemicellulose, and cellulose while excluding lignin (Choct, 1997). In the case of starch, polysaccharides are formed through glycosidic bonds in α 1,4 or α 1,6 formation. However, in the case of an NSP, like cellulose, these bonds are formed in β conformation and, thus, cannot be broken using normal starch hydrolyzing enzymes, such as amylase (Englyst et al., 1982).

Soluble dietary fiber can contain pectins, β-glucans, gum and hemicelluloses while insoluble fiber contains cellulose and lignin (Davidson and Mcdonald 1998). Furthermore, soluble dietary fiber can also be calculated from the difference of total dietary fiber (TDF) and insoluble fiber (Van Soest et al., 1991).

Total dietary fiber accounts for all dietary fiber components that cannot be digested by mammalian enzymes. However, this definition may be unfitting for ruminant animals, but for swine, plant cell walls cannot be digested enzymatically (Mertens 2003). Further measurement methods to define fiber content are neutral detergent fiber (NDF), which is an estimate of the cell wall contents within a fiber source, including cellulose, hemicellulose and lignin (Rayburn 1997) and acid detergent fiber (ADF), which estimates the level of cellulose and lignin in a feedstuff (Van Soest et al., 1991). The difference between ADF and NDF can be used to calculate the amount of hemicellulose within a fibrous feedstuff (Bach Knudsen 2001).

	Wheat Midds[1,2]	Corn DDGS[2]	Soybean Hulls[3,4]
β-glucans	21	63	--
Cellulose	67	58	336
Lignin[4]	39	32	13
Total NSP	250	192	574
NDF[2]	283	271	486
ADF[2]	92	94	354
TDF	289	322	592
Soluble	12	34	47
Insoluble	227	158	545

[1] Jaworski et al., 2015
[2] De Jong et al., 2014
[3] Jaworski et al., 2017
[4] Mitaru et al., 1984

Figure 2. Fiber composition of wheat midds, corn DDGS and soybean hulls (g/kg DM)

Fiber Types in Swine Diets

Glucans are glycosidic linked polymers of the simple sugar molecule glucose. In swine diets, α-linked glucose polymers (starch) are the most common energy source and are digested in the small intestine of swine by enzymes such as pancreatic amylase (Giuberti et al., 2012).

However, β-glucans are glucose polymers linked through β-linkages (Synytsya and Novak 2014) and cannot be hydrolyzed by mammalian enzymes. In swine diets, Knudsen (1993) showed that β-glucans increased in concentration from the stomach to the ileum in samples of pig digesta and decreased when transitioning from the ileum (200 g/kg DM) to the cecum (40 g/kg DM). This suggests that most β-glucan digestion occurred in the cecum. Furthermore, NSP concentrations showed a similar trend, with high concentrations in the ileum (250 g/kg DM) and decreased concentrations in the cecum (80 g/kg DM) (Knudsen et al., 1993). Further studies have confirmed these results, suggesting that β-glucans are almost exclusively digested (>95%) pre-colon. However, some disappearance of β-glucans is observed at the ileal stage. Knudsen (2015) showed that slower digesting carbohydrates such as lactose, can significantly decrease the ileal digestibility of β-glucans, without affecting the total disappearance of β-glucans in the cecum (Knudsen, 2015).

Keys and Debarthe (1974) found that approximately 100% of cellulose disappearance occurs post ileum. Pigs fed varying levels of cell walls and cellulose had negative digestibility coefficients at the terminal ileum, but apparent total tract digestibility coefficients were 31.98 and 37.88 for cell walls and cellulose, respectively, alluding to much of cell wall and cellulose disappearance occurring in the large intestine (Keys et al., 1974). When pig fecal slurries were used for in-vitro fermentation of cellulose, in comparison with other fiber types (beet pulp, citrus pulp, and citrus pectin), cellulose was the least fermentable (Sunvold et al., 2014). Furthermore, cellulose fermentation was greatest (0.03 vs 0.17 mmol/g acetate production) from 24 to 48 h period (vs. 0-6, 6-12, 12-24). Finally, cellulose contributed to acetate production the most over the 48-h period (0.17 mmol/g), followed by propionate (0.10 mmol/g) and butyrate (0.02 mmol/g), respectively. Total short chain fatty acid production over the 48-h period was 0.29 mmol/g (Sunvold et al., 2014).

Hemicellulose digestibility in diets containing 20% or 40% orchard grass pellets was decreased as orchard grass pellets increased in diets. Furthermore, hemicellulose was more digestible than cellulose in both rats and pigs (Keys et al., 1969). Approximately 80% of hemicellulose digestion takes place post terminal ileum (Keys et al., 1974).

Pectin, a methylated hydrophilic non-starch polysaccharide present in cell walls, can occur in swine diets through direct inclusion or indirectly through fibrous byproducts such as citrus pulp, beet pulp and common grains such as rye, or legumes (Drochner et al., 2004). Pectin has been shown to decrease passage time through increasing digesta viscosity (Shah et al., 1983). Furthermore, dietary pectin decreased pancreatic α-amylase secretion in pigs fed 7.5% dietary citrus pectin. Adding increasing levels of pectin (0 to 12%) linearly decreased apparent ileal digestibility of threonine and lysine and decreased threonine and lysine deposition in whole body protein of growing pigs (Zhu et al., 2005). Overall pectin can greatly contribute to decreases in nutrient digestibility and protein deposition in growing pigs.

Lignin is a polyphenol major structural component of plant cell walls. To increase structural integrity, lignin forms cross linking between chains of polysaccharides. Cross linking is accomplished by formation of a covalent bond formed between two polysaccharide chains that increases structural strength by providing stability and rigidity to the lignin complex (Hatfield et al., 1999). As plants mature, lignin becomes more prominent and will increase in concentration (Grabber, 2005). When included in swine diets, increasing dietary lignin (0.60, 1.33, 2.06 % of DM) decreased overall DM digestibility and crude protein digestibility ((Keys et al., 1969)). Thus, if dietary fiber is increased, lignin will also increase resulting in similar effects on digestibility of increasing overall dietary fiber or dietary lignin.

Sources of Dietary Fiber

The use of biomass for alternative fuel production, such as ethanol, has more than tripled (129 trillion btu's to 429 trillion btu's) from 1973 to 2016 (US Energy Information Administration). Thus, increased alternative fuel production from grains has led to increases in feedstuff byproducts, resulting from ethanol production. Similarly, increases in ethanol, flour, and soy oil production have led to increases in availability of byproduct feedstuffs and their dietary inclusion levels, mainly to decrease overall diet costs. Dried distiller's grains with solubles (DDGS), wheat middlings (Midds), and soybean hulls are three of the most common byproducts included in swine diets All three ingredients are high in dietary fiber (Shriver et al., 2003, De Jong et al., 2014).

Corn dried distiller's grains with solubles (DDGS) are a high crude fiber (CF) co-product (> 7% CF) of ethanol production (De Jon et al., 2014). Maximum dietary inclusion level of DDGS varies by stage of growth and animal lifecycle (Stein and Shurson, 2009). In growing-finishing diets formulated to equal Lys:ME, pigs fed up to 30% DDGS did not show reductions in growth performance (Cook et al., 2005). However, in other studies inclusion of 30% DDGS has shown to reduce feed efficiency compared to control diets containing no DDGS (Gaines et al., 2007, Xu et al., 2007). In addition, DDGS have shown to increase carcass iodine value. Iodine value is closely associated with carcass quality and a predictor of belly and loin firmness. In finishing pigs fed diets containing 40 or 50% DDGS, iodine value and concentrations of total unsaturated fatty acids were increased (Dahlen et al., 2011). However, removing DDGS from diets 2 weeks prior to slaughter can mitigate the negative effects of DDGS on carcass softness. Diets containing 30% DDGS have been shown to decrease apparent ileal digestibility (AID) of lysine and increase AID of acid detergent fiber (ADF)(Urriola and Stein 2010). Overall, including DDGS in grower-finisher diets at 30% or less can decrease diet costs while keeping performance reductions to a minimum.

Wheat midds are a common byproduct of the flour milling industry. Wheat midds contain wheat bran, wheat shorts, wheat germ, wheat flour, and a small percentage of offal from the milling process (Blasi et al., 1998). Wheat midds, similar to DDGS, contain >7% CF on a DM basis. Adding increasing levels (0 to 20%) of wheat midds in diets formulated to an equal Lys:ME ratio that were not isocaloric to grower-finisher pig has been shown to decrease gain:feed (G:F), ADG, carcass yield, and loin depth while having no effects on iodine value (Salyer et al., 2012). Similar results regarding ADG were observed by Shaw (2002), who reported that finishing pigs (28 to 65 kg) had decreased ADG when fed increasing levels of dietary wheat midds (5, 15, and 30%). However, in the same study, no effects of wheat midds on feed efficiency, feed intake, or carcass traits were observed between dietary treatments (Shaw et al., 2002). Similarly, Feoli et al. (2006) reported that finishing pigs fed isonitrogenous diets containing wheat midds (0, 15, 30 %) had decreased ADG, feed efficiency and hot carcass weight. Performance decreases can be explained by the decrease in metabolizable energy when corn is replaced by wheat midds in swine diets (De Jong et al., 2014). However, pigs fed isocaloric and isonitrogenous diets containing wheat midds (0 or 19%) still had decreased ADG, feed efficiency, final BW, and HCW (Asmus et al., 2012). Diets that are both isocaloric and isonitrogenous (meeting the SID amino acid requirements) would be expected to have similar G:F. Differences could be related to variation in the quality of wheat midds or values of ME or SID amino acid concentrations that are overestimated. . Overall, increasing dietary wheat midds has shown to decrease growth performance and promote poorer carcass traits.

Soybean hulls are a byproduct of the extraction of oil from soybeans. The hulls are retrieved from the cracked soybeans and removed before oil is extracted from the bean. Soybean hulls contain a high crude fiber concentration at 36%. Including 30% soybean hulls in the diet of growing pigs has been shown to reduce apparent total tract digestibility of energy and crude protein, ADG and GF, as well as decreasing carcass dressing percent (Stewart et al., 2013). In another study, growing pigs were fed high fiber diets (20% soybean hulls, 25% DDGS), medium fiber diets (25% DDGS) and control diet. Apparent ileal digestibility of crude protein and starch was greater in control diets than diets containing fiber, but no differences were observed between medium and high fiber diets (Rojas et al. 2016). In the same study, apparent total tract digestibility of gross energy, starch and dry matter were highest in control diets, but were greater in medium fiber diets (without soybean hulls) than in high fiber diets (20% soybean hulls). Thus, soybean hulls had no effect on ileal digestibility of crude protein and starch, while soybean hulls decreased apparent total tract digestibility of gross energy, starch, and dry matter (Rojas et al., 2016).

Unlike wheat midds, soybean hulls showed no impact on finishing pig ADG, ADFI or G:F when included in the diet at 20% (Schertz et al., 2016). Furthermore, adding 10% soybean hulls to finishing pig diets had no impact on ADG, feed efficiency, carcass back fat (BF) or carcass loin eye area (LEA) (Shriver et al., 2003). However, when growing pigs were fed diets containing 30% soybean hulls decreased ADG and feed efficiency was observed compared to pigs fed a control diet (Stewart et al., 2014). In the same study, during the finishing phase, pigs fed soybean hulls at 30% had similar performance than pigs fed control diets. Overall, soybean hulls have been shown to negatively impact grower pig performance, but have little effect on finishing pig performance.

Digestibility of Dietary Fiber

Fiber digestibility is widely variable depending on the source, type and measurement of fiber. Overall, digestibility of dietary fiber has been shown to increase with size and age of the pig. For example, Noblet et al. (2004) showed that sows had increased NSP digestibility (wheat bran NSP: 46 vs 54%, Corn Bran NSP: 38 vs 82%, growing pigs and sows respectively) when compared to growing pigs when fed diets containing wheat bran or corn bran.

Interactions between specific dietary nutrients and fiber have been shown to be variable. Feeding swine increased levels of dietary fiber or plant cell walls has been shown to decrease dry matter digestibility (Cunningham et al., 1962). When pigs consumed diets containing orchard grass hay at 20, 40, or 60%, total tract digestibility of dry matter was decreased (Keys et al., 1969). Similar results were observed by Guiterrez et al. (2013), who reported that as dietary fiber increased, total tract and ileal digestibility of dry matter decreased. When orchard grass levels increased from 20 to 60% of the diet, apparent total tract digestibility of crude protein significantly decreased (Keys et al., 1969). Similar results were reported more recently by Urriola and Stein (2010) for pigs consuming diets containing either 0 or 30% corn DDGS. While apparent ileal digestibility of crude protein was not significantly different, apparent ileal digestibility of leucine, lysine, and aspartate decreased with increasing levels of DDGS in the diet (Urriola and Stein 2010). In pigs fed increasing levels of insoluble corn fiber (0, 10, 20, 30, 40%), apparent total tract digestibility of dry matter, crude protein, and gross energy decreased linearly (Gutierrez et al., 2013). Ileal digestibility of histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, aspartate, glutamate, and tyrosine decreased linearly with increasing dietary fiber (Gutierrez et al., 2013). This negative correlation between increased dietary fiber and decreased apparent total tract digestibility of protein is also confirmed by Le Goff and Noblet (2001). A compilation of 16 digestibility trials along with 77 different diets, showed that as dietary fiber increased, total tract digestibility of crude protein decreased (Le Goff and Noblet 2001).

Increasing dietary fiber in swine diets decreased apparent total tract digestibility of gross energy (Rojas et al., 2016, Renteria-Flores et al., 2015, Anguita et al., 2014). Anguita et al. (2014) showed that increasing dietary fiber increased energy digestibility in the hindgut (defined as post-ileum), however apparent total tract energy digestibility was decreased for high fiber diets compared to diets that contained lower levels of fiber. The contribution of short chain fatty acids to energy digestibility increased as dietary fiber increased both in vivo and in vitro fermentation vats using pig feces as a medium (Anguita et al., 2014). Similarly, in diets containing increasing amounts of wheat bran, pigs had decreased ileal energy digestibility and increased hindgut energy digestibility (Iyayi and Adeola, 2015). Furthermore, in the same study, the energy produced from short chain volatile fatty acids in the hindgut increased with dietary wheat bran level. Overall, energy from hindgut fermentation accounted for 10.7 to 24.2% of total digestible energy that was available to the pig (Iyayi and Adeola, 2015). These results are similar to those reported by Shi and Noblet (1993), where pigs derived 17 to 25% of dietary digestible energy from hindgut fermentation.

Genetic Selection

Genetic selection of pigs has been used to improve reproductive performance, growth performance and carcass characteristics (Chen et al., 2002, Schwab et al., 2010, Hsu and Johnson 2014). Reproductive efficiency has been a large focus area for genetic selection and management improvement for many years. Selection for litter size is a prominent example. Increasing litter size or number of pigs born alive has been a selection goal over the past few decades (Kim et al., 1999). Genetic parameters for selection are established through population baselines. Once established, these parameters can be used for future selection. Examples of reproductive parameters include sow feed intake, body weight loss, and litter weight gain (Thekkoot et al., 2016). There is a strong negative correlation between sow body condition during gestation with sow feed intake during lactation. Overfeeding in gestation can cause decreased sow feed intake in lactation, decreasing overall litter gain. While heritability remains low, and management is the primary focus in controlling sow body weight loss, selection traits such as this can be used to improve sow reproductive efficiency (Bergsma et al., 2008).

Genetic selection for carcass traits has been widely used to improve meat quality. Selecting for intramuscular fat (IMF) using estimated breeding values has been shown to be moderately-highly heritable (Schwab et al., 2010). Furthermore, in the same study, using IMF as a selection factor can directly affect other carcass traits. Intra-muscular fat is strongly positively correlated with back fat (BF), thusly selecting directly for increased IMF will also increase BF (Schwab et al., 2010). A similar relationship can be seen when selecting for feed intake (FI).

Selecting for increased FI has been shown to be moderately-highly positively correlated with increased average daily gain (ADG). However, this increase is not always proportionate and thus can impact feed efficiency (Ciobanu et al., 2001). The remaining variation in feed intake not explained by production traits, such as BF or ADG, is referred to as residual feed intake (RFI). Residual feed intake can be calculated by actual feed intake minus predicted feed intake (Young et al., 2011). Selecting for RFI has been shown to be moderately-highly heritable (0.15-0.40) and can benefit feed efficiency without affecting other production traits (Cai et al., 2014).

Genetic selection for nutrient digestibility is costly and time consuming, therefore is not a common practice. However, selection for criteria such as feed efficiency is common and important due to its driving force behind operational costs. Residual feed intake has been commonly used as a selection criteria measurement for feed efficiency. Motagne et al. (2014) measured the response to diets high in fiber of pigs selected divergently for residual feed intake. Overall, genetic selection for RFI had no impact on total tract digestibility of nutrients with total tract digestibility of NDF being an exception. Lower RFI lines had decreased NDF digestibility vs. the high RFI line. Furthermore, low RFI line had decreased digestive contents, colon weight, and total empty tract weight. Comparing blood parameters, the low RFI line had more rapid and increased blood glucose concentrations post meal consumption. Overall, digestive tract weights and nutrient digestibility can be influenced through genetic selection (Montagne et al., 2014). In contast, when divergent RFI lines were selected for 6 generations, there were no differences in the total tract digestibility of energy, nitrogen or dry matter. However, low RFI lines had decreased overall heat production, which was suggested to contribute to improved feed efficiency (Barea et al., 2010).

The use of fibrous ingredients can lower feed costs when used in swine diets. However, increasing dietary fiber can cause decreased amino acid, ether extract, and energy digestibility.

This often results in responses such as decreased ADG, ADFI, and G:F as well as decreased loin eye are, carcass weight and carcass yield. Pigs can be genetically selected to improve performance and digestibility of energy and nutrients. Therefore, the current projects focus on genetically selecting pigs to improve fiber utilization, while using a realistic and practical method of selection.

Literature Cited

Anguita, M., N. Canibe, Perez J F, and B. B. Jensen. 2014. Influence of the amount of dietary fiber on the available energy from hindgut fermentation in growing pigs: Use of cannulated pigs and in vitro fermentation. J. Anim. Sci. 84:2766–2778.

Asmus, M. D., J. M. DeRouchey, J. L. Nelssen, M. D. Tokach, S. S. Dritz, and R. D. Goodband. 2012. Effects of increasing NDF from corn dried distillers grains with solubles (DDGS) or wheat middlings (Midds), individually or in combination, on growth performance, carcass characteristics, and fat quality in finishing pigs. J. Anim. Sci. 90(Suppl. 2):275.(Abstr.)

Bach Knudsen K. E. 2001. The nutritional significance of “dietary fibre” analysis. Anim. Feed Sci. Technol. 90 (1) 3-20

Barea, R., S. Dubois, H. Gilbert, P. Sellier, J. van Milgen, and J. Noblet. 2010. Energy utilization in pigs selected for high and low residual feed intake. J. Anim. Sci. 88:2062-2072. Doi:10.2527/jas.2009-2395.

Bergsma, R., e. Kanis, M. W. A. Verstegen, and E. F. Knol. 2008. Genetic parameters and predicted selection results from maternal traits related to lactation efficiency in sows. J. Anim. Sci. 86:1067-1080. Doi:10.2527/jas.2007-0165.

Blasi, D. A., G. L. Kuhl, J. S. Drouillard, C. L. Reed, D. M. Trigo-Stockli, K. C. Behnke, and F. J. Fairchild. 1998. Wheat middlings, composition, feeding values, and storage guidelines. MF-2353. Kansas State Univ., Manhattan

Cai W., Casey, D.S., and Dekkers, J.C. 2014. Selction response and genetic paramers for residual feed intake in Yorkshire swine. J. Anim. Sci. 86: 287-298. doi:10.2527/jas.2007-0396.

Choct M. 1997. Feed Non-Starch Polysaccharides: Chemical Structures and Nutritional Significance. Feed Milling International. June:13-26.

Ciobanu, D.C., Bastiaansen, J.W., Lonegern, S.M., Thomesen, H., Deckers, J.C., Plastow, G.S. and Rothchild, M.F. 1998. Genetics of performance traits. Pages 352-355 in the Genetics of the Pig, edition 2. M.F. Rothschild and A. Ruvinsky, ed. CAB Int., Wallingford, UK.

Cook, D., N. Paton, and M. Gibson. 2005. Effect of dietary level of distillers dried grains with solubles (DDGS) on growth performance, mortality, and carcass characteristics of grow-finish barrows and gilts. J. Anim. Sci. 83(Suppl. 1):335. (Abstr.)

Chen, P., T. J. Baas, J. W. Mabry, J. C. M. Dekkers, and K. J. Koehler. 2002. Genetic parameters and trends for lean growth rate and its components in U.S. Yorkshire, Duroc, Hampshire, and Landrace pigs1. J. Anim. Sci. 80:2062-2070.

Cunningham, H. M., D. W. Friend and J. W. G. Nicholson. 1962. The effect of age, body weight, feed intake and adaptability of pigs on the digestibility and nutritive value of cellulose. Can. J. Anim. Sci. 42:167.

Dahlen, R. B. a, S. K. Baidoo, G. C. Shurson, J. E. Anderson, C. R. Dahlen, and L. J. Johnston. 2011. Assessment of energy content of low-solubles corn distillers dried grains and effects on growth performance, carcass characteristics, and pork fat quality in growing-finishing pigs. J. Anim. Sci. 89:3140–52.

Davidson, M. H. and A. McDonald.1998. Fiber: forms and functions. Nutrition Research 18:617-624.

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, S. S. Dritz, and R. D. Goodband. 2014. Effects of dietary wheat middlings, corn dried distillers grains with solubles, and net energy formulation on nursery pig performance1. J. Anim. Sci. 92:3471-3481.

Drochner W., A. Kerler, and B. Zacharias. 2004. Pectin in pig nutrition, a comparative review. J. Anim. Physiol. a. Anim. Nutr. 88(11-12) 367-380.

Easter R. A. and D. H. Baker. 1980 Lysine and protein levels in corn-soybean meal diets for growing-finishing swine. J. Anim. Sci. 50:467-471.

Englyst H., H. S. Wiggins, and J. H. Cummings. 1982. Determination of non-starch polysaccharides in plant foods by gas liquid chromatography of constituent sugars as alditol acetates. Analyst. 1272(107):307-318.

Feoli, C., J. D. Hancock, C. R. Monge, C. L. Jones, and C. W. Starkey. 2006. Effects of xylanase and wheat middlings in diets for finishing pigs. J. Anim. Sci. 84(Suppl. 1):429(Abstr.).

Gaines, A. M., G. I. Petersen, J. D. Spencer, and N. R. Augspurger. 2007. Use of corn distillers dried grains with solubles (DDGS) in finishing pigs. J. Anim. Sci. 85(Suppl. 2):96(Abstr.)

Giuberti G., A. Gallo, C. Cerioli, and F. Masoero. 2012. In vitro starch digestion and predicted glycemic index of cereal grains commonly utilized in pig nutrition. Anim. Feed Sci. & Tech. 174(3-4):163-173. doi.org/10.1016/j.anifeedsci.2012.03.006.

Goff, G. Le, and J. Noblet. 2001. Comparative total tract digestibility of dietary energy and nutrients in growing pigs and adult sows. J. Anim. Sci.:2418–2427.

Grabber J. H. 2005. How do lignin composition, structure, and cross-linking affect degradability. A review of cell wall model studies. Crop. Sci. 45: 820-831.

Gutierrez, N. A., Serão, N. V. L., Kerr, B. J., Zijlstra, R. T., & Patience, J. F. 2014. Relationships among dietary fiber components and the digestibility of energy, dietary fiber, and amino acids and energy content of nine corn coproducts fed to growing pigs. J. Anim. Sci., 92(10), 4505-4517.

Gutierrez, N. A., B. J. Kerr, and J. F. Patience. 2013. Effect of insoluble-low fermentable fiber from corn-ethanol distillation origin on energy, fiber, and amino acid digestibility, hindgut degradability of fiber, and growth performance of pigs. J. Anim. Sci. 91:5314–5325.

Hatfield, R. D., J. Ralph, and J. H. Grabber. 1999. Cell wall cross-linking by ferulates and diferulates in grasses. J. Sci. Food Agric. 79:403-407.

Hsu, W. L., and R. K. Johnson. 2014. Analysis of 28 generations of selection for reproduction, growth, and carcass traits in swine. J. Anim. Sci. 92:4806-4822.

Hsu, J. T., D. B. Faulkner, K. A. Garleb, R. A. Barclay, G. C. Fahey, and L. L. Berger. 1987. Evaluation of corn fiber, cottonseed hulls, oat hulls and soybean hulls as roughage sources for ruminants. J. Anim. Sci. 65:244-255. doi:10.2527/jas1987.651244x

Iyayi, E. A., and O. Adeola. 2015. Quantification of short-chain fatty acids and energy production from hindgut fermentation in cannulated pigs fed graded levels of wheat bran. J. Anim. Sci. 93:4781–4787.

Jaworski, N. W., H. N. Lærke, K. E. Bach Knudsen, and H. H. Stein. 2015. Carbohydrate composition and in vitro digestibility of dry matter and nonstarch polysaccharides in corn, sorghum, and wheat and coproducts from these grains1. J. Anim. Sci. 93:1103-1113.

Jaworski, N. W., and H. H. Stein. 2017. Disappearance of nutrients and energy in the stomach and small intestine, cecum, and colon of pigs fed corn-soybean meal diets containing distillers dried grains with solubles, wheat middlings, or soybean hulls1. J. Anim. Sci. 95:727-739

Keys, J. E., P. J. Van Soest, and E. P. Young. 1969. Effect of Increasing Dietary Cell Wall Content of the digestibility of hemi-cellulose and cellulose in swine and rats. J. Anim. Sci.:1172–1177.

Keys, J. E., and J. V Debarthe. 1974. Cellulose and hemicellulose digestibility in the stomach, small Intestine, and large intestine of swine. J. Anim. Sci. 39:53–56.

Kim, S. W., I. Osaka, W. L. Hurley, and R. A. Ester. 1999. Mammary gland growth as influenced by litter size in lactating sows: impact on lysine requirement. J. Anim. Sci. 77:3316-3321.

Knudsen, K. E. B., B. B. Jensen, and I. Hansen. 1993. Digestion of polysaccharides and other major components in the smal and larg intestine of pigs fed on diets consisting of oat fractions rich in B-D-Glucan. Brit. J. Nutr. 70:537–556.

Knudsen, B. K. 2015. Lactose in diet influences the degradation of mixed linked β (1-3; 1-4) - D-glucan in the small intestine of pigs. J. Anim. Sci. 90:125–127.

Mertens, D. R. 2003. Challenges in measuring insoluble dietary fiber. J. Anim. Sci. 81:3233-3249. Doi: 10.2527/2003.81123233x

Mitaru, B. N., R. Blair, R. D. Reichert, and W. E. Roe. 1984. Dark and Yellow Rapeseed Hulls, Soybean Hulls and a Purified Fiber Source: Their Effects on Dry Matter, Energy, Protein and Amino Acid Digestibilities in Cannulated Pigs. J. Anim. Sci. 59:1510-1518.

Montagne, L., F. Loisel, T. Le Naou, F. Gondret, H. Gilbert, and M. Le Gall. 2014. Difference in short term-responses to a high-fiber diet in pigs divergently selected for residual feed intake. J. Anim. Sci. 92:1512-1523. Doi: 10.2527/jas2013-6623.

Mosenthin, R., W. C. Sauer, and F. Ahrens. 1994. Nutrient metabolism dietary pectin 's effect on ileal and fecal amino acid digestibility and exocrine pancreatic secretions in growing pigs. J. Nutr. 124:1222–1229.

Noblet, J., and J. Van Milgen. 2004. Energy value of pig feeds: Effect of pig body weight and energy evaluation system. J. Anim. Sci. 82:229–238.

Nortey, T. N., J. F. Patience, J. S. Sands, N. L. Trottier, and R. T. Zijlstra. 2014. Effects of xylanase supplementation on the apparent digestibility and digestible content of energy, amino acids, phosphorus, and calcium in wheat and wheat by-products from dry milling fed to grower pigs. J. Anim. Sci. 86:3450–3464.

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Natl. Acad. Press, Washington, DC

Rayburn. E. B. 1997. Forage quality- fiber and energy. Extension. West Virginia University Extension service. Morgantown, WV.

Renteria-Flores, J. A., L. J. Johnston, G. C. Shurson, and D. D. Gallaher. 2015. Effect of soluble and insoluble fiber on energy digestibility, nitrogen retention, and fiber digestibility of diets fed to gestating sows. J. Anim. Sci. 86:2568–2575.

Rojas, O. J., E. Vinyeta, and H. H. Stein. 2016. Effects of pelleting, extrusion, or extrusion and pelleting on energy and nutrient digestibility in diets containing different levels of fiber and fed to growing pigs. J. Anim. Sci. 94:1951–1960.

Rumessen, J. J., and E. Gudmand-høyer. 1998. Fructans of chicory: intestinal transport and fermentation of different chain lengths and relation to fructose and sorbitol malabsorption 1 – 3. AM J. Clin. Nutr. 68:357–364.

Salyer, J. A., J. M. DeRouchey, M. D. Tokach, S. S. Dritz, R. D. Goodband, J. L. Nelssen, and D. B. Petry. 2012. Effects of dietary wheat middlings, distillers dried grains with solubles, and choice white grease on growth performance, carcass characteristics, and carcass fat quality of finishing pigs. J. Anim. Sci. 90:2620-2630.

Schertz, L. J., G. A. Apgar, L. A. Lekatz, and P. J. Lammers. 2016. Effect of feeding grower-finisher pig diets containing 20% soybean hulls with or without enzyme supplementation. J. Anim. Sci. 94:136-136.

Schmit, T. M., L. Verteramo, and W. G. Tomek. 2009. Implications of growing biofuel demands on northeast livestock feed costs. Agric. Resour. Econ. Rev. 38:200–212.

Schwab, C. R., T. J. Baas, and K. J. Stalder. 2010. Results from six generations of selection for intramuscular fat in Duroc swine using real-time ultrasound. II. Genetic parameters and trends. J. Anim. Sci. 88:69-79.

Shah, N., Atallah, M. T., Mahoney, R. R. &. Pellett, P. L. (1982) Effect of dietary fiber components on fecal nitrogen excretion and protein utilization in growing rats. J. Nutr. 112:656-666.

Shaw, D. T., D. W. Rozeboom, G. A. Hill, A. M. Booren, and J. E. Link. 2002. Impact of vitamin and mineral supplement withdrawal and wheat middling inclusion on finishing pig growth performance, fecal mineral concentration, carcass characteristics, and the nutrient content and oxidative stability of pork. J. Anim. Sci. 80(11):2920-2930

Sheng, Q. K., Z. J. Yang, H. B. Zhao, X. L. Wang, and J. F. Guo. 2015. Effects of L-tryptophan, Fructan, and Casein on Reducing Ammonia, Hydrogen Sulfide, and Skatole in Fermented Swine Manure. Asian-Australasian J. Anim. Sci. 28:1202–1208.

Shriver, J. A., S. D. Carter, A. L. Sutton, B. T. Richert, B. W. Senne, and L. A. Pettey. 2003. Effects of adding fiber sources to reduced-crude protein, amino acid-supplemented diets on nitrogen excretion, growth performance, and carcass traits of finishing pigs12. J. Anim. Sci. 81:492-502.

Srinivasan R., R. A. Moreau, K. D. Rausch, R. L. Belyea, M. E. Tumbleson, and V. Singh. 2005. seperation of fiber from distillers dried grains with solubles (DDGS) using sieving and elutriation. Cereal Chem. 82(5):528-533.

Stein, H. H., and G. C. Shurson. 2009. BOARD-INVITED REVIEW: The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci.87:1292-1303.

Stewart, L. L., D. Y. Kil, F. Ji, R. B. Hinson, A. D. Beaulieu, G. L. Allee, J. F. Patience, J. E. Pettigrew, and H. H. Stein. 2013. Effects of dietary soybean hulls and wheat middlings on body composition, nutrient and energy retention, and the net energy of diets and ingredients fed to growing and finishing pigs1. J. Anim. Sci. 91:2756-2765.

Sunvold, G. D., H. S. Hussein, G. C. Fahey, N. R. Merchen, and G. A. Reinhart. 2014. In vitro fermentation of cellulose, beet pulp, citrus pulp, and citrus pectin using fecal inoculum from cats, dogs, horses, humans, and pigs and ruminal fluid from cattle. J. Anim. Sci. 73:3639–3648.

Synytsya, A., and Novak, M. 2014. Structural analysis of glucans. Annals of Translational Medicine, 2: 17. http://doi.org/10.3978/j.issn.2305-5839.2014.02.07

Thekkoot, D. M., R. A. Kemp, M. F. Rothschild, G. S. Plastow, and J. C. M. Dekkers. 2016. Estimation of genetic parameters associated with reproduction, lactation and efficiency in sows. J. Anim. Sci. 94:4516-4529.doi: 10.2527/jas2015-0255.

Tyner, W. E., and F. Taheripour. 2007. Renewable energy policy alternatives for the future. Am. J. Agric. Econ. 89:1303–1310

United States Energy Information Administration. 2017. Production and consumption by source. Monthly Energy Review. https://www.eia.gov/totalenergy/data/monthly/index.php#renewable, Accessed 05.17.2017

Urriola, P. E., and H. H. Stein. 2010. Effects of distillers dried grains with solubles on amino acid, energy, and fiber digestibility and on hindgut fermentation of dietary fiber in a corn-soybean meal diet fed to growing pigs. J. Anim. Sci. 88:1454–1462.

Van Soest, P., J. Robertson, and B. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.

Woyengo, T. A., E. Beltranena, and R. T. Zijlstra. 2014. NONRUMINANT NUTRITION SYMPOSIUM: Controlling feed cost by including alternative ingredients into pig diets: A review12. J. Anim. Sci. 92:1293-1305. doi:10.2527/jas.2013-7169

Xu, G., S. K. Baidoo, L. J. Johnston, J. E. Cannon, and G. C. Shurson. 2007. Effects of adding increasing levels of corn dried distillers grains with solubles (DDGS) to corn-soybean meal diets on growth performance and pork quality of growing-finishing pigs. J. Anim. Sci.85(Suppl. 2):76 (Abstr)

Ye Sung and J. Cheng. 2002. Hydrolysis of Lingocellulosic materials for ethanol production: A Review. Biores. Techn. 83:1-11.

Young, J. M., W. Cai, and J. C. M. Dekkers. 2011. Effect of selection for residual feed intake on feeding behavior and daily feed intake patterns in Yorkshire swine1. J. Anim. Sci. 89:639-647. doi:10.2527/jas.2010-2892

Zhu, C. L., M. Rademacher, and C. F. M. De Lange. 2005. Increasing dietary pectin level reduces utilization of digestible threonine intake, but not lysine intake, for body protein deposition in growing pigs. J. Anim. Sci. 83:1044–1053.

Growth performance and carcass traits of low and high fiber diet selection lines of pigs fed either low or high fiber diets[1]

J. A. Erceg, J. G. Wiegert, R. Becerra, M. T. Knauer, and E. van Heugten

Department of Animal Science, North Carolina State University, Raleigh, 27695

[1] Funded in part by the North Carolina Pork Council, Raleigh, NC

Abstract: The objective of this study was to determine the impact of high fiber diet and genetic line, developed using either a low or high fiber diet, on grower-finisher pig performance and carcass characteristics. Pigs were selected for lean growth while consuming high fiber or control (low fiber) diets for 3 generations. Barrows (n=175; 45.8 ± 6.5 kg) were used in a 2x2 factorial design with genetic line (selected high fiber and selected control lines) and diet (control or high fiber) as factors. High fiber diets were formulated to include 15% each of DDGS, soybean hulls, and wheat middlings and control diets were corn-soybean meal based diets. A 3-phase feeding program was used with diets formulated to contain equal SID lysine to net energy ratios between treatments (control diets contained 0.93, 0.80, and 0.70% SID lysine and 2,484, 2,518, 2,537 kcal/kg NE for phase 1, 2, and 3, respectively; high-fiber diets contained 0.82, 0.71, and 0.62% SID lysine and 2,187, 2,211 and 2,245kcal/kg NE). Pigs were housed 4 or 5 pigs per pen using a total of 36 pens, resulting in 9 replications per treatment. Pigs were marketed by BW block (light and heavy) with heavy pigs marketed on d 64 (BW = 118 ± 10.9 kg) and light pigs on d 78 (BW = 118 ±10.8kg). Feed disappearance and BW were recorded at the end of each phase, backfat (BF) and loin eye area (LEA) were measured using real-time ultrasound at marketing, and hot carcass weight (HCW) was determined to calculate yield. Data were analyzed using PROC MIXED models with initial BW as a covariate. There were no interactions ($P>0.11$) between diet and genetic line. Genetic line had no effects on ADG, ADFI, Gain:Feed, or caloric efficiency (NE intake:Gain) in phase 1, 2, 3 or overall. Pigs fed high fiber diet had lower ($P<0.05$) ADG for phase 1, 2, and overall, higher ADFI for phase 3 ($P=0.012$), lower Gain:Feed for phase 2, 3, and overall ($P<0.05$) and increased ($P<0.05$) caloric efficiency for phase 1 and 2. Pigs fed high fiber diets had reduced ($P<0.05$) HCW (81.4 vs. 88.8, kg), LEA (16.89 vs. 18.24 cm^2), BF (1.66 vs. 1.98 cm), yield (70.8 vs. 73.5%) and daily lean gain (0.36 vs. 0.39 kg/d). Genetic selection for daily lean gain when using high fiber diets decreased ($P<0.05$) carcass yield (71.7 vs. 72.6%). Regardless of genetic line, feeding high fiber diets decreased growth performance, yield, carcass characteristics, and daily lean gain. Older pigs fed high fiber diets are able to compensate for ADG differences by increasing ADFI over pigs fed control diets.

Key Words: Swine, Genetic Selection, Fiber, Digestibility

Introduction

Feed costs are the largest contributor to swine production costs (Niemi et al., 2010). Increasing dietary inclusion of low cost, high fibrous ingredients can decrease overall feed costs (Woyengo et al., 2013). However, increasing dietary fiber concentrations has shown to decrease dry matter, amino acid, and energy digestibility (Urriola and Stein 2010, Gutierrez et al., 2013) and can negatively impact finishing pig performance. Adding wheat middlings (30% or 19%) decreased average daily gain in late finishing pigs (Shaw et al., 2002; Asmus et al., 2012). Dietary inclusion levels of DDGS (30%) have been shown to decrease ADG (Xu et al., 2014; Cook et al., 2005). Inclusion of soybean hulls in swine diets (30%) has shown to decrease ADG and G:F in grow-finish pigs(Stewart et al., 2014). While lowering diet costs is extremely beneficial, it is not always justifiable with the convergent decreases in pig performance. Therefore, new ways to improve performance while maintaining low diet costs are needed.

Genetic selection for residual feed intake (RFI), a measure of feed efficiency, has resulted in improvements in digestibility of neutral detergent fiber (NDF) and decreased heat production in swine (Motagne et al., 2014, Barea et al., 2010). Genetic selection has also been used to improve carcass traits such as intra-muscular fat (IMF)and back fat (BF) (Schwab et al., 2004). Furthermore, nutrient digestibility and digestive tract characteristics could be manipulated and improved through genetic selection in finishing pigs (Montagne et al., 2014). Therefore, genetic selection provides a potential tool to enhance the digestibility of fiber-rich ingredients and improve performance of pigs when fed high fiber diets.

As part of the long-term goal to improve fiber utilization through genetic selection, North Carolina State University initiated selection of pigs for increased growth performance when fed high and low fiber diets. The objective of the present study was to determine the impact of high fiber diets and genetic line, developed using either a low or high fiber diet, on grower-finisher pig performance and carcass characteristics.

Materials and Methods

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee of North Carolina State University, Raleigh, NC.

Genetic Selection

Pigs were selected using a divergent line selection process (Figure 1). Generation zero consisted of 90 original litters of unselected pigs. All littermates were randomly assigned to a dietary treatment consisting of high fiber or low fiber, with 50% of pigs from each litter being represented in each dietary treatment. Pigs were fed diets containing 45% high fibrous ingredients or control diets consisting of conventional corn and soybean meal based diets. From each dietary treatment, 60 gilts and 10 to 15 boars were kept to begin each specific genetic line representing the High Fiber (HF) or Low Fiber (LF) lines. Within each line, pigs were selected based on calculated lean growth and the top 60 gilts and 10 to 15 boars were kept from each line. Lean gain was calculated based on the following formula:

Lean gain = (-0.534) + (0.2907 * Off-Test Wt.) + (0.8326 * Sex) – (16.4977 * 10^{th} Rib BF) + (5.4247 * 10^{th} Rib LEA) – (0.418 * On-Test Wt.) – (3.650)

(Brannaman et al., 1989, Burson 2006)

In the above equation, lean gain was measured in total gain (kg) over the testing period (80-90 days). Pigs were placed on-test in the growing phase (40 kg), and taken off-test when they reach market weight (114 kg). All pigs are fed standard corn soy control diets prior to the test period, and remain on experimental diets during the entire testing period. Post-test period, pigs are returned to a standard corn- soy diet.

The on-test and off-test weights were measured in kg. The sex effect in this case is 1 for barrows/ boars and 2 for gilts, barrows were used in the current study. 10th rib back fat (cm) was measured using real time ultra sound along with 10th rib loin eye area (cm^2). These values were not adjusted to a standard weight as on-test and off-test weights were already included in the regression model. The outcome of this equation was the total amount of lean gained in the given test period. Dividing pounds of lean by the number of days in the testing period was used to calculate lean gain per day, this was used as the selection criteria for the genetic lines used in the current study.

Boars were selected within family group, no more than 2 boars per family were selected and outcrossed with gilts from opposite family groups. This strategy was used to decrease the inbreeding coefficient of each genetic line. In generation 1, pigs from each line were fed experimental diets respective to their selection criteria (HF or LF). From each line the top 60 gilts and 10 boars were kept, based on highest lean gain per day, to continue selection. This process was repeated for generation 2 and generation 3. Pigs used in the current study were in the third generation of selection.

Animals, Housing, and Experimental Design

One hundred and seventy-five barrows (initial BW = 45.8 ± 6.5 kg), consisting of 102 HF selected and 73 LF selected genetic lines were used. Pigs were housed in group pens with 4 to 5 pigs per pen, with total pen size of 7.44 m^2, where pens with 4 pigs had 1.86 m^2 of space per pig and pens with 5 pigs had 1.49 m^2 per pig. Pigs were blocked by weight, to achieve more uniform marketing weights at the end of the study, into either a light weight or heavy weight block. Block split was determined at the median weight. Treatments were arranged in a 2 x 2 factorial randomized complete block design with genetic line (HF or LF) and dietary treatment increased fiber (IF) or control (CT)as factors. Three rooms were used with 12 pens per room, resulting in 36 pens total and 9 replicates per treatment. Within room, pens were randomly assigned to treatments with each treatment represented equally in each room. Within genetic line, pigs were randomly assigned to a dietary treatment. Pigs were randomly assigned within weight block to pens within dietary treatment and genetic line.

Pigs were taken off test by weight block to achieve a similar end weight of 118 kg. Heavy weight block pigs were marketed on d 64 while light weight pigs were marketed on d 78. Pigs were provided ad libitum access to feed and water.

Diets and Sample Collection

Diets were manufactured in meal form at the North Carolina State University Feed Mill Educational Unit. Treatment diets were fed in three phases. Dietary phase splits were determined by days on feed. Phase 1 was fed from d 0 to d 25, phase 2 from d 26 to d 50, and phase 3 was provided to pigs from d 51 until marketing. High fiber diets were formulated to contain 45% fibrous byproducts, consisting of 15% DDGS, 15% soybean hulls and 15% wheat middlings. Control diets were formulated as standard corn and soybean meal based diets (Table

1). Within phase, diets were formulated to an equal lysine:NE ratio and to meet the nutrient requirements suggested by the swine NRC (2012). Diet bulk density was measured using a 1 liter box. 5 random samples were taken throughout each phase and results were combined to form an average bulk density by phase. Bulk densities were reported in grams per liter.

Measurements

Pens of pigs were weighed on d 0, 25, 50, and at marketing. Feed additions and feeders with remaining feed at the end of each phase were weighed and feed disappearance was determined on d 0, 25, 50, and at marketing. At the end of the study, pigs were weighed individually and loin eye area and back fat thickness were determined using real time ultrasound. Post marketing, hot carcass weights (HCW) were recorded at a commercial abattoir where pigs were processed. Carcass yield was calculated as pig hot carcass weight divided by pig live weight.

Calculations and Statistical Analysis

Pen was considered the experimental unit. Pig performance was calculated using pig days, correcting for the number of pigs per pen and the number of days in each period and overall. Caloric efficiency was calculated using total calories of NE consumed per day per unit of daily gain. Data were analyzed using the MIXED procedure of SAS (SAS Institute Inc., Cary, NC). The model included diet (IF or CT), genetic line (HF or LF), and the diet x genetic line interaction. Marketing block was used as a random variable and day 0 body weight was included as a covariate for all performance data, but not for carcass data. Statistical differences were considered significant at $\alpha \leq 0.05$ with tendencies considered at $0.05 < \alpha \leq 0.10$.

Results

There were no interactions between diet and genetic line for any of the growth performance or carcass characteristics measurements. Dietary bulk density was higher in control diets than IF diets for all phases (Table 2). In phase 1, pigs fed IF diets had decreased ADG ($P < 0.05$) and tended to have decreased ($P < 0.10$) ADFI compared to pigs fed CT diets. Feed efficiency tended to be poorer for HF selected pigs ($P = 0.06$) compared to LF selected lines (0.46 vs. 0.48 respectively). Caloric efficiency was increased ($P < 0.05$) in pigs fed IF diets compared to CT and caloric efficiency also tended to increase ($P < 0.10$) in LF selection lines compared to HF lines. In Phase 2, pigs fed control diets had increased ($P < 0.05$) ADG and G:F compared to pigs fed IF diets. There were no differences in ADFI between dietary treatments or genetic lines. However, HF selected pigs tended to have increased ($P < 0.10$) ADG compared to LF selected pigs. Caloric efficiency was increased ($P < 0.05$) in pigs fed IF diets versus CT diets, while there were no differences due to genetic line. In phase 3, pigs fed CT diets had greater ($P < 0.05$) G:F than pigs fed IF and pigs fed IF diets had increased ($P < 0.05$) ADFI than pigs fed CT diets. There were no differences in ADG or caloric efficiency between diets or genetic lines. Overall (phase 1-3), pigs fed CT diets had increased ($P < 0.05$) ADG and greater G:F than pigs fed IF (Table 3). There were no differences between diet or genetic section line for overall ADFI or caloric efficiency.

Pigs fed CT diets had greater ($P < 0.05$) HCW than pigs fed IF diets. Furthermore, pigs fed CT diets had greater ($P < 0.05$) LEA, BF, yield, and LG/d than pigs fed IF diets. There were no differences between HF and LF selected pigs for HCW, LEA, BF, or LG/d. However, HF selected pigs had decreased yield compared to LF selected pigs (Table 4)

Discussion

There were no interactions between genetic line and diet type for any traits measured. This may be attributed to the indirect method of selection. Pigs were indirectly selected for fiber utilization using lean gain, rather than directly selected for increased energy and nutrient digestibility from fiber diets.

Perhaps 3 generations of selection may have been insufficient to detect results. Schwab et al. (2014) used 6 generations of selection to significantly improve intramuscular fat in finishing pigs. In Cai et al., (2014), 4 generations of divergent section lines, using residual feed intake (RFI), were needed before low RFI lines had decreased ADG and BF. In the current study, 3 generations of selection were used which may not have been adequate for detecting significant differences between genetic lines and genetic line by diet interactions.

Carcass yield was significantly decreased in pigs selected while fed HF diets. The lean gain equation used did not account for yield and, therefore did not account for intestinal volume or fill. Sayler et al., (2012) fed pigs varying levels of wheat middlings (0, 10, and 20%) and DDGS (0 and 30%) and reported that carcass yield linearly decreased as wheat midds and DDGS inclusion increased in the diets. Similar results were seen by Whitney et al. (2006) where diets with increasing levels (0, 10, 20, and 30%) of DDGS linearly decreased dressing percent in finishing pigs was. Turlington et al. (1984) reported that increasing dietary fiber increased gut fill and colon size. Thus, pigs fed increased levels of fiber have decreased carcass yield, likely resulting from increased gut fill and larger visceral organ weights from fibrous diets. In the current study pigs selected when fed high fiber diets, without carcass yield being considered, would have been directly selected for increased body weight gain, increased LEA and decreased BF. Indirectly, these pigs may have been selected for increased gut fill and organ weights.

As expected, increasing dietary fiber decreased ADG and G:F. While ADFI was not different when measured over the entire finishing period, limited pig gut fill capacity may be the reason for reduced feed intake in pigs fed high fiber diets during the early phases of the finishing period. In phase 1 and 2, ADFI was not significantly different between diets, however as pig body weight increased and gut capacity increased, ADFI was greater in pigs fed IF diets compared to pigs fed CT diets during phase 3. Similar results were reported by Asmus et al. (2013) with pigs fed varying levels of fibrous diets during the finishing period. In early periods, there were no differences in ADFI between dietary treatments. However, in late finishing periods, pigs fed high fiber diets (19% wheat midds and 30% DDGS) had greater feed intake than those fed control diets. Pigs tend to eat to meet their energy requirements, but in diets containing large quantities of high fibrous ingredients, pig gut capacity limits the amount of total feed intake, which directly limits pig ADG. This can be supported when dietary bulk densities are considered. In the current study, bulk density was greater in CT diets than IF diets. Thus, with each fixed amount of feed consumed, the CT diet was more energy dense as well as higher in amino acid content. Similar results were observed with nursery pigs, when wheat midds were added to diets (>10%). Pigs had increased ADG and ADFI when fed diets with a higher bulk density (De Jong et al., 2014). Further, results in growing pigs fed diets with decreased bulk density (high fiber diets) showed that pigs had decreased feed intake, suggesting that pigs were not able to eat enough feed to meet their nutrient requirements (Ndou et al., 2012). In the current study, while no reductions in early ADFI were observed, later increases in ADFI of pigs on IF diets prove a similar effect that pigs fed high fiber diets that are lower in energy, are unable to meet their energy requirement due to gut fill restrictions on feed intake.

In the present study, 45% fibrous byproduct ingredients were included in IF diets. This resulted in decreased ADG, G:F, HCW, LEA, BF, and carcass yield. These results are consistent with other studies where increasing dietary fiber has been shown to decrease pig performance and carcass characteristics. Pigs fed increasing levels of DDGS (0 to 30%) were reported to have linear decreased ADG and ADFI and larger decreases in ADFI were observed in pigs fed greater than 10% DDGS (Linneen et al., 2014). Furthermore, pigs fed varying levels or DDGS (0,15,30%) and wheat midds (0,19%) had decreased ADG, poorer G:F and decreased caloric efficiency over pigs fed control diets (Nemecheck et al., 2015) . Even though these reports are similar to the current study, results from increasing dietary fiber can be variable and inconsistent. No effects on carcass yield, BF, LEA or carcass lean percentage were detected when pigs were fed increasing level of DDGS at 0, 15, 30% inclusion in diets (Xu et al., 2014). These results are concurrent with studies by Widmer et al. (2007) and Stein and Shurson (2009), where no effects on ADG, ADFI or GF were observed.

Diets in the current study were formulated to contain equal lysine : NE ratios within phases, however diets were not formulated to be isonitrogenous or isocaloric. Adding increased levels of amino acids or fat would be possible to maintain these isocaloric and isonitrogenous values between diets within each phase. In the current study, diets maintained different net energy values to determine the true effects of increasing dietary fiber without confounding results of added fat or amino acids. However in other research where diets remained isonitrogenous, but contained varying levels of wheat midds (0, 15, 30%) and differed in metabolizable energy, pigs had decreased ADG, G:F, and hot carcass weight (HCW) with increasing levels of wheat midds (Feoli et al., 2006). However, in a more recent study where diets remained isonitrogenous and isocaloric, but had varying levels of wheat midds (0 or 19%) and DDGS (0 or 25%), pigs fed high fiber diets had decreased ADG, G:F, and HCW (Asmus et al., 2012). In the current study, due to the large amount of fiber included in diets, creating isonitrogenous and isocaloric diets would have still shown a decrease in performance, mainly due to decreased digestibility when compared with control diets. However, the impact of this result may have been slightly mitigated due to added fat and amino acids in experimental diets.

Caloric efficiency differences observed in phase 1 and 2 may be primarily related to feed intake. As previously discussed, pigs were not able to compensate by increasing feed intake when fed diets with high levels of fiber that limited gut fill capacity. Differences in ADG were driven directly by feed intake, thus in phase 1 pigs fed IF diets consumed less feed and therefore had decreased ADG. However, the difference in ADG was not as great as the difference in the caloric content of the diets (phase 1: 2187 vs 2484 kcal/kg, phase 2: 2235 vs 2518 kcal/kg NE) high fiber and control diets respectively. Thus, due to the increased caloric content of CT diets and similar feed intake, the increases in phase 1 and 2 ADG of pigs fed CT diets was not enough to compensate for the caloric deficit seen between diets and therefore, pigs fed high fiber diets had increased caloric efficiency.

Literature Cited

Asmus, M. D., J. M. DeRouchey, M. D. Tokach, S. S. Dritz, T. A. Houser, J. L. Nelssen, and R. D. Goodband. 2014. Effects of lowering dietary fiber before marketing on finishing pig growth performance, carcass characteristics, carcass fat quality, and intestinal weights. J. Anim. Sci. 92:119-128. doi:10.2527/jas.2013-6679

Barea, R., S. Dubois, H. Gilbert, P. Sellier, J. van Milgen, and J. Noblet. 2010. Energy utilization in pigs selected for high and low residual feed intake. J. Anim. Sci. 88:2062-2072. doi:10.2527/jas.2009-2395.

Brannaman, J. L., L. L. Christian, M. F. Rothschild and E. A. Kline. 1984. Prediction equations for estimating lean quantity in 15 to 50-kg Pigs. J. Anim Sci. 59:991-996

Burson, D. 2006, Procedures for Estimating Pork Carcass Composition. Fact Sheet, Pork Information Gateway, 12-04-06.

Cai, W., D. S. Casey, and J. C. M. Dekkers. 2014. Selection response and genetic parameters for residual feed intake in Yorkshire swine. J. Anim. Sci. 86:287-298. Doi:10.2527/jas.2007-.396.

Cook, D., N. Paton, and M. Gibson. 2005. Effect of dietary level of distillers dried grains with solubles (DDGS) on growth performance, mortality, and carcass characteristics of grow-finish barrows and gilts. J. Anim. Sci. 83(Suppl. 1):335. (Abstr.)

De Jong, J. A., J. M. DeRouchey, M. D. Tokach, S. S. Dritz, and R. D. Goodband. 2014. Effects of dietary wheat middlings, corn dired distillers grains with solubles, and net energy formulation on nursery pig performance. J. Anim. Sci. 92(8):3471-3481.

Feoli, C., J. D. Hancock, C. R. Monge, C. L. Jones, and C. W. Starkey. 2006. Effects of xylanase and wheat middlings in diets for finishing pigs. J. Anim. Sci. 84(Suppl. 1):429. (Abstr.).

Gutierrez, N. A., B. J. Kerr, and J. F. Patience. 2013. Effect of insoluble-low fermentable fiber from corn-ethanol distillation origin on energy, fiber, and amino acid digestibility, hindgut degradability of fiber, and growth performance of pigs. J. Anim. Sci. 91:5314–5325.

Linneen, S. K., J. M. DeRouchey, S. S. Dritz, R. D. Goodband, M. D. Tokach, and J. L. Nelssen. 2008. Effects of dried distillers grains with solubles on growing and finishing pig performance in a commercial environment. J. Anim. Sci. 86:1579-1587. doi:10.2527/jas.2007-0486

Montagne, L., F. Loisel, T. Le Naou, F. Gondret, H. Gilbert, and M. Le Gall. 2014. Difference in short term-responses to a high-fiber diet in pigs divergently selected for residual feed intake. J. Anim. Sci. 92:1512-1523. doi: 10.2527/jas2013-6623.

Niemi J. K., M. L. Sevon-Aimonen, K. Pietola, and K. J. Stlader. 2010. The Value of Precision Feeding Technologies for Grow-Finish Swine. J. Liv. Sci. 129(1-3)13-23.

Nemechek, J. E., M. D. Tokach, S. S. Dritz, R. D. Goodband, J. M. DeRouchey, and J. C. Woodworth. 2015. Effects of diet form and type on growth performance, carcass yield, and iodine value of finishing pigs1. J. Anim. Sci. 93:4486-4499. doi:10.2527/jas.2015-9149

Salyer, J. A., J. M. DeRouchey, M. D. Tokach, S. S. Dritz, R. D. Goodband, J. L. Nelssen, and D. B. Petry. 2012. Effects of dietary wheat middlings, distillers dried grains with solubles, and choice white grease on growth performance, carcass characteristics, and carcass fat quality of finishing pigs1. J. Anim. Sci. 90:2620-2630. doi:10.2527/jas.2011-4472

Schwab, C. R., T. J. Baas, and K. J. Stalder. 2014. Results from six generations of selection for intramuscular fat in Duroc swine using real-time ultrasound. II. Genetic parameters and trends1. J. Anim. Sci. 88:69-79.

Shaw, D. T., D. W. Rozeboom, G. M. Hill, A. M. Booren, and J. E. Link. 2002. Impact of vitamin and mineral supplement withdrawal and wheat middling inclusion on finishing pig growth performance, fecal mineral concentration, carcass characteristics, and the nutrient content and oxidative stability of pork1. Journal of Animal Science 80:2920-2930. doi:10.2527/2002.80112920x

Son, A. R., S. Y. Ji, and B. G. Kim. 2012. Digestible and metabolizable energy concentrations in copra meal, palm kernel meal, and cassava root fed to growing pigs1. J. Anim. Sci. 90(Suppl4):140-142.

Stein, H. H., and G. C. Shurson. 2009. Board-invited review: The use and application of distillers dried grains with solubles in swine diets. J. Anim. Sci. 87:1292–1303. doi:10.2527/jas.2008-1290

Stewart, L. L., D. Y. Kil, F. Ji, R. B. Hinson, A. D. Beaulieu, G. L. Allee, J. F. Patience, J. E. Pettigrew, and H. H. Stein. 2013. Effects of dietary soybean hulls and wheat middlings on body composition, nutrient and energy retention, and the net energy of diets and ingredients fed to growing and finishing pigs. J. Anim. Sci. 91:2756-2765.

Urriola, P. E., and H. H. Stein. 2010. Effects of distillers dried grains with solubles on amino acid, energy, and fiber digestibility and on hindgut fermentation of dietary fiber in a corn-soybean meal diet fed to growing pigs. J. Anim. Sci. 88:1454–1462.

W. H. Turlington 1984. Interactive effects of dietary fiber levels and environmental temperature on growing pigs. MS Thesis, University of Kentucky, Lexington, KY.

Whitney, M. H., G. C. Shurson, L. J. Johnston, D. M. Wulf, and B. C. Shanks. 2006. Growth performance and carcass characteristics of grower-finisher pigs fed high-quality corn distillers dried grain with solubles originating from a modern Midwestern ethanol plant1. Journal of Animal Science 84:3356-3363. doi:10.2527/jas.2006-099

Widmer, M. R., L. M. McGinnis, D. M. Wulf, and H. H. Stein. 2008. Effects of feeding distillers dried grains with solubles, high-protein distillers dried grains, and corn germ to growing-finishing pigs on pig performance, carcass quality, and the palatability of pork1. Journal of Animal Science 86:1819-1831. doi:10.2527/jas.2007-0594

Woyengo, T. A., E. Beltranena, and R. T. Zijlstra. 2014. NONRUMINANT NUTRITION SYMPOSIUM: Controlling feed cost by including alternative ingredients into pig diets: A review. J. Anim. Sci. 92:1293-1305.

Xu, G., S. K. Baidoo, L. J. Johnston, D. Bibus, J. E. Cannon, and G. C. Shurson. 2010. The effects of feeding diets containing corn distillers dried grains with solubles, and withdrawal period of distillers dried grains with solubles, on growth performance and pork quality in grower-finisher pigs1. J. Anim. Sci. 88:1388-1397. doi:10.2527/jas.2008-1403

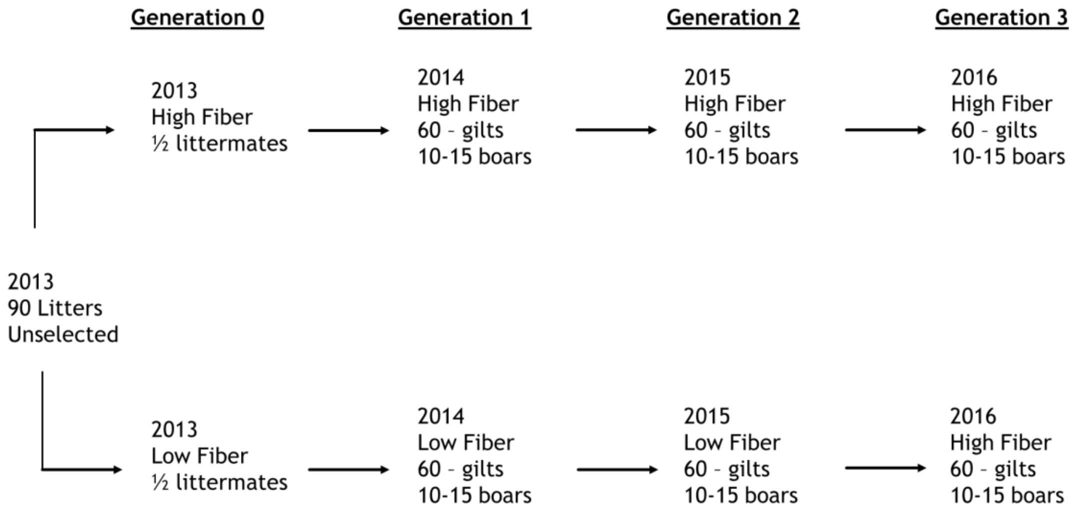

Figure 1. Flow diagram of genetic selection process.

Table 1. Ingredient and nutrient composition (as-fed basis) of Phase1, Phase 2, and Phase 3 diets.

	Phase 1		Phase 2		Phase 3	
Dietary Treatment	IF[1]	CT[2]	IF	CT	IF	CT
Ingredient, %						
Corn	44.00	78.10	46.65	81.80	50.67	84.07
Soybean Meal (47.5%)	8.03	18.52	5.96	15.11	2.26	13.34
Corn DDGS	15.00	--	15.00	--	15.00	--
Soybean Hulls	15.00	--	15.00	--	15.00	--
Wheat Middlings	15.00	--	15.00	--	15.00	--
L-Lysine HCL	0.39	0.37	0.31	0.32	0.32	0.24
DL-Methionine	0.02	0.08	0.01	0.06	--	0.01
L-Threonine	0.09	0.12	0.08	0.1	0.06	0.06
Monocalcium Phosphate	0.52	1.15	0.30	0.93	0.18	0.80
Limestone	0.96	0.97	0.94	0.94	0.97	0.93
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin Premix	0.04	0.04	0.04	0.04	0.04	0.04
Mineral Premix	0.30	0.30	0.15	0.15	0.15	0.15
Calculated Composition						
SID Lysine	0.82	0.93	0.71	0.80	0.62	0.70
NE (kcal/kg)	2,187	2,484	2,235	2,518	2,245	2,537
ADF, %	16.19	3.22	10.90	3.15	10.82	3.13
NDF, %	23.04	8.61	23.11	8.69	23.17	8.75
SID Lys:NE (g/Mcal)	3.74	3.74	3.17	3.17	2.76	2.76

[1] IF = Increased fiber diet

[2] CT = Control diet

Table 2. Bulk density (g/L) of Increased fiber and Control diets that were fed to pigs in phase 1, phase 2, phase 3 and overall.

Diet	CT[1]	IF[2]	SEM CT	SEM IF
Phase,				
Phase 1[3]	607.0	452.5	12.26	4.26
Phase 2	609.1	456.6	7.87	3.78
Phase 3	611.2	460.7	2.21	1.45
Average Overall,	609.6	456.6		

[1] CT = Control dietary treatment

[2] IF = Increased fiber dietary treatment

[3] All units are expressed in grams of feed per liter

Table 3. Growth performance of high and low fiber diet selection lines of pigs when fed diets low or high in fiber[1].

Genetic Line	HF[2]		LF[3]					
Diet	CT[4]	IF[5]	CT	IF	SEM	Diet	Line	Diet x Line
Phase 1 (d 0 to25)								
ADG	1.09	0.98	1.08	1.01	0.027	0.001	0.600	0.413
ADFI	2.32	2.32	2.21	2.12	0.088	0.058	0.176	0.676
G:F	0.47	0.45	0.49	0.48	0.015	0.153	0.061	0.708
Caloric[6] Efficiency (Kg/Mcal)	0.1928	0.2040	0.2006	0.2189	0.005	0.010	0.043	0.521
Phase 2 (d 25 to 50)								
ADG	1.10	1.02	1.08	0.98	0.027	<0.001	0.102	0.565
ADFI	3.25	3.24	3.19	3.13	0.088	0.502	0.068	0.559
G:F	0.34	0.31	0.34	0.31	0.056	<0.001	0.868	0.886
Caloric Efficiency	0.1359	0.1418	0.1356	0.1414	0.002	0.009	0.879	0.981
Phase 3 (d 50 to d 64/78)[7]								
ADG	0.99	0.90	0.95	0.94	0.038	0.102	0.949	0.261
ADFI	3.33	3.42	3.14	3.54	0.090	0.012	0.733	0.114
G:F	0.30	0.26	0.30	0.26	0.011	<0.001	0.613	0.900
Caloric Efficiency	0.1178	0.1168	0.1200	0.1180	0.003	0.642	0.670	0.886
Overall (d 0 to 64/78)								
ADG	1.06	0.96	1.05	0.95	0.027	0.002	0.554	0.991
ADFI	2.95	2.92	2.82	2.91	0.062	0.542	0.143	0.232
G:F	0.36	0.33	0.37	0.33	0.084	<0.001	0.711	0.312
Caloric Efficiency	0.1432	0.1487	0.1483	0.1475	0.003	0.424	0.508	0.305

[1] Values in this table represent the least squares means of 9 experimental pens per treatment with 4 to 5 pigs per pen.

[2] HF = High Fiber genetic selection line

[3] LF = Low Fiber genetic selection line

[3] IF = Increased Fiber dietary treatment

[5] CT = Control dietary treatment

[6] Caloric efficiency is expressed in Kg. of gain per Mcal of energy consumed. Whereas increased numbers represent high caloric efficiency

[7] Heavy weight block weighed off test on d 64, light weight block weighed off test d 78. Due to differences in pig initial age and body weight

Table 4. Carcass traits of high and low fiber diet selection lines of pigs when fed diets low or high in fiber[1].

Genetic Line	HF[1]		LF[2]					
Diet	CT[3]	IF[4]	CT	IF	SEM	Diet	Line	Diet x Line
Hot Carcass Wt. (kg)	88.94	81.07	88.74	81.81	0.890	<0.001	0.779	0.628
Loin Eye Area (cm[2])	18.14	16.74	18.33	17.02	0.813	<0.001	0.501	0.895
Back Fat (cm)	2.06	1.65	1.91	1.66	0.065	<0.001	0.350	0.245
Yield (%)	73.0	70.4	74.0	71.2	0.003	<0.001	<0.001	0.844
Lean Gain/ day (kg/d)[5]	0.40	0.36	0.39	0.37	0.366	0.001	0.843	0.461

[1] Least squares means of 9 experimental pens of pigs with 4 to 5 pigs per pen, Carcass traits were reported as pen means, where pen was used as the experimental unit.

[2] HF = High Fiber genetic selection line

[3] LF = Low Fiber genetic selection line

[4] IF = Increased Fiber dietary treatment

[5] CT = Control dietary treatment

[6] Lean gain per day was calculated using the following equation: Lean gain = (-0.534) + (0.2907 * Off-Test Wt.) + (0.8326 * 1) – (16.4977 * 10th Rib BF) + (5.4247 * 10th Rib LEA) – (0.418 * On-Test Wt.) – (3.65) / total number of days on feed

Selection of pigs for lean gain when fed high or low fiber diets to improve fiber, nitrogen, and energy digestibility and digestive tract characteristics[1]

J. A. Erceg., K. Moran, M. T. Knauer, and E. van Heugten

Department of Animal Science, North Carolina State University, Raleigh, North Carolina 27695

[1] Funded in part by the North Carolina Pork Council, Raleigh, NC

Abstract: The objective of this study was to determine the impact of high fiber diet and genetic selection line, developed using either a low or high fiber diet, on digestibility of fiber, N, and energy and digestive tract characteristics. Barrows (n=32; 50.4±3 kg) were used in a 14 d metabolism study with a 2x2 factorial design with genetic line (high fiber selected and control selected lines) and diet (high fiber or control) as factors. Genetic lines were selected for lean growth over 3 generations while consuming the high fiber or control diets. Barrows were separated into 2 replicate groups of 16 consisting of 4 littermate pairs from each genetic line. Diets were randomly assigned within littermate pairs. High fiber diets were formulated to include 15% of each DDGS, wheat middlings and soy hulls and control diets were corn-soybean meal based. Diets were formulated to contain equal SID lysine to net energy ratios (0.93 and 0.82% SID lysine and 2,484 and 2,187 kcal/kg NE for control and high fiber diets, respectively). Pigs had ad libitum access to feed for an 11 d adaptation period and were restricted to 90% ad libitum on d 12, 13, and 14 while fecal samples were collected to determine digestibility of ADF, NDF, N, and energy, using titanium dioxide as indigestible marker. Total transit time was measured by feeding a color marker (chromic oxide) and recording time until first fecal appearance of marker. Pigs were euthanized on d 14, pH was measured in the ileum and cecum along with cecum weights. Ileal digesta samples were collected to determine the apparent ileal digestibility (AID) of ADF and NDF. Data were analyzed using MIXED procedures of SAS. There were no interactions between diet and genetic line (*P*>0.05). Digesta transit time, cecal and colon pH were not impacted by diet. No effects of genetic line on digesta pH or digestibility were observed. High fiber genetic selection tended to increase (*P*=0.09) digesta transit time (1,704 vs. 1,521±75.5 min). Pigs fed high fiber diets had increased (*P*<0.05) ileal pH (6.61 vs. 6.32), apparent total tract digestibility (ATTD) of ADF (56.3 vs. 41.7%) and NDF (61.0 vs. 41.6%), and had decreased (*P*<0.05) ATTD of N (77.8 vs. 84.5%) and gross energy (GE; 78.3 vs. 84.2%). AID of ADF and NDF was not affected by genetic line. AID of NDF was greater in pigs fed high fiber diets, while no dietary effects of AID of ADF were shown. Genetic selection for lean gain of pigs when fed high fiber diets increased total transit time, but did not impact digestibility. Feeding high fiber diets decreased N and GE digestibility while increasing ileal pH and fiber digestibility, regardless of whether pigs had been selected on high fiber diets or not.

Key Words: Swine, Genetic Selection, Fiber, Digestibility

Introduction

Feed costs remain the largest portion of operational costs in swine production. Adding high fibrous byproduct ingredients to diets can help mitigate high feed costs. However, increasing fiber and plant cell walls in swine diets has been shown to decrease digestibility of dry matter (Keys et al., 1969) and other nutrients. Increasing levels of dietary corn fiber decreased apparent total tract digestibility (ATTD) of crude protein (CP) (Gutierrez et al., 2013). Adding 30% dried distillers grains with solubles (DDGS) to growing pig diets decreased the ileal digestibility of lysine, leucine, and aspartate (Urriola and Stein 2010). Increasing dietary fiber by feeding diets containing either 25% DDGS (medium fiber) or 25% DDGS and 20% soy hulls (high fiber), along with a control diet (low fiber) decreased (low to high) ATTD of energy (Rojas et al., 2016). Similar results were found by Iyayi and Adeloa (2015), who reported that growing pigs fed increasing levels of dietary wheat bran (10 to 30%) had decreased apparent ileal digestibility (AID) of energy. In the same study, energy digestion in the hindgut was also measured and results indicated that pigs fed diets containing 30% wheat bran had increased energy digestion in the hindgut, most of which resulted in increased volatile fatty acid (VFA) concentrations (Iyayi and Adeola 2015). Furthermore, pigs fed diets containing sugar beet pulp at 23% had decreased energy digestion in the small intestine compared to diets with no added beet pulp, resulting in an increase in hindgut energy availability; however total tract digestibility of energy was decreased in diets containing beet pulp (Anguita et al., 2006).

Overall increasing dietary fiber has been shown to decrease digestibility of crude protein and energy, which in turn can decrease feed efficiency. Methods such as genetic selection have been previously used to influence factors affecting feed efficiency and nutrient digestibility. Genetic selection for residual feed intake (RFI), a measure of feed efficiency, has resulted in improvements in digestibility of neutral detergent fiber (NDF) and decreased heat production in swine (Motagne et al., 2014, Barea et al., 2010). Furthermore, genetic selection for tissue size and structure has been successful. Schwab et al. (2010) showed that selecting for IMF using estimated breeding values was a moderately heritable trait. Thus, genetic selection for feed efficiency, digestibility and tissue traits may be used to manipulate animal performance and growth.

As part of the long-term goal to improve fiber utilization through genetic selection, North Carolina State University initiated selection of pigs for increased growth performance when fed high and low fiber diets. The objective of this study was to determine the impact of high fiber diet and genetic line, developed using either a low or high fiber diet, on digestibility of fiber, N, and energy and digestive tract characteristics.

Materials and Methods

The protocol for this experiment was reviewed and approved by the Institutional Animal Care and Use Committee at North Carolina State University, Raleigh, North Carolina.

Genetic Selection

Pigs were selected using a divergent line selection process (Figure 1). Generation zero consisted of 90 original litters of unselected pigs. All littermates were randomly assigned to a dietary treatment consisting of high fiber or low fiber, with 50% of pigs from each litter being represented in each dietary treatment. Pigs were fed diets containing 45% high fibrous ingredients or control diets consisting of conventional corn and soybean meal based diets. From each dietary treatment, 60 gilts and 10 to 15 boars were kept beginning each specific genetic line representing the high fiber (HF) or low fiber (LF) lines. Within each line, pigs were selected based on calculated lean growth and the top 60 gilts and 10 to 15 boars were kept from each line. Lean gain was calculated based on the following formula:

Lean gain = (-0.534) + (0.2907 * Off-Test Wt.) + (0.8326 * Sex) – (16.4977 * 10th Rib BF) + (5.4247 * 10th Rib LEA) – (0.418 * On-Test Wt.) – (3.650)

(Brannaman et al., 1989, Burson 2006)

In the above equation, lean gain was measured in total gain (kg) over the testing period (80-90 days). Pigs were placed on-test in the growing phase (40 kg), and taken off-test when they reach market weight (114 kg). All pigs are fed standard corn soy control diets prior to the test period, and remain on experimental diets during the entire testing period. Post-test period, pigs are returned to a standard corn- soy diet.

The on-test and off-test weights were measured in kg. The sex effect in this case is 1 for barrows/ boars and 2 for gilts, barrows were used in the current study. 10^{th} rib back fat (cm) is measured using real time ultra sound along with 10^{th} rib loin eye area (cm^2). These values were not adjusted to a standard weight as on-test and off-test weights were already included in the regression model. The outcome of this equation was total amount of lean gained in the given test period. Furthermore, taking this result over the number of days in the testing period was used to calculate lean gain per day, this was used as the selection criteria for the genetic lines used in the current study.

Boars were selected within family group. No more than 2 boars per family were selected and outcrossed with gilts from opposite family groups. This strategy was used to decrease the inbreeding coefficient of each genetic line. In generation 1, pigs from each line were fed experimental diets respective to their selection criteria (HF or LF).

Animals, Diets, and Experimental Design

Thirty-two barrows (initial BW = 50.4 ± 3 kg), 16 HF selected and 16 LF selected (North Carolina State University selection lines) were used in a 2x2 factorial design with diet and genetic line as the factors. Pigs were housed in individual metabolism crates and were separated into two groups of 16 barrows each. Littermate pairs were used to decrease genetic diversity within dietary treatments. One littermate was randomly assigned to a diet with the other littermate receiving the other dietary treatment. Once assigned to diet, pigs were randomly assigned to metabolism crates, without any further blocking method used.

Pigs were provided ab libitum access to water. Diets were manufactured in meal form at the North Carolina State University Feed Mill. Pigs were fed one dietary phase for the duration of the experiment. Increased fiber (IF) diets were formulated to contain 45% high fibrous byproducts, including 15% DDGS, 15%, wheat middlings, and 15% soybean hulls. Control diets (CT) were standard corn and soybean meal based diets (Table 1). Diets were formulated to contain an equal SID lysine to net energy ratio. Titanium dioxide was included in the diets at 0.30% and used as an indigestible marker for calculating digestibility. Pigs were fed twice daily to appetite, at 0800 h and 1600h, to determine voluntary feed intake. Feed allowance was increased when pigs consumed all of their meal to ensure near ad libitum consumption of feed. Feed disappearance was measured twice daily for each pig. Total feed intake per pig per day was determined and the average of the 11 d period was used to calculate feed allowance during the metabolism study when feed intake was restricted to 90% of near ad libitum intake.

Sample Collection

Pigs were fed for an 9d adaptation period prior to sampling for digestibility measurements. On d 9, Cr_20_3 was mixed with morning diets and used as a coloring agent to determine total transit time. Time was considered “start” when pigs first began consuming their meal. Time was considered “stop” at the first appearance of green feces; the difference between “start” and “stop” was considered total transit time and was measured in minutes. Pigs were checked every hour until 18 hours post consumption, then every 15 minutes thereafter until transit time was determined for each individual pig.

On d 12 pigs were restricted to a feed intake to 90% of the average feed intake that was previously determined during the 11 d adjustment period in which pigs were allowed near ad libitum consumption. Fecal and urine sampling began on d 12. Total feces were collected twice daily, weighed and subsampled at 15% of total sample weight. Total urine volume was collected and subsampled at 15% of total daily volume, 10ml of sulfuric acid was used to acidify collection samples, and total sulfuric acid volume was subtracted from urine total volume. Sub samples were frozen and stored at -30^0C.

On d 14 pigs were euthanized using captive bolt procedures and were restrained post-stunning until nerve responses had subsided. Abdominal cavities of pigs were opened for collection of intestinal samples. Digesta were collected from the terminal ileum 30 cm proximal to the ileal-cecal valve, the entire cecal contents and a central section of colon, 50 cm posterior to the cecum. All samples were collected within 5 minutes postmortem to reduce sample variation from intestinal sloughing. Digesta pH was measured using a pH meter and recorded immediately after collection. Digesta samples were frozen and stored at -20^0C. Ceca were emptied, patted dry and weighed to determine empty cecum weight.

Sample Analysis

Digesta, feed and fecal samples were ground using a Wiley mill with a 2 mm screen. Ileal, feed and fecal samples were analyzed for DM (method 930.15; AOAC 2007). ADF and NDF were analyzed in feed, ileal digesta and fecal samples using an ANKOM fiber analyzer (model 200: ANKOM Technology, Macedon, NY) in accordance with procedures outlined by Van Soest et al., (1991). Gross energy was determined using a bomb calorimeter (C 6000: IKA Works Inc., Wilmington, NC) in feed and fecal samples. Benzoic acid was used as the standard for all calorimetric samples. Crude protein was determined as N x 6.25 (method 990.03; AOAC, 2007). Titanium dioxide was used as an indigestible marker to ATTD and AID of energy, fiber, and N. Ileal, feed and fecal samples were analyzed for titanium dioxide using procedures adapted from Myers et al., (2004).

Statistical Analysis

Pig was considered the experimental unit. Data were analyzed using the MIXED procedures of SAS (SAS Institute, Cary NC). Two replicate groups of 16 barrows were used and group was considered a random effect. The model main effects included diet (IF or CT), genetic line (HF or LF), and all the diet x genetic line interactions. Statistical differences were considered significant at $\alpha \leq 0.05$ with tendencies considered at $0.05 < \alpha \leq 0.10$.

Results

There were no interactions between diet and genetic line for any digestibility, transit time, digesta pH, or cecal weight. Dietary composition was as expected and as formulated (Table 2). Total transit time tended ($P = 0.098$) to be longer in pigs that were selected using high fiber diets (Table 3), but there were no differences between dietary treatments for transit time. No differences were observed for cecal weight due to diet or genetic line. Cecal and colon pH also were not significantly different due to diet or genetic line. Ileal pH was lower ($P = 0.019$) in pigs fed control diets compared to pigs fed increased fiber diets. However, there were no differences in ileal pH between genetic lines (Table 4).

Apparent total tract digestibility (ATTD) of crude protein was not statistically different between genetic line, however, ATTD of crude protein was higher ($P < 0.001$) in pigs fed control diets compared to those fed increased fiber diets. Similarly, ATTD of energy was not statistically different between genetic line, but pigs fed control diets had increased ($P < 0.001$) energy digestibility compared to those fed increased fiber diets. Conversely, ATTD of acid detergent fiber (ADF) was decreased ($P < 0.001$) in pigs fed control diets compared to those fed increased fiber diets. There were no differences between genetic lines for ATTD of ADF. Likewise, ATTD of neutral detergent fiber (NDF) was not statistically different between genetic lines; however, ATTD of NDF was decreased ($P < 0.001$) in pigs fed control diets compared to those fed increased fiber diets (Table 5). AID of ADF and NDF were not significantly different ($P > 0.10$) for genetic line. Furthermore, there were no differences between dietary treatments for ADF, however pigs fed high fiber diets had increased ($P = 0.042$) AID of NDF compared to control diets (Table 6).

Discussion

There were no interactions between diet and genetic selection line in this study. No differences were observed between dietary treatments for total transit time. This was unexpected, because previous research has been shown that increasing dietary fiber decreased total digesta transit time (Bastianelli et al., 1996 and Schneeman 1998). On the other hand, the results of the current study concur with Urriola and Stein (2014), who fed pigs diets containing either 0 or 30% DDGS and used Cr_2O_3 as a color marker. First appearance of marked digesta was monitored at the ileum, cecum and in feces. The authors reported no differences between diets (0 or 30% DDGS) at the ileum, cecum or in feces for first appearance time (Urriola and Stein 2014). However, in the current study transit time tended to be increased in pigs selected on high fiber diets compared to those selected on low fiber diets. This may suggest increased intestinal length or gut capacity has resulted from selection of pigs on high fiber diets.

There were no differences in cecum weight due to genetic line or dietary treatments. Jørgensen et al. (1996) found that increasing dietary fiber content (59 vs. 268 g dietary fiber/kg dry matter) increased cecum and colon mass as well as length. Furthermore, adding alfalfa meal, barley, or both as a fiber sources to diets formulated to an equal digestible energy (DE) to crude protein ratio (0.088 MJ DE/g CP) increased cecum and colon weights compared to pigs fed control diets (Nyachoti et al., 2000). However, in agreement with the present study, diets containing 0 or 30% DDGS formulated to an equal SID Lys/ ME ratio (2.63 g/Mcal) and fed to growing pigs had no impact on cecal weight, but increased colon and rectum weight (Agyekum et al., 2015). Furthermore, when 10% wheat straw was added to diets that were formulated to an equal Lys/ ME ratio, there were no differences in small intestine, cecum or colon weights compared to control diets (Jin et al., 1994). These studies suggest that there is a relationship between fiber source or type and visceral weights, however, in the present study using diets containing high amounts of NDF and insoluble fiber no differences in cecum weight were observed. In previous research, cecum weight is measured as a function of empty body weight. Also, included in these studies are visceral weights on other digestive tissues and organs. In the current study, only cecum weights were recorded and therefore done so without the function of empty body cavity. Future studies may be needed to determine the effects of genetic selection and diet type on visceral weight and cecum weight as a percentage of empty body cavity weight.

Ileal digesta pH was increased in pigs fed high fiber diets compared to those fed control diets. Similar results were reported by Chen et al. (2013); as pigs were fed increasing levels of alfalfa meal (0 to 20%), ileal pH increased linearly as dietary fiber increased. However, differences in dietary crude protein have also shown to decrease ileal pH. Nyachoti et al. (2006) showed that decreasing dietary crude protein from 21% to 17% decreased ileal pH (6.74 to 6.09 respectively). In the current study, differences in dietary crude protein were not as drastic

(17.27 and 16.48between high fiber and control diets, respectively), however ileal pH was decreased in control diets, which also had a lower crude protein content.

As expected, pigs fed high fiber diets had decreased ATTD of crude protein and energy compared to pigs fed control diets. These results are congruent with previous studies, which indicated that dietary fiber decreased the apparent total tract digestibility of crude protein and energy (Uriola and Stein 2014, Berrocoso et al., 2015, Gutierrez et al., 2014, Renteria-Flores et al., 2015). Apparent total tract digestibility of ADF and NDF were increased in pigs fed high fiber diets compared to those fed control diets. However, effects of dietary fiber level on the digestibility of fiber is still unclear. The addition of wheat bran (22 or 44%) did not affect the total tract digestibility of NDF, but decreased the digestibility of ADF (Chabeauti et al., 1991). Furthermore, with fiber sources such as DDGS, ATTD of ADF and NDF has been shown to widely vary (7.2 to 17.3%) and (20.1 to 32.9%) respectively (Stein and Shurson 2009). Schulze et al. (1994) used a purified source of NDF (pNDF) from wheat bran in semi-synthetic diets, where dietary pNDF was increased from 0, 60, 120, 180 (g/kg) in diets. Increasing pNDF in diets had no effects on AID of NDF.

Digestibility coefficients in the present study were negative for AID ADF for both high and low fiber diets, while pigs fed high fiber diets had positive ileal NDF digestibility. These results are similar to Wilfart et al., (2014) who fed pigs isocaloric diets containing either 0, 20, or 40% wheat bran and showed negative ileal TDF digestibility (-31 and -5%) for low and medium fiber diets, respectively, while showing positive ileal TDF digestibility (16.3%) for high fiber diets.

Overall, fiber digestibility has been shown to vary greatly depending on fiber type, source and dietary inclusion level (Jha and Berrocoso 2015). In the present study, increasing dietary fiber decreased ATTD of N and energy while increasing the digestibility of ADF and NDF. Dietary fiber had no impact on transit time, but did lower ileal digesta ph. Genetic selection for lean gain while feeding high fiber diets did not improve digestibility of fiber, energy utilization of fiber diets or digestive tract characteristics. Further research is needed to determine the impact of genetic selection on fiber utilization and digestibility.

Literature Cited

Agyekum, A. K., B. A. Slominski, and C. M. Nyachoti. 2012. Organ weight, intestinal morphology, and fasting whole-body oxygen consumption in growing pigs fed diets containing distillers dried grains with solubles alone or in combination with a multienzyme supplement. J. Anim. Sci. 90:3032-3040.

Anguita, M, N. Canibe, J. F. Perez, and B. B. Jensen. 2006. Influence of the amount of dietary fiber on the available energy from hindgut fermentation in growing pigs: Use of cannulated pigs and in vitro fermentation. J. Anim. Sci. 84:2766-2778.

AOAC. 2007. Official methods of analysis of AOAC International. 18th ed. AOAC Int., Gaithersburg, MD

Barea, R., S. Dubois, H. Gilbert, P. Sellier, J. van Milgen, and J. Noblet. 2010. Energy utilization in pigs selected for high and low residual feed intake. J. Anim. Sci. 88:2062-2072. doi:10.2527/jas.2009-2395.

Bastianelli, D., D. Sauvant, and A. Rerat 1996. Mathematical modeling of digestion and nutrient absorption in the pig. J. Anim. Sci. 74:1873–1887

Berrocoso, J. D., D. Menoyo, P. Guzmán, B. Saldaña, L. Cámara, and G. G. Mateos. 2015. Effects of fiber inclusion on growth performance and nutrient digestibility of piglets reared under optimal or poor hygienic conditions. J. Anim. Sci. 93:3919-3931.

Brannaman, J. L., L. L. Christian, M. F. Rothschild and E. A. Kline. 1984. Prediction equations for estimating lean quantity in 15 to 50-kg Pigs. J. Anim Sci. 59:991-996

Burson, D. 2006, Procedures for Estimating Pork Carcass Composition. Fact Sheet, Pork Information Gateway, 12-04-06.

Chabeauti, E., J. Noblet, and B. Carre. 1991. Digestion of plant cell walls from four different sources in growing pigs. Anim. Feed Sci. Technol. 32:207-213.

Chen, L., H. F. Zhang, L. X. Gao, F. Zhao, Q. P. Lu, and R. N. Sa. 2013. Effect of graded levels of fiber from alfalfa meal on intestinal nutrient and energy flow, and hindgut fermentation in growing pigs. J. Anim. Sci. 91:4757-4764.

Gutierrez, N. A., B. J. Kerr, and J. F. Patience. 2013. Effect of insoluble-low fermentable fiber from corn-ethanol distillation origin on energy, fiber, and amino acid digestibility, hindgut degradability of fiber, and growth performance of pigs. J. Anim. Sci. 91:5314–5325

Iyayi, E. A. and O. Adeola. 2015. Quantification of short-chain fatty acids and energy production from hindgut fermentation in cannulated pigs fed graded levels of wheat bran. J. Anim. Sci. 93:4781-4787.

Jin, L., L. P. Reynolds, D. A. Redmer, J. S. Caton, and J. D. Crenshaw. 1994. Effects of dietary fiber on intestinal growth, cell proliferation and morphology in growing pigs. J. Anim. Sci. 72:2270-2278.

Jørgensen, H., X.Q. Zhao, and K.E. Bach-Knudsen. 1996. The influence of dietary fibre and environmental temperature on the development of the gastrointestinal tract, digestibility, degree of fermentation in the hind-gut and energy metabolism in pigs. Br. J. Nutr. 75:365–378.

Keys, J. E., P. J. Van Soest, and E. P. Young. 1969. Effect of Increasing Dietary Cell Wall Content of the digestibility of hemi-cellulose and cellulose in swine and rats. J. Anim. Sci.:1172–1177.

Kass, M. L., P. J. Van Soest, W. G. Pond, B. Lewis, and R. E. McDowell. 1980. Utilization of Dietary Fiber from Alfalfa by Growing Swine. I. Apparent Digestibility of Diet Components in Specific Segments of the Gastrointestinal Tract1. J. Anim. Sci. 50:175-191.

Montagne, L., F. Loisel, T. Le Naou, F. Gondret, H. Gilbert, and M. Le Gall. 2014. Difference in short term-responses to a high-fiber diet in pigs divergently selected for residual feed intake. J. Anim. Sci. 92:1512-1523. doi: 10.2527/jas2013-6623.

Myers, W. D., P. A. Ludden, V. Nayigihugu, and B. W. Hess. 2004. Technical note: A procedure for the preparation and quantitative analysis of samples for titanium dioxide. J. Anim. Sci. 82:179-183.

Nyachoti, C. M., F. O. Omogbenigun, M. Rademacher, and G. Blank. 2006. Performance responses and indicators of gastrointestinal health in early-weaned pigs fed low-protein amino acid-supplemented diets. J. Anim. Sci. 84:125-134.

Nyachoti, C. M., C. F. M. de Lange, B. W. McBride, S. Leeson, and H. Schulze. 2000. Dietary influence on organ size and in vitro oxygen consumption by visceral organs of growing pigs. Livest. Prod. Sci. 65:229-237.

Renteria-Flores, J. A., L. J. Johnson, G. C. Shurson, and D. D. Gallaher. 2015. Effect of soluble and insoluble fiber on energy digestibility, nitrogen retention and fiber digestibility of diets fed to gestating sows. J. Anim. Sci. 86:2568-2575.

Rojas, O. J., E. Vinyeta, and H. H. Stein. 2016. Effects of pelleting, extrusion, or extrusion and pelleting and nutrient digestibility in diets containing different levels of fiber and fed to growing pigs. J. Anim. Sci. 94:1951-1960.

Schneeman, B. O. 1998. Dietary fiber and gastrointestinal function. Nutr. Res. 18(4):625-632.

Schulze, H., P. van Leeuwen, M. W. A. Verstegen, J. Huisman, W. B. Souffrant, and F. Ahrens. 1994. Effect of level of dietary neutral detergent fiber on ileal apparent digestibility and ileal nitrogen losses in pigs. J. Anim. Sci. 72:2362-2368.

Schwab, C. R., T. J. Baas, and K. J. Stalder. 2010. Results from six generations of selection for intramuscular fat in Duroc swine using real-time ultrasound. II. Genetic parameters and trends. J. Anim. Sci. 88:69-79.

Stein, H. H. and G. C. Shurson. 2009. Board invited review: The use and application of distillers grains with solubles in swine diets. J. Anim. Sci. 87:1292-1303.

Urriola, P. and H. H. Stein. 2014. Effects of distillers dried grains with solubles on amino acid, energy, and fiber digestibility and on hindgut fermentation of dietary fiber in a corn-soybean meal diet fed to growing pigs. J. Anim. Sci. 88:1454-1462.

Van Soest, P. J., J. B. Robinson, and B. A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583-3597.

Wilfart, A., L. Montagne, P. H. Simmins, J. van Milgen, and J. Noblet. 2007. Sites of nutrient digestion in growing pigs: Effect of dietary fiber. J. Anim. Sci. 85:976-983.

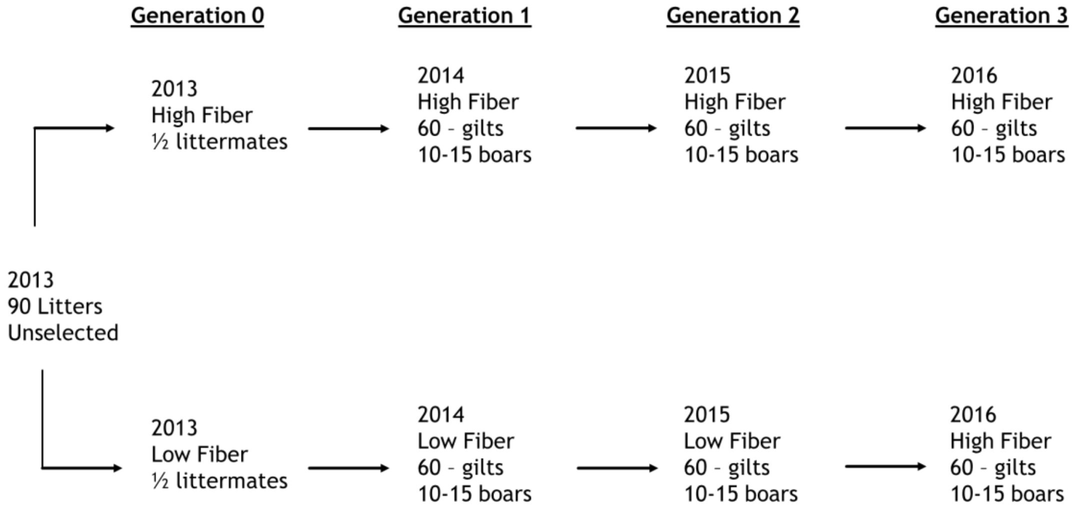

Figure 1. Flow diagram of genetic selection process

Table 1. Ingredient and nutrient composition (as-fed basis) of increased fiber (IF) and control diets (CT), as fed basis.

Dietary Treatment	IF	CT
Ingredient, %		
Corn	44.00	77.44
Soybean Meal (47.5%)	8.03	18.52
Corn DDGS	15.00	--
Soybean Hulls	15.00	--
Wheat Middlings	15.00	--
L-Lysine HCL	0.39	0.37
DL-Methionine	0.02	0.08
L-Threonine	0.09	0.12
Monocalcium Phosphate	0.52	1.15
Limestone	0.96	0.97
Salt	0.35	0.35
Vitamin Premix	0.04	0.04
Mineral Premix	0.30	0.30
Titanium Dioxide	0.30	0.30
Calculated Composition		
SID Lysine	0.82	0.93
NE (kcal/kg)	2,187	2,484
ADF, %	10.94	3.22
NDF, %	23.04	8.61
SID Lys:NE (g/Mcal)	3.74	3.74

Table 2. Analyzed composition (DM basis) of Increased Fiber and Control diets.

Dietary Treatment	IF[1]	CT[2]
Nutrient Analysis.		
Crude Protein, %	17.27	16.48
Gross Energy, (kcal/kg)	4286	4127
ADF, %	11.43	3.07
NDF, %	26.43	10.38
Titanium Dioxide	3.28	3.27

[1] IF = Increased Fiber Diet (15% DDGs, 15% soybean hulls, 15% wheat middlings)
[2] CT = Control Diet

Table 3. **Total transit time (in minutes) in pigs selected on high (HF) or low fiber (LF) diets when fed increased fiber (IF) or control diets (CT)[1].**

Genetic Line	Diet	Transit Time	SEM	Diet	Line	Diet x Line
HF	IF[2]	1698	147.2	0.674	0.098	0.765
HF	CT	1711	74.1			
LF	IF	1483	92.5			
LF	CT	1560	99.6			

[1] Values in this table represent the least squares means of 8 experimental pigs per treatment.

[2] IF = Increased Fiber dietary treatment (15% DDGs, 15% SBH, 15% WM)

Table 4. **Cecal weight and ileal, cecal and colon pH of pigs selected on high (HF) or low fiber (LF) diets when fed increased fiber (IF) or control diets (CT)[1].**

Genetic Line	HF		LF					
Diet	CT	IF[2]	CT	IF	SEM	Diet	Line	Diet x Line
pH of digesta								
Ileum	6.29	6.65	6.36	6.59	0.114	0.019	0.991	0.511
Cecum	5.71	5.70	5.74	5.71	0.038	0.653	0.773	0.844
Colon	5.66	5.78	5.50	5.32	0.174	0.470	0.246	0.776
Cecal weight. (g)	103.3	102.6	111.5	111.75	6.500	0.977	0.193	0.947

[1] Values in this table represent the least squares means of 8 experimental pigs per treatment.

[2] IF = Increased fiber dietary treatment (15% DDGs, 15% soybean hulls, 15% wheat middlings)

Table 5. **Apparent total tract digestibility of nutrients (CP, GE, ADF, NDF) in pigs selected on high (HF) or low fiber (LF) diets when fed increased fiber (IF) or control diets (CT)[1].**

Genetic Line	HF		LF					
Diet	CT	IF[2]	CT	IF	SEM	Diet	Line	Diet x Line
ATTD, %								
Crude Protein	84.3	77.9	84.6	77.7	0.948	<0.001	0.981	0.816
Gross Energy	84.3	77.8	84.2	78.8	0.836	<0.001	0.412	0.325
ADF	42.1	53.9	41.2	58.6	2.943	<0.001	0.531	0.360
NDF	41.7	59.2	41.4	62.8	1.998	<0.001	0.614	0.522

[1] Values in this table represent the least squares means of 8 experimental pigs per treatment.

[2] IF = Increased fiber dietary treatment (15% DDGs, 15% soybean hulls, 15% wheat middlings).

Table 6. **Apparent ileal digestibility of fiber (ADF and NDF) in pigs selected on high (HF) or low fiber (LF) diets when fed increased fiber (IF) or control diets (CT)[1].**

Genetic Line	HF		LF					
Diet	CT	IF[2]	CT	IF	SEM	Diet	Line	Diet x Line
Apparent ileal digestibility, %								
ADF	-9.20	10.71	-8.76	9.35	9.917	0.958	0.042	0.921
NDF	-23.38	-5.86	-21.90	-8.48	8.783	0.956	0.139	0.842

[1] Values in this table represent the least squares means of 8 experimental pigs per treatment.

[2] IF = Increased fiber dietary treatment (15% DDGs, 15% soybean hulls, 15% wheat middlings)