EFFECTS OF DIETARY FIBER ON THE GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND CARCASS FAT QUALITY IN GROWING-FINISHING PIGS

by

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Abstract

Three experiments used 777 pigs to study the effects of fiber source; wheat middlings (midds), dried distillers grains with solubles (DDGS), and choice white grease (CWG), and reduction strategies for growing and finishing pigs. Also a fourth study utilizing 1,360 pigs was conducted to determine the effect of immunocastration (IC) and DDGS withdrawal on growth performance, carcass characteristics, fatty acid analysis, and iodine value (IV) of pork fat depots in growing and finishing pigs. Experiment 1 determined that the ingredient source of fiber (wheat middlings or DDGS) was more important than NDF level alone, for characterization of growth, carcass, and yield responses. Experiment 2 showed that a short (23 d) fiber reduction strategy was successful at fully recovering yield loss; however, a longer reduction (47 d) was necessary for further improvements in carcass fat quality (IV). Experiment 3 further proved that yield loss can be recovered with a short fiber reduction strategy (19 d), and that adding energy from CWG during the fiber reduction period can improve feed efficiency, but was unsuccessful at further improving carcass yield or carcass fat quality. Experiment 4 showed that carcass yield was lower for IC pigs than barrows regardless of dietary DDGS or withdrawal strategy. Also pigs fed 30% DDGS throughout had decreased carcass yield; however, withdrawing DDGS from the diet on d 74 was effective at recovering the yield loss. While DDGS withdrawal strategy was successful at lowering IV, but was unsuccessful at fully lowering IV to values of pigs fed the control diet throughout. Iodine values were somewhat variable within fat depot, showing the jowl and clear plate fat were less accurate in showing changes from the diet, most likely due to the fact they are deposited earlier and are slower to turnover. Iodine value tended to be greater for IC pigs than barrows on d 107, but by d 125 there were no differences in IV between IC and barrows. This dramatic improvement from d 107 to 125 could be caused by the dilution of unsaturated fatty acids, specifically C18:2 and C18:3, due to the rapid deposition of fat in IC pigs.

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Dedication

I dedicate this thesis to my family: Grandparents - Duane and Lois Asmus, James and Ruby Green; parents - Steven and Kathy Asmus; Siblings – Edward Asmus Angela Asmus, Amy Asmus, and Kristin Asmus; and nieces – Bailey Asmus and Abigail Asmus for making this all possible. I love each and every one of you very much!

Chapter 1 - Effects of Increasing NDF from either Dried Distillers Grains with Solubles or Wheat Middlings, Individually or in Combination, on the Growth Performance, Carcass Characteristics, and Carcass Fat Quality in Growing-Finishing Pigs

Abstract

A total of 288 pigs (TR4 × 1050: PIC Hendersonville, TN; initially 38 kg BW) were used in a 87-d experiment to determine the effects of increasing dietary NDF from wheat middlings (midds) and dried distillers grains with solubles (DDGS) on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs. Pens of pigs were randomly allotted by initial weight and gender (4 barrows and 4 gilts per pen) to 1 of 6 dietary treatments with 6 replications per treatment. Treatments were arranged in a 2 × 2 factorial plus 2 additional treatments with the main effects of added wheat middlings (0 or 19%) or DDGS (0 or 30%) to corn-soybean meal-based diets. The additional treatments were a diet containing 9.5% midds and 30% DDGS and a diet containing 19% midds and 15% DDGS. These various combinations of midds and DDGS provided diets with differing NDF concentrations ranging from 9.3 to 18.9%. Diets were fed in 4 phases. Choice white grease was added to maintain similar ME in all diets within each phase. The only DDGS × midds interaction was a trend for carcass yield ($P = 0.09$). Adding either midds or DDGS to the diet reduced carcass yield by a similar magnitude but the effect was not additive. Overall (d 0 to 87), adding midds to the diet worsened (linear, $P < 0.001$) G/F and jowl iodine value (IV). Increasing DDGS did not influence growth performance or carcass traits except for an increase (linear, $P < 0.001$) in jowl fat IV. Pigs fed increasing NDF had decreased (linear, $P < 0.04$) ADG and HCW and poorer (linear, $P < 0.02$) G/F; however, these effects were driven by the pigs fed diets containing midds and do not appear to be attributed solely to NDF. Increasing NDF also increased jowl fat IV, but increasing NDF with DDGS had a greater negative effect than increasing NDF through midds (due to the oil content of DDGS). Thus, increasing NDF has negative impacts on pig performance, carcass yield, and fat IV; however, the effects appear to be more closely related to the individual ingredients used to increase NDF rather than NDF itself.

Key words: carcass, DDGS, finishing pigs, fiber, NDF, wheat middlings

Introduction

Feed cost accounts for 60 to 75% of the total cost of pork production. Combined with increased demand for corn use in ethanol production, producers are forced to look for viable low cost ingredients. Feed ingredients such as wheat middlings (midds) and dried distiller grains with solubles (DDGS) are often used as alternatives to corn and soybean meal in swine diets. While these ingredients are used with the intent of lowering feed costs, it has been shown that they can negatively affect performance and carcass characteristics. Thus, it must be determined whether the reduction in performance and carcass yield is due to fiber parse or related more closely with individual ingredients.

Wheat middlings are among the cereal by-products commonly used in commercial pig feed (Cromwell, 2000). Often referred to as wheat midds, they are by-products from flour milling. Most U.S. wheat that is not exported is processed into flour, so milling by-products are widely available for use in the animal feed industry. Wheat middlings have higher crude protein and fiber but lower dietary energy than corn (corn ME =3,395 kcal/kg; wheat middlings ME = 2,968 kcal/kg; NRC, 2012). Because of the low ME content, producers can expect reduced gains and poorer feed efficiency in finishing pigs (Shaw et al., 2002). To mitigate these effects, dietary fat can be added to increase the DE content (Salyer et al., 2012). However, limited data are available on the effects of combining midds with choice white grease (CWG) in diets for finishing pigs. Also, due to opportunities to reduce diet cost with midds, its effect on performance needs further investigation.

Considerable research has been conducted in recent years on the addition of DDGS to finishing diets. DDGS have approximately 3 times the crude fat, CP, and fiber content of corn as well as greater phosphorus bioavailability which reduces the need for supplemental phosphorus (Pedersen et al., 2007). With proper diet formulation up to 30% high quality DDGS can be fed without reducing pig performance (Stein and Shurson, 2009); however, carcass yield is often reduced and fat iodine value (IV) is increased with DDGS inclusion in the diet (Linneen et al., 2008; Hill et al., 2008). Adding DDGS and midds to the diet increases dietary fiber levels; however, little information is available on the potential interrelationship between these ingredients.

Therefore, the objective of this trial was to determine the effects of increasing fiber levels from midds and/or DDGS on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs.

Materials and Methods

General

The Institutional Animals Care and Use Committee at Kansas State University approved the protocol used in this experiment. This experiment was conducted at the Kansas State University Swine Teaching Research Center in Manhattan, KS.

The facility used was a totally enclosed, environmentally controlled, mechanically-ventilated barn containing 36 pens (2.4 × 3.1 m). The pens had adjustable gates facing the alleyway that allowed for 0.93 sq m/pig. Each pen was equipped with a cup waterer and a Farmweld (Teutopolis, IL), single-sided, dry self-feeder with 2 eating spaces located in the fence line. Pens were located over a completely slatted concrete floor with a 1.2-m pit underneath for manure storage. The facility was also equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Wilmar, MN) that delivered and recorded diets as specified on an individual pen basis. The equipment provided pigs with ad libitum access to food and water.

Animals and diets

A total of 288 pigs (TR4 × 1050: PIC Hendersonville, TN; initially 38 kg BW) were used in an 87-d growth trial. Pens of pigs (4 barrows and 4 gilts per pen) were randomly allotted by initial weight to 1 of 6 dietary treatments with 6 replications per treatment. The treatments were arranged in a 2 × 2 factorial plus 2 additional treatments with the main effects of added wheat middlings (0 or 19%) and DDGS (0 or 30%). The additional treatments were a diet containing 9.5% midds and 30% DDGS and a diet containing 19% midds and 15% DDGS. Dietary treatments were corn-soybean meal-based and fed in 4 phases (Tables 1.1, 1.2, 1.3, and 1.4). All diets were fed in meal form and balanced to similar ME concentrations and standardized ileal digestible (SID) lysine:ME ratios within each phase. Choice white grease was added to diets to maintain the same ME level within phase. The ME values used in formulation for dietary ingredients included: Corn = 3,420 ME kcal/kg; soybean meal = 3,380 ME kcal/kg; DDGS = 3,414 ME kcal/kg; midds = 3,025 ME kcal/kg; and CWG = 17,589 ME kcal/kg.

Wheat middling and DDGS samples were collected at the time of feed manufacturing and a composite sample was analyzed (Table 1.5) for moisture (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fat (AOAC 920.39 A, 2006), crude fiber (AOAC 978.10, 2006), ash (AOAC 942.05, 2006), Ca (AOAC 965.14/985.01, 2006), and P (AOAC 965.17/985.01, 2006) as well as a complete AA profile (AOAC 982.30 Ea,b, chp. 45.3.05, 2006.) at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO). Also, feed samples were collected from each feeder during each phase to measure bulk density (Seedburo Model 8800, Seedburo Equipment, Chicago, IL; Table 1.6). Bulk density of a material represents the mass per unit volume (g per liter).

Pigs and feeders were weighed approximately every 3 wk to calculate ADG, ADFI, and G/F. On d 87, all pigs were weighed and transported to Triumph Foods LLC., St. Joseph, MO. Before harvest, pigs were individually tattooed according pen number to allow for carcass data collection at the plant and data retrieval by pen. Hot carcass weights were measured immediately after evisceration and each carcass was evaluated for percentage yield, back fat, loin depth, and percentage lean. Percentage yield was calculated by dividing HCW by live weight obtained before transport to the packing plant. Fat depth and loin depth were measured with an optical probe inserted between the 3^{rd} and 4^{th} last rib (counting from the ham end of the carcass) at a distance approximately 7.1 cm from the dorsal midline. Fat-free lean index was calculated according to National Pork Producers Council (1991) equations for lean containing 5% fat where Lean (5% fat), lb = 2.83 + (0.469 × HCW, lb) – (18.47 × last rib fat thickness, in.) + (9.824 × loin muscle depth, in.). Jowl samples were collected and analyzed by Near Infrared Spectroscopy (NIR; Bruker MPA; Multi-Purpose Analyzer) for fat iodine value using the equation of Cocciardi et al. (2009). Because there were differences in HCW, it was used as a covariate for back fat, loin depth, and percentage lean.

Statistical analysis

Data were analyzed as a completely randomized design using the PROC-Mixed procedure of the Statistical Analysis System (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. The main effects and potential interactions of the different treatment regimens of midds and DDGS, and their interaction were tested. Linear and quadratic contrasts were used to determine the effects of midds (0, 9.5, 19%), DDGS (0, 15, and 30%), and NDF levels. The contrast coefficients for NDF were determined using PROC IML for unequally spaced treatments in SAS (9.2, 14, 16.4, and 18.8% NDF). Because there were treatment differences in HCW, it was used as a covariate for backfat, loin depth, and FFLI. Differences between treatments were determined by using least squares means ($P < 0.05$), and trends were declared a $P < 0.10$.

Results

Chemical analysis

Analyzed samples of DDGS and midds had higher levels of NDF than those used in formulation (Table 1.5) and thus, resulted in higher levels in the final diets than formulated; however, the incremental increase in NDF levels still existed. Using the actual NDF values from analysis, the NDF levels in the diet were 9.2, 15.4, 18.4, and 21.6 which was a 3% unit increase as opposed to the planned levels of 9.2, 14.0, 16.4, and 18.8 which had an increase of 2.4% unit between levels. Although the dietary NDF was higher than planned, the increase in NDF between treatments was still proportionally the same.

Bulk density tests showed that adding midds and DDGS to the diet decreased diet bulk density with density being reduced more with the addition of midds (Table 1.6).

Growth and carcass

The only DDGS × midds interaction that occurred was a trend ($P = 0.09$) for carcass yield (Table 1.7). Adding DDGS and midds to the diet decreased carcass yield; however, the interaction occurred because the effects were not additive. Overall (d 0 to 87), adding midds to finishing pig diets decreased (linear $P < 0.001$) ADG, G/F, final BW, and HCW, and worsened (linear, $P < 0.001$) jowl IV. As DDGS increased, there was no influence on growth performance or carcass characteristics with the exception of the expected increase (linear, $P < 0.001$) in jowl fat IV. Pigs fed increasing dietary NDF had decreased (linear; $P < 0.05$) ADG, G/F, and HCW; however these effects were driven by the pigs on the midds diets and does not appear to be attributed solely to increased dietary NDF.

Discussion

There are multiple items to consider when determining the role of fiber in swine nutrition, from complex issues like the influence of fiber on absorption and utilization of non-fiber components, to things as simple as the definition of fiber itself. Total fiber, as defined by Van Soest (1974), is represented by plant cell wall structural components made of carbohydrates that consist of pectins, glycoproteins, cellulose, hemicellulose, polysaccharides and other plant cell wall substances that are resistant to mammalian digestive enzymes. However, the definition can vary greatly. Trowell et al. (1976) defined fiber as the sum of lignin and polysaccharides that are not digested by endogenous secretions of the digestive tract. Conversely, Johnston et al. (2003) reported total digestible fiber (TDF) and its constituents, soluble dietary fiber (SDF) and insoluble dietary fiber (IDF), are a more appropriate measure of dietary fiber for monogastrics because they account for water-soluble non starch polysaccharides (NSP) such as pectins, β-glucans, fructans and other soluble sugars.

There are multiple ways to evaluate fiber levels in diets. Acid-detergent fiber (ADF) is the residue recovered after extraction with strong acid solutions and represents the lignin and cellulose fractions but excludes the hemicellulose as part of total fiber and has a very low digestibility of 38% (Patience, 2011). Neutral-detergent fiber (NDF) is the residue recovered after extraction with sodium lauryl sulphate and ethylenedinitrotetraacetic acid (EDTA). This leaves three components, cellulose, lignin, and hemicellulose termed the plant cell wall by Goering and Van Soest (1970) and has a higher digestibility of approximately 60% (Patience, 2011). However, starch and protein are not readily removed by the NDF solution and values may be variable due to the formation of starch-gel clogging the filter, which can result in high variability of results within lab. Just et al. (1982) reported that crude fiber had a negative influence on the digestibility of all nutrients with the exception of soluble carbohydrates which were 99% digestible in all diets tested. It was determined that a 1% increase in dietary crude fiber reduced digestibility of GE by approximately 3.5% and feed efficiency by 0.7% in growing pigs. To determine whether NDF explains the negative effect of adding fiber to finishing pig diets, we formulated diets with increasing levels of NDF from different sources (midds and DDGS).

This experiment found that pigs fed diets with increasing levels of NDF had decreased ADG and G/F with no difference in ADFI. However, the inclusion of midds was the main reason for the reduction in growth performance while the inclusion of DDGS had no impact on growth performance. These results agree with Feoli et al. (2006) and Salyer et al. (2012) who also reported decreased ADG and G/F when midds were increased in diets fed to swine when diets were not balanced on an energy basis, however, it should be noted that in the current trial CWG was utilized to equalize ME within phase. Stein and Shurson (2009) also reported no difference in growth characteristics when DDGS where included up to 30% in a properly balanced diet. On the other hand, work by Whitney et al. (2006) reported a linear decrease in ADG and G/F when DDGS was increased from 0 to 30% with no difference in ADFI. Linneen et al. (2008) also reported decreased ADG with increasing levels of DDGS, but it was associated with reduction in ADFI rather than differences in G/F. Although diets were formulated to equal levels of NDF from either midds or DDGS, the midds had a larger negative impact on growth performance than the DDGS. This variability within source of fiber shows that the increase in NDF content alone cannot be used as the sole predictor of ADG, ADFI, or G/F.

The apparent digestibility of fiber can vary greatly from 0 to 97% in the monogastric animal (Turlington, 1984). The largest difference in digestibility between fiber components is between non-lignified fiber (78 to 90% digestible), and lignified fiber (11 to 23% digestible), according to Baker and Harris (1947) and Cranwell (1968). This agrees with work by Bach Knudsen and Hansen (1991) and Le Goff and Noblet (2001) who reported that starch is almost completely digested (90 to 100%) by the time digesta reaches the ileal-cecal junction. However, lignin, a non-structural carbohydrate is thought to coat the other parts of dietary fiber and prevent microbial degradation (Van Soest, 1974). Thus, lignin is not digested by pigs nor is there any significant fermentation by microbes in the gut (Graham et al., 1986; Shi and Noblet, 1993). Cellulose becomes intertwined with lignin as a plant matures which makes it less accessible to microbes in the hindgut, depressing the rate and extent of fermentation. Because midds and DDGS have varying levels of cellulose, hemicellulose, and lignin, it could be plausible that these levels are more important than NDF when considering growth performance and may explain the differences in performance between pigs fed midds and DDGS even though NDF and ME levels were identical.

The lower utilization of ME in diets with high fiber levels may be explained by Kass et al. (1980) who found that pigs fed increased fiber had lower digestibilities of nutrients due to an increased rate of passage of the digesta through the lower tract. However, Farrell and Johnson (1970) reported that pigs are able to increase the capacity of their cecum when fed increased levels of fiber, allowing greater amounts of digesta to remain in the large intestine mitigate the increased rate of passage. This could help explain work by Turlington and Stahly (1984) that observed an increase in gut fill and colon contents when fiber was increased swine diets fed to growing-finishing pigs.

Noblet and Le Goff (2001) hypothesized that pectins, fructans, β-glucans, and other components of SDF increase viscosity of the digesta. This increased viscosity in the small intestine can slow gut transit time via suppressed intestinal contractions (Cherbut et al., 1990). The net result is less mixing of dietary components with endogenous enzymes, causing interference with complete digestion of both fibrous and non-fibrous components in the small intestine. However, the swelling associated with increased fiber could create a greater surface area for microbial digestion in the hindgut which would decrease the time digesta is in the small intestine where nutrients are absorbed more readily and cause a larger portion of the carbohydrates to be fermented in the cecum and large intestine. The end product of fermentation in the hind gut is volatile fatty acids (acetic, butyric, and propionic acid) which are thought to be less efficiently absorbed when compared to glucose absorption in the small intestine. This could partly explain why there were still differences in growth performance even though CWG was added to the diets to maintain similar ME levels in each phase. This agrees with previous research by Salyer et al. (2012) where adding 5% added CWG to diets containing 20% Midds (an increase of ~150 kcal/kg ME over the control) showed no improvement in growth performance, despite the increased energy level in the diet to offset the negative effects of increased fiber levels. This indicated a possible overestimation of energy in diet formulation, or reduced digestibility of energy due to the increased fiber levels when fed to pigs in the current study.

Another theory with feeding increased midds and/or DDGS is the effects of increased heat increment, exogenous gas production, and increased excretion of protein through urine, which can result in an overall reduction in energy utilization. Gas losses can vary and are typically low for conventional diets fed to growing-finishing pigs (0.5% DE; Noblet et al., 1994), but can be as high as 3% of DE in sows fed high-fiber diets (Ramonet et al., 1999). Rijnen (2003) found that methane production by pigs can be directly estimated from fermentable fiber content. Fasting heat production (FHP) represents the greatest portion of maintenance energy (NRC, 2012). Baldwin (1995) estimated that the gastrointestinal tract and liver can account for as much as 30% of FHP. Just (1983) reported diets containing fibrous ingredients produce higher heat increment and less efficient utilization of ME than that of starch. As previously stated increased fiber levels can cause an increase in gut fill and colon content, which could translate to increased maintenance requirements. This relationship between fiber and energy losses could help explain why pigs fed increased dietary wheat midds had reduced ADG despite the fact that CWG was added to account for the difference in ME.

Reduced bulk densities of fibrous ingredients such as midds has been suggested to restrict the ability of the pig to consume the dietary energy required to maximize average daily gain. Bulk density, especially in midds, is thought to be an indicator of ingredient quality (Cromwell et al. (2000). Cromwell (2000) reported that bulk density measurements can provide an estimation of quality based on the level of bran and flour present in the midds. Typically, lighter bulk density midds will have a higher level of bran, which in turn means increased fiber and protein content. Heavier midds however, are thought to have a higher percentage of starch and in turn, a higher energy value. In the present study, midds had a greater reduction in bulk density than that of DDGS, which could have led to increased gut fill.

Pedersen et al. (2007) determined the apparent total tract digestibility (ATTD) of GE to be 90.4% for corn and 76.8% for corn DDGS. The measured concentrations of DE and ME of corn DDGS were found to be similar to those found in corn. Feoli et al. (2006) reported corn DDGS to have a greater GE than corn, but digestibility of GE was lower than that of corn.

Increasing fiber level in the diet did not appear to limit energy and feed intake in our experiment as all diets had similar ME content and resulted in similar ADFI.

Although there were no major reductions in growth performance, increasing DDGS in finishing pig diets increased the proportion of unsaturated carcass fatty acids as measured by IV as anticipated. Because DDGS have a greater concentration of UFA, the fat IV linearly increased as DDGS increase in the diet. Due to the reduction in fat saturation associated with increasing DDGS level, some commercial packing plants have begun placing limits on the maximum fat IV allowed, which could potentially limit the inclusion level of DDGS in swine diets. Xu et al. (2010) found backfat and jowl IV linearly increased as DDGS increased in corn-based diets, which agrees with the linear increase in jowl IV found in the current study. These results agree with previous research by Benz et al. (2011), who found higher concentrations of UFA in pigs fed diets containing DDGS resulting in increased jowl and backfat IV. However, there is little research on the effects of wheat midds on fat quality. Research by Salyer et al. (2012) found increased jowl IV when 20% midds was added to diets containing 15% DDGS. However, when midds were increased (0%, 10%, 20%) in diets containing 30% DDGS no significant differences were detected although there was a numerical increase with higher levels of midds. In the present study, increasing midds (0%, 9.5%, 19%) in diets containing 30% DDGS resulted in a quadratic increase in IV with a large increase from 0 to 9.5% but no further increase from 9.5 to 19%. It is possible that jowl fat IV was increased for pigs fed midds, due to the reduced growth rate. In fact, Bergstrom et al. (2010) reported that pigs at lighter weights tended to have reduced BF depth and in turn increased IV. Diets containing midds would also be expected to contain more unsaturated fat than corn-soybean meal based diets, which may have increased jowl fat IV.

In conclusion, these data indicate that increasing NDF has negative impacts on pig performance, carcass yield, and fat IV; however, the effects appear to be more closely related to the individual ingredients used to increase NDF rather than NDF itself. Adding dietary energy from CWG was unsuccessful in mitigating the negative effects on live performance when midds where included in the diet.

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Figures and tables

Table 1-1 Phase 1 diet composition (as-fed basis)[1]

Item	NDF, %:	9.2	14.0	14.0	16.4	16.4	18.8
	Wheat midds, %:	0	19	0	9.5	19	19
	DDGS, %:	0	0	30	30	15	30
Ingredient, %							
Corn		77.05	61.10	52.90	44.90	49.10	36.90
Soybean meal, 46.5% CP		20.05	15.60	14.70	12.35	12.80	10.05
DDGS[2]		---	---	30.00	30.00	15.00	30.00
Wheat middlings		---	19.00	---	9.50	19.00	19.00
Choice white grease		0.20	1.70	---	0.80	1.60	1.60
Monocalcium phosphate, 21% P		0.55	0.25	---	---	---	---
Limestone		0.98	1.10	1.28	1.28	1.25	1.28
Salt		0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]		0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[4]		0.15	0.15	0.15	0.15	0.15	0.15
L-Lys HCl		0.28	0.35	0.34	0.38	0.39	0.42
DL-Met		0.03	0.03	---	---	---	---
L-Thr		0.07	0.09	---	---	0.05	0.01
Phytase[5]		0.13	0.13	0.13	0.13	0.13	0.13
Total		100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis							
Standardized ileal digestible (SID) AA							
Lys, %		0.92	0.92	0.92	0.92	0.92	0.92
Met:Lys, %		29	29	33	33	29	32
Met and Cys:Lys, %		57	57	68	67	60	67
Thr:Lys, %		62	62	64	62	62	62
Trp:Lys, %		17	17	17	17	17	17
Total Lys, %		1.02	1.01	1.08	1.08	1.04	1.07
CP, %		16.2	15.9	19.8	19.6	17.6	19.4
SID Lys:ME, g/Mcal		2.75	2.75	2.75	2.75	2.75	2.75
ME, kcal/kg		3,340	3,340	3,340	3,340	3,340	3,340
Ca, %		0.56	0.56	0.56	0.56	0.56	0.56
Available P, %		0.29	0.29	0.32	0.35	0.31	0.38
Crude fat, %		3.5	5.1	5.5	6.3	6.1	7.2
Crude fiber, %		2.5	3.3	4.0	4.4	4.1	4.8

[1]Dietary treatment fed in meal form from 36 to 59 kg BW for phase 1.

[2]Corn distillers dried grains with solubles.

[3]Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[4]Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 778.4 FTU/kg of feed and 0.11% available P released.

Table 1-2 Phase 2 diet composition (as-fed basis)[1]

NDF, %:	9.2	14.0	14.0	16.4	16.4	18.8
Wheat midds, %:	0	19	0	9.5	19	19
Item DDGS, %:	0	0	30	30	15	30
Ingredient, %						
Corn	81.70	65.80	57.45	49.45	53.70	41.30
Soybean meal, 46.5% CP	15.65	11.15	10.25	7.90	8.35	5.70
DDGS[2]	---	---	30.00	30.00	15.00	30.00
Wheat middlings	---	19.00	---	9.50	19.00	19.00
Choice white grease	0.15	1.65	---	0.80	1.60	1.60
Monocalcium phosphate, 21% P	0.40	0.10	---	---	---	---
Limestone	1.03	1.15	1.25	1.25	1.23	1.25
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[4]	0.15	0.15	0.15	0.15	0.15	0.15
L-Lys HCl	0.24	0.32	0.31	0.35	0.35	0.38
DL-Met	0.01	0.01	---	---	---	---
L-Thr	0.04	0.06	---	---	0.03	---
Phytase[5]	0.13	0.13	0.13	0.13	0.13	0.13
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standardized ileal digestible (SID) AA						
Lys, %	0.78	0.78	0.78	0.78	0.78	0.78
Met:Lys, %	29	29	37	36	32	36
Met and Cys:Lys, %	59	59	74	74	65	74
Thr:Lys, %	62	62	67	66	62	64
Trp:Lys, %	17	17	17	17	17	17
Total Lys, %	0.87	0.86	0.93	0.93	0.89	0.92
CP, %	14.5	14.1	18.1	17.9	15.9	17.7
SID Lys:ME, g/Mcal	2.33	2.33	2.33	2.33	2.33	2.33
ME, kcal/kg	3,342	3,342	3,342	3,342	3,342	3,342
Ca, %	0.54	0.54	0.54	0.54	0.54	0.54
Available P, %	0.25	0.25	0.32	0.35	0.30	0.38
Crude fat, %	3.6	5.2	5.6	6.5	6.2	7.3
Crude fiber, %	2.4	3.2	4.0	4.4	4.0	4.8

[1]Dietary treatment fed in meal form from 59 to 82 kg BW for phase 2.

[2]Corn distillers dried grains with solubles.

[3]Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[4]Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 778.4 FTU/kg of feed and 0.11% available P released.

Table 1-3 Phase 3 diet composition (as-fed basis)[1]

Item	NDF, %:	9.2	14.0	14.0	16.4	16.4	18.8
	Wheat midds, %:	0	19	0	9.5	19	19
	DDGS, %:	0	0	30	30	15	30
Ingredient, %							
Corn		85.05	69.10	60.75	52.65	56.90	44.50
Soybean meal, 46.5% CP		12.45	7.95	6.95	4.70	5.15	2.50
DDGS[2]		---	---	30.00	30.00	15.00	30.00
Wheat middlings		---	19.00	---	9.50	19.00	19.00
Choice white grease		0.15	1.65	---	0.80	1.60	1.60
Monocalcium phosphate, 21% P		0.25	---	---	---	---	---
Limestone		1.10	1.20	1.25	1.25	1.23	1.25
Salt		0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]		0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[4]		0.15	0.15	0.15	0.15	0.15	0.15
L-Lys HCl		0.22	0.29	0.28	0.32	0.33	0.36
DL-Met		---	0.01	---	---	---	---
L-Thr		0.02	0.05	---	---	0.01	---
Phytase[5]		0.13	0.13	0.13	0.13	0.13	0.13
Total		100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis							
Standardized ileal digestible (SID) AA							
Lys, %		0.68	0.68	0.68	0.68	0.68	0.68
Met:Lys, %		30	30	40	39	34	39
Met and Cys:Lys, %		63	62	81	80	71	80
Thr:Lys, %		62	62	71	69	62	67
Trp:Lys, %		17	17	17	17	17	17
Total Lys, %		0.77	0.76	0.82	0.82	0.78	0.81
CP, %		13.2	12.9	16.8	16.6	14.6	16.5
SID Lys:ME, g/Mcal		2.03	2.03	2.03	2.03	2.03	2.03
ME, kcal/kg		3,344	3,344	3,344	3,344	3,344	3,344
Ca, %		0.53	0.53	0.53	0.53	0.53	0.53
Available P, %		0.22	0.23	0.31	0.34	0.30	0.37
Crude fat, %		3.7	5.3	5.7	6.5	6.3	7.4
Crude fiber, %		2.4	3.2	3.9	4.3	3.9	4.7

[1]Dietary treatment fed in meal form from 82 to 105 kg BW for phase 3.

[2]Corn distillers dried grains with solubles.

[3]Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[4]Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 778.4 FTU/kg of feed and 0.11% available P released.

Table 1-4 Phase 4 diet composition (as-fed basis)[1]

Item	NDF, %:	9.2	14.0	14.0	16.4	16.4	18.8
	Wheat midds, %:	0	19	0	9.5	19	19
	DDGS, %:	0	0	30	30	15	30
Ingredient, %							
Corn		87.05	71.10	62.60	54.60	58.85	46.45
Soybean meal, 46.5% CP		10.55	6.00	5.10	2.80	3.25	0.60
DDGS[2]		---	---	30.00	30.00	15.00	30.00
Wheat middlings		---	19.00	---	9.50	19.00	19.00
Choice white grease		0.10	1.60	---	0.80	1.60	1.60
Monocalcium phosphate, 21% P		0.20	---	---	---	---	---
Limestone		1.10	1.20	1.25	1.25	1.23	1.25
Salt		0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]		0.15	0.15	0.15	0.15	0.15	0.15
Trace mineral premix[4]		0.15	0.15	0.15	0.15	0.15	0.15
L-Lys HCl		0.20	0.28	0.27	0.31	0.31	0.34
DL-Met		---	---	---	---	---	---
L-Thr		0.03	0.05	---	---	0.02	---
Phytase[5]		0.13	0.13	0.13	0.13	0.13	0.13
Total		100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis							
Standardized ileal digestible (SID) AA							
Lys, %		0.62	0.62	0.62	0.62	0.62	0.62
Met:Lys, %		32	31	42	42	36	41
Met and Cys:Lys, %		66	65	86	85	75	85
Thr:Lys, %		65	65	74	71	65	69
Trp:Lys, %		17	17	17	17	17	17
Total Lys, %		0.70	0.69	0.76	0.75	0.72	0.75
CP, %		12.5	12.2	16.1	15.9	13.9	15.7
SID Lys:ME, g/Mcal		1.85	1.85	1.85	1.85	1.85	1.85
ME, kcal/kg		3,344	3,344	3,344	3,344	3,344	3,344
Ca, %		0.52	0.52	0.52	0.52	0.52	0.52
Available P, %		0.21	0.22	0.31	0.34	0.30	0.37
Crude fat, %		3.7	5.3	5.7	6.6	6.3	7.4
Crude fiber, %		2.3	3.1	3.9	4.3	3.9	4.7

[1]Dietary treatment fed in meal form from 105 to 127 kg BW for phase 4.

[2]Corn distillers dried grains with solubles.

[3]Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[4]Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 778.4 FTU/kg of feed and 0.11% available P released.

Table 1-5 Analyzed composition of dietary ingredients on an as-fed basis[1]

Item	DDGS	Wheat middlings
Item, %		
DM	90.40	89.55
CP	24.92 (27.2)[2]	14.09 (15.9)
Crude fat (oil)	12.21	4.10
Crude fiber	5.44 (7.7)	9.55 (7.0)
ADF	9.38 (9.9)	12.53 (10.7)
NDF	30.44 (25.3)	42.13 (35.6)
Ash	6.04	6.47
Bulk density, g/L	499	271
Indispensable AA		
Arg	1.18	1.04
His	0.66	0.40
Ile	0.94 (1.01)	0.48 (0.53)
Leu	2.69 (3.17)	0.94 (1.06)
Lys	0.80 (0.78)	0.63 (0.57)
Met	0.48 (0.55)	0.21 (0.26)
Phe	1.26	0.60
Thr	0.90 (1.06)	0.47 (0.51)
Trp	0.20 (0.21)	0.17 (0.20)
Val	1.27 (1.35)	0.71 (0.75)
Dispensable AA		
Ala	1.59	0.72
Asp	1.45	1.06
Cys	0.44 (0.55)	0.29 (0.32)
Glu	2.82	2.60
Gly	0.95	0.80
Pro	1.66	0.85
Ser	0.97	0.52
Tyr	0.88	0.41

[1]Samples of dried distillers grains with solubles (DDGS) and wheat middlings (Midds) were collected at the time of feed manufacturing and a composite sample was analyzed at University of Missouri (Experiment Station Chemical Laboratories; Columbia, MO).

[2]Values in parenthesis indicate those used in diet formulation

Table 1-6 Bulk density of experimental diets (as-fed basis)[1]

		Treatments					
	NDF, %:	9.2	14.0	14.0	16.4	16.4	18.8
	Wheat midds, %:	0	19	0	9.5	19	19
Bulk density, g /L[1,2]	DDGS, %:	0	0	30	30	15	30
Phase 1		629	507	597	542	492	479
Phase 2		649	508	597	534	490	472
Phase 3		631	517	578	525	492	472
Phase 4		622	519	577	524	498	493

[1]Diet samples collected from the top of each feeder during each phase.
[2]Phase 1 was d 0 to 23; Phase 2 was d 23 to 43; Phase 3 was d 43 to 64; Phase 4 was d 64 to 87.

Table 1-7 Effects of dietary NDF on finishing pig growth performance and carcass characteristics[1]

Treatment:	1	2	3	4	5	6	
NDF, %:	9.2	14	14	16.4	16.4	18.8	
Wheat midds, %:	0	19	0	9.5	19	19	
DDGS, %:	0	0	30	30	15	30	SEM
Initial BW, kg	38.0	38.0	38.0	38.1	38.1	38.0	0.76
D 0 to 87							
ADG, kg	1.07	1.02	1.11	1.08	1.03	1.01	0.01
ADFI, kg	2.91	2.90	3.00	2.94	2.87	2.95	0.05
G:F	0.37	0.35	0.37	0.37	0.36	0.34	0.01
Final BW, kg	130.1	126.3	133.2	132.7	126.6	125.8	1.30
Carcass characteristics[2]							
Carcass yield, %[3,4]	73.8	72.2	71.9	71.5	72.2	72.4	0.69
HCW, kg	95.1	91.4	95.9	95.2	91.9	91.1	1.15
BF, mm[2]	24.1	24.6	25.1	22.7	23.1	24.0	0.86
LD, mm[2]	59.2	58.9	58.2	57.4	59.0	59.1	0.71
Lean, %[2]	51.0	50.8	50.5	51.1	51.3	51.0	0.38
Jowl iodine value	68.2	70.3	74.6	77.0	73.4	76.6	0.42

[1]A total of 288 pigs (TR4 × 1050, Initial BW= 38.0 kg) were used in this 87-d study with 8 pigs per pen and 6 pens per treatment.
[2]Carcass characteristics other than yield and iodine value were adjusted by using hot carcass weight as a covariate.
[3]Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.

Table 1-8 Effects of dietary NDF on finishing pig growth performance and carcass characteristics[1]

	Probability, *P* <							
	Main Effects		Midds		DDGS		NDF	
	Midds[2]	DDGS[3]	Linear[4]	Quadratic[4]	Linear[5]	Quadratic[5]	Linear[6]	Quadratic[6]
Initial BW, kg	1.00	0.99	1.00	0.96	0.99	0.96	0.98	0.99
D 0 to 87								
ADG, kg	0.001	0.16	0.001	0.28	0.90	0.48	0.04	0.07
ADFI, kg	0.49	0.19	0.45	0.57	0.50	0.46	0.89	0.88
G:F	0.001	0.72	0.001	0.09	0.34	0.11	0.02	0.13
Final BW, kg	0.001	0.32	0.001	0.06	0.77	0.74	0.07	0.08
Carcass characteristics[7]								
Carcass yield, %[8,9]	0.37	0.17	0.52	0.29	0.78	0.89	0.06	0.07
HCW, kg	0.001	0.82	0.01	0.24	0.89	0.66	0.04	0.49
BF, mm[7]	0.77	0.87	0.42	0.09	0.58	0.23	0.39	0.66
LD, mm[7]	0.68	0.52	0.38	0.16	0.84	0.96	0.63	0.27
Lean, %[7]	0.76	0.71	0.39	0.43	0.66	0.36	0.68	0.49
Jowl iodine value	0.001	0.001	0.002	0.01	0.001	0.91	0.001	0.78

[1]A total of 288 pigs (TR4 × 1050, Initial BW= 38.0 kg) were used in this 87-d study with 8 pigs per pen and 6 pens per treatment.

[2]Main effect of adding midds was tested using treatments 1 and 3 vs. 2 and 6.

[3]Main effect of adding DDGS was tested using treatments 1 and 2 vs. 3 and 6.

[4]Linear and quadratic effects of midds level (0%, 9.5%, and 19%) was tested using treatments 3, 4, and 6.

[5]Linear and quadratic effects of DDGS level (0%, 15%, and 30%) was tested using treatments 2, 5, and 6.

[6]Linear and quadratic effects of NDF level (9.2%, 14.0%, 16.4%, and 18.8%) was tested using treatments 1, average of 2 and 3, average of 4 and 5, and 6.

[7]Carcass characteristics other than yield and iodine value (IV) were adjusted by using hot carcass weight as a covariate.

[8]Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.

[9] There was an interaction (P = 0.09) detected for carcass yield, yield was reduced when DDGS and midds were added, however the effect was not additive.

Chapter 2 - Effects of Lowering Dietary Fiber Prior to Marketing on Finishing Pig Growth Performance, Carcass Characteristics, Carcass Fat Quality and Intestinal Weights

Abstract

A total of 264 pigs (327 × 1050: PIC Hendersonville, TN; initially 41.0 kg BW) were used in a 90-d study to determine the effects of lowering dietary fiber prior to market on pigs fed high dietary fiber (provided by wheat middlings (midds) and dried distillers grains with solubles; DDGS) on growth performance, carcass characteristics, carcass fat quality, and intestinal weights of growing-finishing pigs. Pens of pigs were randomly allotted by initial weight and gender to 1 of 6 dietary treatments with 6 replications per treatment. There were 24 pens with 7 pigs per pen (3 barrows and 4 gilts) and 12 pens with 8 pigs per pen (4 barrows and 4 gilts). There was a positive control (corn-soybean meal based) diet containing no DDGS or midds, and a negative control diet containing 30% DDGS and 19% midds that were fed throughout the entire trial (d 0 to 92). The other 4 treatments were arranged in a 2 × 2 factorial with the main effects of length of fiber reduction (23 or 47 d) and fiber level fed during the reduction period (low or medium). Pigs on these treatments were fed the negative control (high fiber) diet containing 30% DDGS and 19% wheat midds (19% NDF) prior to their reduction treatment. The medium fiber reduction diet contained 15% DDGS and 9.5% midds (14.2% NDF). The low fiber reduction diet was the positive control diet without DDGS or midds (9.3% NDF). Increasing the feeding duration of the low fiber diets lowered overall ADFI (linear, $P < 0.03$) and improved G:F (linear, $P < 0.01$); however, overall ADG was not affected. Lowering the fiber level for the last 23 d did not influence ($P > 0.62$) growth performance. However, lowering the fiber level improved carcass yield ($P < 0.002$) with a greater response ($P < 0.001$) when the low fiber diet was fed for 23-d. Pigs fed the medium fiber diet for 23-d had carcass yield intermediate to that of pigs fed the high or low fiber diet. Overall, increasing the fiber reduction time from 23 to 47 d did not further improve yield ($P = 0.11$). Jowl fat iodine value (IV) decreased the longer lower fiber diets were fed (linear, $P < 0.01$) and was lower ($P < 0.001$) for pigs fed the low fiber diet during the fiber reduction period than pigs fed the medium fiber diet during the same time period; however, increasing the time lower fiber diets were fed from 23 to 47 d further reduced ($P < 0.01$) jowl IV. Increasing the duration that the control diet was fed by increasing the reduction time from 23 to 47 d increased ($P < 0.01$) backfat depth and tended ($P < 0.11$) to decrease percentage lean. The length of the fiber reduction had minor effects on several organ weights; however, the large intestine was the most influenced with the response similar to the yield response. Reducing the fiber level decreased full large intestine weight (linear, $P < 0.005$) with a greater response ($P < 0.04$) when the low fiber diet was fed during the reduction period instead of the medium fiber diet; however, increasing the duration of the fiber reduction period from 23 to 47 d did not further decrease ($P = 0.20$) large intestine weights. In summary, lowering the fiber level prior to market for pigs fed a high fiber diet can improve G:F, carcass yield, carcass IV, and reduce large intestine weight; however, the optimal duration of the fiber reduction period depends on the response criteria targeted.

Key words: carcass, DDGS, fiber, finishing pig, wheat middlings, yield

Introduction

Considerable research has been conducted in recent years on the addition of DDGS to finishing diets. The DDGS have approximately 3 times the crude fat, CP, and fiber content of corn as well as greater P availability which reduces the need for dietary supplemental phosphorus (Pedersen et al., 2007). Considerable research has investigated dietary DDGS using growth performance as the main determinant for optimal inclusion level (Fu et al., 2004; Whitney et al., 2006). With proper diet formulation up to 10% high quality DDGS (Whitney et al., 2006) or 30% (Senne et al., 1995; DeDecker et al., 2005) have been fed without reducing pig performance. Reductions in carcass yield in pigs fed high levels of DDGS were reported by Linneen et al. (2008), and due to the large economic impact for lowered carcass yield further nutritional studies are required to help understand this impact of dressing percent. The unsaturated fat found in DDGS, mainly C 18:2, leads to reduced carcass fat quality (Whitney et al., 2006, Widmer et al., 2007). With soft and off-white fat being a main factor associated with price reductions of processed products like bacon (Carr et al., 2005), some packers have begun setting price reductions for pigs that have increased fat iodine value. Therefore it is crucial to find methods to improve fat quality when pigs are fed high levels of DDGS.

Wheat middlings are also among the cereal by-products commonly used in commercial pig feed (Cromwell, 2000). Most U.S. wheat that is not exported is processed into flour, so milling by-products are widely available for use in the animal feed industry. Midds have higher crude protein and fiber but lower dietary energy than corn (corn ME = 3,395 kcal/kg; wheat middlings ME = 2,968 kcal/kg; NRC, 2012). Salyer et al. (2012) determined that adding 20% dietary wheat middlings decreased ADG and worsened G:F. Due to the low ME content, producers can expect reduced gains and poorer feed efficiency when midds are fed to finishing pigs (Shaw et al., 2002). Adding midds to the diet has been shown to decrease percentage yield, HCW, and backfat depth (Salyer et al., 2012). The reduction in carcass yield is thought to be caused by the increased fiber resulting in increased gut fill. Although midds are lower in fat than DDGS, they are higher in fat than corn and increases in IV have been reported with addition of midds to the diet (Shaw et al., 2002; Salyer et al., 2012).

The main areas of concern with addition of high fiber ingredients, such as DDGS and midds to the diet are the reduction in carcass yield and negative effects on fat quality (Jacela et al., 2009; Barnes et al., 2010; Asmus et al., 2011). Soft carcass fat with a high IV has consistently been observed in pigs fed high levels of DDGS (Stein and Shurson 2009). While reducing the level of DDGS in the diet prior to market has been successful in lowering IV and improving yield (Jacela et al., 2009; Gaines et al., 2007), no data has been published to determine the length of time required and level of reduction needed to achieve desired endpoints for carcass yield and fat quality when pigs are fed DDGS and midds in combination. Also more data is required to determine the reasons why yield is reduced when feeding diets containing ingredients with high fiber content, such as DDGS or midds.

Therefore, the objective of this trial was to determine the effects of decreasing or fully removing DDGS and midds at different times prior to market on growth performance, carcass yield, carcass fat quality, and intestinal weights of growing-finishing pigs.

Materials and methods

General

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. The facility was a totally enclosed, environmentally regulated, mechanically ventilated barn containing 36 pens (2.4 × 3.1 m). The pens had adjustable gates facing the alleyway that allowed for 0.93 sq m/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL), with 2 eating spaces located in the fence line. Pens were located over a completely slatted concrete floor with a 1.2-m pit underneath for manure storage. The facility was also equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. The equipment provided pigs with ad libitum access to food and water.

Animals and diets

A total of 264 pigs (327 × 1050: PIC Hendersonville, TN; initially 40.0 kg) were used in a 90-d trial. Pens of pigs (4 barrows and 4 gilts per pen or 3 barrows and 4 gilts per pen) were randomly allotted by initial weight to 1 of 6 dietary treatments with 6 replications per treatment. There was a positive control diet containing no DDGS or midds, and a negative control diet containing 30% DDGS and 19% midds fed the duration of the trial. The other 4 treatments were arranged in a 2 × 2 factorial with the main effects of length of fiber reduction (23 or 47 d) and fiber level fed during the reduction period (low or medium). Pigs on these treatments were fed the negative control (high fiber) diet containing 30% DDGS and 19% wheat midds (19% NDF) prior to their reduction treatment. The medium fiber diet fed during the reduction period contained 15% DDGS and 9.5% midds (14.2% NDF). The low fiber diet fed during the reduction period was the positive control diet without DDGS or midds (9.3% NDF). Dietary treatments were corn-soybean meal-based and fed in 4 phases (Tables 2.1 and 2.2). All diets were fed in meal form and balanced to similar SID lysine ratios within each phase, however diets were not isocaloric. Due to the high level of available P in DDGS and midds, no supplemental P was required in diets containing high levels of DDGS and midds. Phytase was added to all diets at a constant level of 0.13% of the diet which provided 778.4 FTU/kg of complete diet and a 0.12% P release.

Wheat middling and DDGS samples were collected at the time of feed manufacturing and a composite sample was analyzed (Table 2.3) for moisture (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fat (AOAC 920.39 A, 2006), crude fiber (AOAC 978.10, 2006), ash (AOAC 942.05, 2006), Ca (AOAC 965.14/985.01, 2006), and P (AOAC 965.17/985.01, 2006) as well as a complete AA profile (AOAC 982.30 Ea,b, chp. 45.3.05, 2006.) at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO). Also, feed samples were collected from each feeder during each phase and combined for a single composite sample by treatment for each phase to measure bulk density (Seedburo Model 8800, Seedburo Equipment, Chicago, IL; Table 2.4). Bulk density of a material represents the mass per unit volume (g per Liter).

Pens of pigs and feeders were weighed on d 0, 20, 43, 67, and 90 to calculate ADG, ADFI, and G:F. On d 90, all pigs were weighed individually, the second heaviest gilt in each pen (1 pig per pen, 6 pigs per treatment) was identified to be harvested at the Kansas State University Meats Lab (KSU), and all other pigs were then transported to Triumph Foods LLC., St. Joseph, MO. The pigs selected for harvest at KSU were blocked within treatment and randomly allotted to a harvest order to equalize the withdrawal time from feed before slaughter within treatments. Feeders were removed from pens at 18:00 the night before harvest and harvest began at 06:00 the next morning. Hot carcass weights were measured immediately after evisceration. Following evisceration, the entire pluck (heart, lungs, liver, kidneys, spleen, stomach, cecum, large intestine, small intestine, and reproductive tract) was weighed and then the individual organs were weighed. After full organ weights were recorded, the large intestine, stomach, and cecum were physically stripped of contents and reweighed; then were flushed with water, physically stripped of contents, and weighed again. For pigs harvested at the commercial packing plant, pigs were individually tattooed in sequential order by pen and gender to allow for carcass data collection at the packing plant and data retrieval by pen. Hot carcass weights were measured immediately after evisceration and each carcass was evaluated for percentage yield, back fat, loin depth, and percentage lean. Percentage carcass yield was calculated by dividing

HCW by live weight obtained before transport to the packing plant. Fat depth and loin depth were measured with an optical probe inserted between the 3rd and 4th last rib (counting from the ham end of the carcass) at a distance approximately 7.1 cm from the dorsal midline. Fat-free lean index was calculated according to National Pork Producers Council (1991) equations for lean containing 5% fat where Lean (5% fat), lb = 2.83 + (0.469 × HCW, lb) – (18.47 × last rib fat thickness, in.) + (9.824 × loin muscle depth, in.). Jowl samples were collected and analyzed by Near Infrared Spectroscopy (NIR; Bruker MPA; Multi-Purpose Analyzer) for fat iodine value using the equation of Cocciardi et al. (2009).

Statistical analysis

Data were analyzed as a completely randomized design using the PROC MIXED procedure of the Statistical Analysis System (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. The main effects of the different withdrawal regimens of NDF level and withdrawal time were tested. Linear and quadratic contrasts were used to determine the effects of withdrawal time (23 or 47 d before market) and fiber during reduction period (low, medium, high). Differences between treatments were determined by using least squares means. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results and discussion

Bulk density tests showed that adding dietary fiber from wheat midds and DDGS dramatically decreased diet bulk density, which agrees with work by Salyer et al. (2012) and Asmus et al. (2011a) who found a significant reduction when midds or DDGS were included in the diet respectively.

Overall, there was no difference in ADG from d 0 to 90 (Table 2.5 and 2.6); however, overall ADFI was reduced ($P < 0.03$) and G:F was improved ($P < 0.004$) the longer low fiber (higher energy) diets were fed with the greatest reductions in ADFI from d 43 to 67 and 67 to 90. Interestingly, when pigs were switched from the high fiber (low energy) diet to the control (high energy) diet, they had numerically increased ADFI. It is possible that this increase in feed intake could be driven by the differences in diet bulk density, so that when pigs were switched to the low fiber diet, they consumed the same volumetric amount of feed for a period of time but the actual intake in kg was higher. This increased feed intake for pigs fed the high fiber diet disagrees with work by Fu et al (2004) and Linneen et al. (2008) that showed linear decreases in ADFI when increasing levels of DDGS (up to 30%) were fed; however, their diets did not contain wheat midds, which are of lower energy and could contribute to the need for increased ADFI (Barnes et al. 2010b). It is also possible that ADFI was affected in their trials due to pigs reduced preference for diets containing high levels of DDGS (Hastad et al., 2004).

From d 0 to 43, there was no difference in ADG or ADFI, however, pigs fed the high energy, control (low fiber) diet had improved G:F ($P < 0.05$) when compared to pigs fed the negative control (high fiber) diet, due to numerically improved ADG (0.95 vs. 0.92 kg, for low and high fiber treatments respectively). From d 43 to 67, pigs that were switched from the high fiber diet had improved ($P < 0.02$) ADG regardless of which diet they were switched to (medium or low fiber). This improvement in ADG was driven by increased ($P < 0.01$) ADFI and had no impact ($P > 0.40$) on G:F. Interestingly, lowering the fiber level for only 23 d before market did not alter ($P > 0.61$) ADFI or G:F which differs from work by Jacela et al. (2009) who saw a tendency for improved feed efficiency when DDGS were removed from the diet and pigs were fed a corn-soybean meal based diet, indicating that the DDGS in our trial could potentially be of a higher quality than that used by Jacela et al. (2009). Although there were no differences in ADG ($P < 0.30$) from d 67 to 90, the improvements from d 43 to 67 were large enough to result in improved ($P < 0.04$) ADG for the entire fiber reduction period (d 43 to 90) which was driven by increased ADFI, and a tendency ($P < 0.09$) for improved G:F. Jacela et al. (2009) also showed a tendency for improved ADG and G:F when DDGS were removed from the diet for a longer amount of time, however, this differs from other research with DDGS withdrawal by Xu et al. (2010) and Gaines et al. (2008) who showed no differences in ADFI or feed efficiency regardless of reduction strategy. This could be partly explained by the fact that the high fiber diets used in our study also included wheat midds which resulted in the diets being lower in energy, requiring a greater ADFI to meet energy requirements.

Reducing the fiber level in the diet improved carcass yield ($P < 0.004$) with a greater response ($P < 0.001$) when the low fiber diet was fed for 23-d (Table 2.7 and 2.8), and the medium fiber diet being intermediate. Increasing the duration of fiber reduction time from 23 to 47 d did not further improve carcass yield (*P* = 0.11). Gaines et al. (2008) reported improvements in yield when DDGS were reduced for 3 or 6 wk prior to harvest which agrees with our findings; however, Gaines reported that the 6 wk, but not the 3 wk, reduction strategy was able to fully recover the yield loss, whereas in our trial the entire loss in yield was recovered by the 3 wk (23 d) reduction period. Conversely Xu et al. (2010) reported no differences in yield when pigs were removed from 15 or 30% DDGS at 3, 6, or 9 wk prior to harvest; this difference may be partly due to variation in source of DDGS as well as the reduction in yield from the added midds (Salyer et al. 2012).

Increasing the duration of feeding the low fiber diets, by extending the fiber reduction time, increased (*P* = 0.01) backfat depth and tended (*P* = 0.10) to decrease percentage lean. This is supported in literature by Jacela et al. (2009) who also reported an increase in backfat depth when pigs were switched from high DDGS diets and fed corn-soybean meal diets. Conversely, Xu et al. (2010) reported no differences in backfat depth or percentage lean regardless of DDGS inclusion or fiber reduction strategy. The change in backfat depth in our study would be expected because our lower energy, high fiber diets contained wheat midds, which have been shown to reduce backfat depth by Salyer et al. (2012).

In our study, as expected, jowl fat IV decreased as fiber reduction time increased (linear, *P* < 0.01) and was lower (*P* < 0.001) for pigs fed the low fiber diet during the reduction period than pigs fed the medium fiber diet. This further improvement as reduction time increased from 23 to 47 d agrees with other published data (Jacela et al., 2009). However, the 23-d reduction time only improved IV by 37 or 19% (IV= 74.8 and 76.6, respectively) when pigs were moved to the low or medium fiber diet. The 47-d reduction period improved IV by 78 and 27% (IV= 70.6 and 75.8, respectively) when pigs were moved to the low and medium fiber diets, respectively. These results indicate that IV is improved by approximately 0.35 g per week for every 10% DDGS removed from the diet, which is supported by recent research conducted by Xu et al. (2010), Hill et al. (2008), and Jacela et al. (2009). However, these studies looked at the incorporation of unsaturated fatty acids into the carcass, not the removal (clearance) of unsaturated fatty acids after they have been deposited. The current trial was not able to show the same magnitude of response. It is possible that the rapid improvement in fat quality was not obvious in this trial because fat quality was measured in jowl fat samples which are deposited early and have a slow turnover rate which could cause them to be slow to show improvements due to a dietary change (Bergstrom et al., 2010).

The greatest impact of fiber reduction strategy was on large intestine weights with the response similar to the yield response. These results agree with research by Agyekum et al. (2012) that reported pigs fed DDGS diets for 28 d had heavier colon plus rectum and portal-drained viscera than pigs fed the control diet. Increasing duration of fiber reduction decreased (linear, $P < 0.05$) full and stripped large intestine weights. As fiber level increased in the diet from d 43 to 67 or 67 to 90, full and stripped large intestine weights also increased ($P < 0.04$), with pigs fed the low fiber diet during the reduction period also having lighter ($P < 0.04$) full large intestine weight than those fed the medium fiber diet. High dietary fiber may indirectly increase the animals' maintenance requirement by repartitioning of nutrients from carcass to the visceral organs (Ferrell 1988). Anugwa et al. (1989) saw significantly greater weights of the total gastrointestinal tract and greater relative stomach weight when pigs were fed high fiber diets (40% alfalfa meal). This agrees with the increased large intestine weights in our current study; however, no differences were detected in stomach weights in our study. The high fiber diet fed in the last feeding period in the present study was higher in CP than the low fiber diet (16.8 vs. 13.5%) which could be a confounding factor as excess crude protein could be causing part of the increases in liver and kidney weights (Anugwa et al., 1989). Agyekum et al. (2012) found no differences in liver weights with diets similar in CP (18.2% vs 18.1%); however the pigs used in their study were much lighter in final BW than in our study (36.5 vs. 103 kg).

The fiber level fed and length of fiber reduction had minor effects on most organ weights except for the digestive tract, which, as expected, was most influenced by dietary fiber levels. But, unexpectedly, lowering the fiber level in the diet for the last 47 d actually increased ($P = 0.03$) small intestine weight whether calculated on a weight basis (Table 2.9 and 2.10) or percentage of live weight basis (Table 2.11 and 2.12). Stomach weights were not influenced by feeding duration other than a tendency ($P < 0.08$) for stripped stomach weight to be decreased as the length of fiber reduction increased. Similarly, the influence of fiber reduction strategy on cecum weights was minor with only small reductions (P < 0.08) in full, stripped, and rinsed cecum weights when the low fiber diet was fed during the reduction period instead of the medium fiber diet.

For the other organs, there was a reduction (quadratic, $P < 0.02$) in spleen weight as the duration of fiber reduction increased; however there were no other differences ($P > 0.11$) in spleen weight. As fiber levels were lowered 47 d prior to market, there was a reduction (quadratic, $P < 0.01$) in kidney weight, with greater reductions when pigs were fed the low fiber diet compared to the medium fiber diet during the reduction period. Pond et al. (1988) also found reduced kidney weight but no difference in heart weight when high fiber (80% alfalfa meal) was fed. Conversely, lungs, liver, and reproductive tract weights were not influenced ($P > 0.10$) by fiber level or fiber reduction strategy in the current study. It should be noted that Pond et al. (1988) found differences in empty colon, small intestine, and cecum weights showing increases in actual organ weights. In our study, the most significant differences were in full intestinal weights implying gut fill was a large contributor to the yield reduction compared to increased intestine weights.

In summary, reducing the fiber level fed prior to market for pigs fed diets containing high levels of DDGS and midds can improve G:F, carcass yield, carcass IV, and reduce large intestine weight; however, the optimal length of fiber reduction time depends on the response criteria being targeted, shorter reductions are effective at recovering yield, but longer reductions are necessary to improve carcass fat quality.

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Figures and tables

Table 2-1. Phase 1 and 2 diet composition (as-fed basis)[1]

	Phase 1		Phase 2	
Fiber level:	Low	High	Low	High
Wheat midds, %:	0	19	0	19
Item DDGS,[2] %:	0	30	0	30
Ingredient, %				
Corn	73.70	34.90	78.95	40.00
Soybean meal, 46.5% CP	23.80	13.75	18.85	8.70
DDGS	---	30.00	---	30.00
Wheat middlings	---	19.00	---	19.00
Monocalcium phosphate, 21% P	0.45	---	0.35	---
Limestone	1.05	1.30	1.00	1.28
Salt	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.15	0.15	0.13	0.13
Trace mineral premix[4]	0.15	0.15	0.13	0.13
L-Lys HCl	0.17	0.31	0.15	0.29
DL-Met	0.02	---	---	---
L-Thr	0.03	---	0.01	---
Phytase[5]	0.13	0.13	0.13	0.13
Total	100.0	100.0	100.0	100.0
Calculated analysis				
Standardized ileal digestible (SID) AA				
Lys, %	0.93	0.93	0.79	0.79
Met:Lys, %	30	34	30	37
Met and Cys:Lys, %	59	70	62	77
Thr:Lys, %	63	66	63	69
Trp:Lys, %	19	19	19	19
Total Lys, %	1.04	1.09	0.89	0.94
CP, %	17.52	20.83	15.62	18.91
SID Lys:ME, g/Mcal	2.79	2.84	2.36	2.41
ME, kcal/kg	3,329	3,265	3,335	3,269
Ca, %	0.59	0.58	0.53	0.56
Available P, %	0.27	0.39	0.25	0.38
Crude fiber, %	2.5	4.9	2.5	4.9
NDF, %	9.2	18.9	9.3	19.0

[1]Phase 1 diets were fed from approximately 41 to 59 kg; Phase 2 diets were fed from 59 to 82 kg.

[2]Dried distillers grains with solubles.

[3]Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.

[4]Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 778.4 FTU/kg of feed and 0.11% available P released.

Table 2-2. Phase 3 and 4 diet composition (as-fed basis)[1]

		Phase 3			Phase 4	
	Fiber level:	Low	Med	High	Low	Med	High
	Wheat midds, %:	0	9.5	19	0	9.5	19
Item	DDGS,[2] %:	0	15	30	0	15	30
Ingredient, %							
Corn		82.65	63.30	43.55	84.95	65.60	45.80
Soybean meal, 46.5% CP		15.30	10.20	5.20	13.15	8.05	3.05
DDGS		---	15.00	30.00	---	15.00	30.00
Wheat middlings		---	9.50	19.00	---	9.50	19.00
Monocalcium P, 21% P		0.25	---	---	0.20	---	---
Limestone		0.98	1.10	1.29	0.93	1.05	1.28
Salt		0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]		0.10	0.10	0.10	0.08	0.08	0.08
Trace mineral premix[4]		0.10	0.10	0.10	0.08	0.08	0.08
L- Lys HCl		0.14	0.21	0.28	0.13	0.20	0.27
DL-Met		---	---	---	---	---	---
L-Thr		---	---	---	---	---	---
Phytase[5]		0.13	0.13	0.13	0.13	0.13	0.13
Total		100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis							
Standardized ileal digestible (SID) AA							
Lys, %		0.69	0.69	0.69	0.63	0.63	0.63
Met:Lys, %		32	36	40	33	38	43
Met and Cys:Lys, %		66	74	83	69	78	88
Thr:Lys, %		64	68	72	66	70	74
Trp:Lys, %		19	19	19	19	19	19
Total Lys, %		0.78	0.81	0.83	0.72	0.74	0.77
CP, %		14.28	15.92	17.57	13.46	15.10	16.75
SID Lys:ME, g/Mcal		2.06	2.08	2.10	1.88	1.90	1.92
ME, kcal/kg		3,344	3,313	3,271	3,348	3,318	3,274
Ca, %		0.49	0.49	0.55	0.46	0.46	0.54
Available P, %		0.22	0.27	0.38	0.21	0.27	0.37
Crude fiber, %		2.4	3.6	4.8	2.4	3.6	4.8
NDF, %		9.3	14.2	19.0	9.3	14.2	19.0

[1]Phase 3 diets were fed from approximately 82 to 105 kg; Phase 4 diets were fed from 105 to 127 kg.
[2]Dried distillers grains with solubles.
[3]Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D_3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B_{12}.
[4]Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.
[5]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 778.4 FTU/kg of feed and 0.11% available P released.

Table 2-3. Chemical analysis of dried distillers grains with solubles (DDGS) and wheat middlings (as-fed basis)

Item	DDGS	Wheat middlings
Nutrient,%		
DM	90.2	88.8
CP	24.3 (27.2)[1]	16.6 (15.9)
Fat (oil)	12.3	4.0
Crude fiber	6.0 (7.7)	7.9 (7.0)
ADF	10.6 (9.9)	10.3 (10.7)
NDF	36.1 (25.3)	36.6 (35.6)
Ash	4.3	5.7

[1] Values in parenthesis indicate those used in diet formulation.

Table 2-4. Bulk density of experimental diets (as-fed basis)[1]

		Treatments	
Fiber level:	Low	Med	High
Wheat midds,%:	0	9.5	19.0
Bulk density, g/L[1,2] DDGS[3],%:	0	15.0	30.0
Phase 1	653	---	488
Phase 2	669	---	488
Phase 3	647	609	515
Phase 4	636	547	493

[1] Diet samples collected from the tops of each feeder during each phase.
[2] Phase 1 was d 0 to 20; Phase 2 was d 20 to 43; Phase 3 was d 43 to 67; Phase 4 was d 67 to 90.
[3]Dried distillers grains with solubles.

Table 2-5. Effect of dietary fiber level prior to marketing on finishing pig growth performance[1]

Treatment:	1	2	3	4	5	6	
d 0 to 43:	Low[2]	High[3]	High	High	High	High	
d 43 to 67:	Low	Low	Med[4]	High	High	High	
d 67 to 90:	Low	Low	Med	Low	Med	High	SEM
BW, kg							
d 0	41.0	41.1	41.0	41.0	40.9	41.0	0.81
d 20	61.3	60.7	60.7	60.8	60.5	60.7	0.98
d 43	81.7	80.5	80.6	80.7	80.7	80.7	1.36
d 67	101.1	101.6	102.5	101.3	101.2	101.5	1.31
d 90	120.6	122.1	122.8	121.9	121.5	121.6	1.40
d 0 to 43							
ADG, kg	0.95	0.92	0.92	0.92	0.92	0.92	0.02
ADFI, kg	2.41	2.42	2.39	2.42	2.42	2.43	0.05
G:F	0.39	0.38	0.39	0.38	0.38	0.38	0.01
d 43 to 67							
ADG, kg	0.81	0.88	0.91	0.86	0.85	0.87	0.02
ADFI, kg	2.64	2.79	2.85	2.86	2.85	2.87	0.07
G:F	0.31	0.32	0.32	0.30	0.30	0.30	0.01
d 67 to 90							
ADG, kg	0.85	0.89	0.88	0.90	0.88	0.87	0.02
ADFI, kg	2.80	2.83	2.94	3.02	3.03	3.05	0.06
G:F	0.30	0.31	0.30	0.30	0.29	0.29	0.01
d 43 to 90							
ADG, kg	0.83	0.88	0.90	0.88	0.87	0.87	0.01
ADFI, kg	2.72	2.81	2.90	2.93	2.94	2.96	0.06
G:F	0.30	0.31	0.31	0.30	0.30	0.29	0.01
d 0 to 90							
ADG, kg	0.89	0.90	0.91	0.90	0.89	0.89	0.01
ADFI, kg	2.57	2.62	2.64	2.69	2.69	2.70	0.05
G:F	0.35	0.34	0.34	0.33	0.33	0.33	0.01

[1]A total of 264 pigs (PIC 327 × 1050, initial BW= 41.0 kg) were used in this 90-d study.

[2]Refers to low fiber corn-soybean meal based diet without dried distillers grains with solubles (DDGS) or wheat middlings (midds).

[3]Refers to high fiber diet with 30% DDGS and 19.0% midds.

[4]Refers to medium fiber diet with 15% DDGS and 9.5% midds.

Table 2-6. Main effects of dietary fiber level prior to marketing on finishing pig growth performance[1]

	Probability, $P <$						
	Duration[2]		Fiber level, d 43 to 90[3]		Fiber level, d 67 to 90[4]		Low vs. medium fiber[5]
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	
BW, kg							
d 0	0.96	0.97	0.99	0.92	0.96	0.91	
d 20	0.63	0.75	0.98	0.98	0.91	0.82	
d 43	0.59	0.66	0.92	0.98	1.00	0.99	
d 67	0.90	0.74	0.98	0.57	0.89	0.89	
d 90	0.64	0.43	0.81	0.58	0.89	0.90	
d 0 to 43							
ADG, kg	0.20	0.33	0.92	0.93	0.91	0.98	
ADFI, kg	0.75	0.79	0.92	0.49	0.94	0.89	
G:F	0.05	0.47	0.95	0.34	0.99	0.81	
d 43 to 67							
ADG, kg	0.02	0.01	0.64	0.04	0.59	0.66	
ADFI, kg	0.01	0.29	0.42	0.75	0.91	0.92	
G:F	0.40	0.22	0.20	0.14	0.75	0.95	
d 67 to 90							
ADG, kg	0.30	0.24	0.65	0.92	0.45	1.00	
ADFI, kg	0.001	0.81	0.008	0.99	0.63	0.98	
G:F	0.06	0.12	0.005	0.94	0.24	0.99	
d 43 to 90							
ADG, kg	0.04	0.02	0.56	0.28	0.79	0.82	0.82
ADFI, kg	0.003	0.61	0.07	0.86	0.76	0.94	0.42
G:F	0.09	0.08	0.01	0.35	0.57	0.96	0.54
d 0 to 90							
ADG, kg	0.65	0.36	0.76	0.47	0.91	0.90	0.83
ADFI, kg	0.03	0.86	0.22	0.74	0.82	0.86	0.83
G:F	0.004	0.43	0.03	0.16	0.62	0.86	0.99

[1] A total of 264 pigs (PIC 327 × 1050, initial BW= 41.0 kg) were used in a 90-d study.

[2] Effect of duration of fiber reduction regardless of fiber level fed during reduction period.

[3] Effect of fiber level (high, medium, low) fed from d 43 to 90 (last 47 d before market; treatments 2, 3, and 6).

[4] Effect of fiber level (high, medium, low) fed from d 67 to 90 (last 23 d before market; treatments 4, 5, and 6).

[5] Effect of low vs. medium fiber after pigs were fed high fiber from d 0 to 43 (treatments 2 and 4 vs. 3 and 5).

Table 2-7. Effect of dietary fiber level prior to marketing on finishing pig carcass characteristics[1]

	Treatment						
	1	2	3	4	5	6	
d 0 to 43:	Low[2]	High[3]	High	High	High	High	
d 43 to 67:	Low	Low	Med[4]	High	High	High	
d 67 to 90:	Low	Low	Med	Low	Med	High	SEM
Carcass yield, %[5]	73.2	72.9	71.6	73.0	72.4	71.7	0.26
HCW, kg	88.3	89.0	88.0	88.9	88.0	87.0	1.15
Backfat depth, mm.[6]	18.8	18.4	17.5	18.3	18.9	16.8	0.45
Loin depth, mm.[6]	58.4	59.8	58.6	59.2	57.1	59.3	1.06
Lean, %[6]	53.0	53.4	53.6	53.3	52.7	54.0	0.31
Jowl iodine value	68.4	70.6	75.8	74.8	76.6	78.5	0.94

[1] A total of 264 pigs (PIC 327 × 1050, initial BW= 41.0 kg) were used in this 90-d trial.
[2] Refers to low fiber corn-soybean meal based diet without dried distillers grains with solubles (DDGS) or wheat middlings (midds).

[3] Refers to high fiber diet with 30% DDGS and 19% midds.

[4] Refers to medium fiber diet with 15% DDGS and 9.5% midds.
[5] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.

[6] Adjusted by using HCW as a covariate.

Table 2-8. Main effects of dietary fiber level prior to marketing on finishing pig carcass characteristics[1]

	Probability, $P <$						
	Duration[2]		Fiber level, d 43 to 90[3]		Fiber level, d 67 to 90[4]		Low vs. medium fiber[5]
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	
Carcass yield, %[6]	0.002	0.85	0.004	0.03	0.002	0.97	0.001
HCW, kg	0.49	0.38	0.23	0.98	0.26	0.98	0.43
Backfat depth, mm[7]	0.01	0.22	0.02	0.80	0.03	0.02	0.74
Loin depth, mm[7]	0.71	0.94	0.74	0.46	0.95	0.12	0.14
Lean, %[7]	0.11	0.45	0.27	0.73	0.18	0.02	0.46
Jowl iodine value	0.001	0.91	0.001	0.27	0.01	0.94	0.001

[1] A total of 264 pigs (PIC 327 × 1050, initial BW= 41.0 kg) were used in a 90-d study.

[2] Effect of duration of fiber reduction regardless of fiber level fed during reduction period.

[3] Effect of fiber level (low, medium, high) fed from d 43 to 90 (last 47 d before market; treatments 2, 3, and 6).

[4] Effect of fiber level (low, medium, high) fed from d 67 to 90 (last 23 d before market; treatments 4, 5, and 6).

[5] Effect of low vs. medium fiber after pigs were fed high fiber from d 0 to 43 (treatments 2 and 4 vs. 3 and 5).

[6] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.

[7] Adjusted by using HCW as a covariate.

Table 2-9. Effect of dietary fiber level prior to marketing on finishing pig intestinal and organ weights, kg[1]

Treatment:	1	2	3	4	5	6	
d 0 to 43:	Low[2]	High[3]	High	High	High	High	
d 43 to 67:	Low	Low	Med[4]	High	High	High	
d 67 to 90:	Low	Low	Med	Low	Med	High	SEM
Full pluck	12.14	12.86	13.02	12.43	12.69	13.07	0.41
Whole intestine	7.52	8.03	8.37	7.65	8.02	8.45	0.32
Stomach							
Full	0.87	0.98	0.98	1.02	0.95	0.95	0.07
Stripped	0.63	0.67	0.67	0.67	0.66	0.68	0.02
Rinsed	0.63	0.63	0.63	0.64	0.64	0.66	0.02
Cecum							
Full	0.72	0.58	0.86	0.68	0.74	0.77	0.09
Stripped	0.27	0.25	0.28	0.23	0.25	0.25	0.01
Rinsed	0.25	0.23	0.25	0.23	0.25	0.25	0.01
Large intestine							
Full	2.98	3.23	3.72	3.04	3.40	3.95	0.21
Stripped	1.54	1.54	1.66	1.48	1.55	1.79	0.08
Rinsed	1.44	1.47	1.55	1.39	1.45	1.62	0.06
Small intestine							
Full	2.75	3.09	2.75	2.56	2.76	2.67	0.13
Heart	0.45	0.42	0.42	0.42	0.43	0.42	0.01
Lungs	0.61	0.64	0.56	0.56	0.62	0.59	0.03
Liver	1.78	1.80	1.73	1.81	1.76	1.92	0.06
Kidneys	0.36	0.37	0.42	0.37	0.39	0.39	0.02
Spleen	0.17	0.20	0.22	0.20	0.19	0.19	0.01
Reproductive tract	0.55	0.60	0.53	0.57	0.52	0.54	0.08

[1] A total of 264 pigs (PIC 327 × 1050, initial BW= 90.1 lb) were used in this 90-d trial.

[2] Refers to low fiber corn-soybean meal based diet without dried distillers grains with solubles (DDGS) or wheat middlings (midds).

[3] Refers to high fiber diet with 30% DDGS and 19% midds.

[4] Refers to medium fiber diet with 15% DDGS and 9.5% midds.

Table 2-10. Main effects of dietary fiber level prior to marketing on finishing pig intestinal and organ weights, kg[1]

	Probability, *P* <						
	Duration[2]		Fiber level d 43 to 90[3]		Fiber level d 67 to 90[4]		Low vs. medium fiber[5]
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	
Full pluck	0.16	0.71	0.74	0.92	0.28	0.91	0.62
Whole intestine	0.08	0.94	0.36	0.74	0.09	0.95	0.27
Stomach							
Full	0.32	0.28	0.76	0.86	0.52	0.71	0.65
Stripped	0.12	0.74	0.66	0.80	0.74	0.57	0.81
Rinsed	0.36	0.58	0.36	0.69	0.65	0.69	1.00
Cecum							
Full	0.73	0.69	0.13	0.12	0.46	0.89	0.07
Stripped	0.38	0.79	0.70	0.12	0.33	0.57	0.08
Rinsed	0.93	0.68	0.39	0.32	0.28	0.26	0.05
Large intestine							
Full	0.01	0.44	0.02	0.61	0.01	0.72	0.05
Stripped	0.07	0.11	0.03	0.95	0.01	0.38	0.22
Rinsed	0.13	0.29	0.11	0.92	0.02	0.51	0.27
Small intestine							
Full	0.50	0.26	0.03	0.43	0.58	0.38	0.58
Heart	0.07	0.38	0.91	0.87	0.84	0.73	0.85
Lungs	0.65	0.78	0.34	0.12	0.42	0.28	0.71
Liver	0.15	0.13	0.18	0.10	0.22	0.16	0.33
Kidneys	0.39	0.36	0.44	0.03	0.53	0.59	0.03
Spleen	0.19	0.03	0.54	0.13	0.54	0.90	0.66
Reproductive tract	0.92	0.82	0.58	0.69	0.81	0.73	0.47

[1] A total of 264 pigs (PIC 327 × 1050, initial BW= 41.0 kg) were used in an 90-d study.

[2] Effect of duration of fiber reduction regardless of fiber level fed during reduction period.

[3] Effect of fiber level (low, medium, high) fed from d 43 to 90 (last 47 d before market; treatments 2, 3, and 6).

[4] Effect of fiber level (low, medium, high) fed from d 67 to 90 (last 23 d before market; treatments 4, 5, and 6).

[5] Effect of low vs. medium fiber after pigs were fed high fiber from d 0 to 43 (treatments 2 and 4 vs. 3 and 5).

Table 2-11. Effect of dietary fiber levels prior to marketing on finishing pig intestinal and organ weights, %[1, 2]

Treatment:	1	2	3	4	5	6	
d 0 to 43:	Low[3]	High[4]	High	High	High	High	
d 43 to 67:	Low	Low	Med[5]	High	High	High	
d 67 to 90:	Low	Low	Med	Low	Med	High	SEM
Full pluck	9.83	10.75	10.77	10.29	10.57	10.70	0.30
Whole intestine	6.09	6.64	6.92	6.33	6.69	6.92	0.25
Stomach							
Full	0.70	0.82	0.81	0.84	0.79	0.78	0.05
Stripped	0.51	0.55	0.55	0.55	0.55	0.56	0.02
Rinsed	0.51	0.52	0.52	0.53	0.53	0.54	0.02
Cecum							
Full	0.58	0.49	0.72	0.57	0.62	0.63	0.07
Stripped	0.21	0.20	0.23	0.19	0.21	0.21	0.01
Rinsed	0.20	0.19	0.21	0.19	0.21	0.20	0.01
Large intestine							
Full	2.42	2.67	3.07	2.52	2.84	3.23	0.17
Stripped	1.25	1.27	1.37	1.22	1.29	1.47	0.06
Rinsed	1.17	1.21	1.28	1.15	1.21	1.33	0.05
Small intestine							
Full	2.22	2.56	2.28	2.12	2.29	2.18	0.10
Heart	0.37	0.35	0.35	0.35	0.36	0.34	0.01
Lungs	0.49	0.53	0.46	0.46	0.51	0.49	0.02
Liver	1.44	1.48	1.43	1.50	1.47	1.57	0.05
Kidneys	0.29	0.30	0.35	0.31	0.32	0.32	0.01
Spleen	0.14	0.17	0.18	0.17	0.16	0.16	0.01
Reproductive tract	0.44	0.50	0.44	0.47	0.43	0.44	0.06

[1] A total of 264 pigs (PIC 327 × 1050, initial BW= 41.0 kg) were used in this 90-d trial.

[2] All values are a percent of live weight ((i.e., (reproductive tract/ live weight) × 100)).

[3] Refers to low fiber corn-soybean meal based diet without dried distillers grains with solubles (DDGS) or wheat middlings (midds).

[4] Refers to high fiber diet with 30% DDGS and 19% midds.

[5] Refers to medium fiber diet with 15% DDGS and 9.5% midds.

Table 2-12. Main effect of dietary fiber levels prior to marketing on finishing pig intestinal and organ weights, %[1]

	Probability, *P* <						
	Duration[2]		Fiber level d 43 to 90[3]		Fiber level d 67 to 90[4]		Low vs medium fiber[5]
	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	
Full pluck	0.09	0.22	0.92	0.91	0.34	0.85	0.63
Whole intestine	0.05	0.52	0.45	0.65	0.11	0.83	0.21
Stomach							
Full	0.33	0.12	0.63	0.81	0.43	0.78	0.63
Stripped	0.08	0.28	0.79	0.89	0.90	0.77	0.91
Rinsed	0.19	0.85	0.42	0.78	0.79	0.92	0.88
Cecum							
Full	0.65	0.86	0.16	0.11	0.51	0.82	0.07
Stripped	0.53	0.87	0.77	0.10	0.39	0.45	0.07
Rinsed	0.86	0.99	0.46	0.28	0.37	0.18	0.04
Large intestine							
Full	0.005	0.74	0.03	0.57	0.006	0.88	0.04
Stripped	0.04	0.23	0.04	0.97	0.009	0.50	0.18
Rinsed	0.06	0.49	0.12	0.83	0.02	0.65	0.20
Small intestine							
Full	0.44	0.21	0.01	0.47	0.68	0.27	0.58
Heart	0.17	0.71	0.66	0.86	0.68	0.51	0.85
Lungs	0.80	0.93	0.19	0.08	0.45	0.18	0.63
Liver	0.04	0.37	0.18	0.10	0.26	0.22	0.37
Kidneys	0.34	0.16	0.45	0.01	0.62	0.44	0.02
Spleen	0.29	0.02	0.49	0.11	0.47	0.99	0.62
Reproductive tract	0.94	0.75	0.53	0.69	0.76	0.71	0.43

[1] A total of 264 pigs (PIC 327 × 1050, initial BW= 41.0 kg) were used in an 90-d study.

[2] Effect of duration of fiber reduction regardless of fiber level fed during reduction period.

[3] Effect of fiber level (low, medium, high) fed from d 43 to 90 (last 47 d before market; treatments 2, 3, and 6).

[4] Effect of fiber level (low, medium, high) fed from d 67 to 90 (last 23 d before market; treatments 4, 5, and 6).

[5] Effect of low vs. medium fiber after pigs were fed high fiber from d 0 to 43 (treatments 2 and 4 vs. 3 and 5).

Chapter 3 - Effects of Lowering Dried Distillers Grains with Solubles and Wheat Middlings With or Without the Addition of Choice White Grease Prior to Marketing on Finishing Pig Growth Performance, Carcass Characteristics, Carcass Fat Quality and Intestinal Weights

Abstract

The objectives of this study was to compare the effects of adding choice white grease in combination with a 19-d fiber reduction strategy for pigs fed high fiber diets containing wheat middlings and DDGS on growth performance, carcass characteristics, carcass fat quality, and intestinal weights of finishing pigs. A total of 225 pigs (327 × 1050: PIC Hendersonville, TN; initially 45.5 kg) were used in a 92-d study. Pens of pigs were allotted to 1 of 7 dietary treatments (5 or 6 pens/treatment). Treatments were arranged in a 2 × 3 factorial plus control with main effects of added choice white grease (CWG; 0 or 3%) during the fiber reduction period (d 73 to 92) and fiber levels of low (corn-soybean meal diet), medium (9.5% wheat middlings [midds] and 15% dried distillers grains with solubles [DDGS]), or high (19% midds and 30% DDGS) during the reduction period. Pigs fed reduction diets (d 73 to 92) were first fed high-fiber (19% midds and 30% DDGS) diets from d 0 to 73. Control pigs were fed low-fiber corn-soybean meal diets from d 0 to 92. No CWG × fiber interactions occurred except for jowl iodine value (IV; $P < 0.03$). Pigs fed high levels of DDGS and midds had increased ($P < 0.001$) jowl IV, with the interaction occurring because there was a larger increase in IV when CWG was added to the diets. Adding CWG during the reduction period (d 73 to 92) improved ($P < 0.02$) ADG and G:F, leading to an overall (d 0 to 92) improvement ($P < 0.02$) in G:F. Carcass yield and backfat depth increased (linear, $P < 0.05$) when low-fiber diets were fed from d 73 to 92. Feeding low levels of DDGS and midds during the reduction period decreased (linear, $P < 0.01$) whole intestine weights, mainly due to the reduction ($P < 0.02$) in rinsed stomach and full large-intestine weights. Lowering dietary DDGS and midds during a 19-d fiber reduction period increased yield through reduced large intestine weight and content and improved jowl IV. The

addition of CWG improved growth performance, but did not improve carcass characteristics that were negatively influenced by high levels of DDGS and midds.

Key words: DDGS, carcass, fiber, finishing pigs, wheat middlings, yield, intestinal weights

Introduction

Feed ingredients, such as wheat middlings (midds) and dried distiller grains with solubles (DDGS), are often used as alternatives to corn and soybean meal in swine diets. While these ingredients are used with the intent of lowering feed costs, it has been shown that they can negatively affect performance and carcass characteristics (Asmus et al., 2011a). The two main areas of concern are the reduction in carcass yield and negative effect of on carcass fat quality (Salyer et al., 2012).

Multiple studies have been conducted to evaluate the effect of dietary inclusion of DDGS on growth performance, carcass yield, and carcass characteristics (Whitney et al., 2006; Stein and Shurson, 2009). Similarly, research with wheat middlings (midds) has shown negative effects on growth performance, carcass yield, and carcass characteristics (Feoli et al., 2006; Cromwell et al., 1992).

Previous work by Asmus et al. (2011a) developed a model utilizing 30% DDGS and 19% midds that has consistently shown reduced carcass yield. Further work by Asmus et al. (2011b) utilized different fiber reduction strategies to improve carcass yield and improve carcass fat IV; it was determined that a short fiber reduction period of 23 d was successful at fully recovering yield loss with no further improvements with a longer reduction time. However, it was also concluded that while the short reduction period (23 d) was successful at reducing carcass fat IV, a longer reduction period (47 d) had a larger impact.

Multiple studies have shown the addition of CWG can improve ADG and G:F (Benz et al., 2007; De La Llata et al., 2001; Linneen et al., 2008). Similarly, studies by Baudon et al. (2003) and Benz et al. (2007) have shown the addition of CWG to swine diets can successfully improve carcass yield. However, no data exists to evaluate the potential effects of adding CWG to pig diets during the fiber reduction period prior to marketing. Soft carcass fat with a high IV has been observed in pigs fed high levels of DDGS and midds (Salyer et al., 2012; Asmus et al., 2011a). Reducing the level of DDGS in the diet prior to market has been successful in lowering carcass fat IV and improving yield (Jacela et al., 2009; Gaines et al., 2007). Previous work by Asmus et al. (2011b) has shown that increased fiber levels from diets containing DDGS and midds have increased gut fill mainly in the large intestine.

Therefore, the objective of this trial was to confirm that a short fiber reduction period of 19 d can successfully recover yield as well as determine the effects of CWG in combination with a fiber reduction period prior to market has effects on growth performance, carcass characteristics, and carcass fat quality of growing-finishing pigs.

Materials and methods

General

The Kansas State University (K-State) Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the K-State Swine Teaching and Research Center in Manhattan, KS. The facility was a totally enclosed, environmentally regulated, mechanically ventilated barn containing 36 pens (2.4 × 3.1 m). The pens had adjustable gates facing the alleyway that allowed for 0.93 sq m/pig. Each pen was equipped with a cup waterer and a single-sided, dry self-feeder (Farmweld, Teutopolis, IL), with 2 eating spaces located in the fence line. Pens were located over a completely slatted concrete floor with a 1.2-m pit underneath for manure storage. The facility was also equipped with a computerized feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. The equipment provided pigs with ad libitum access to food and water.

Animals and diets

A total of 225 pigs (327 × 1050: PIC Hendersonville, TN; initially 45.5 kg) were used in a 92-d trial. Pens of pigs (4 gilts and 2 barrows per pen) or (4 gilts and 3 barrows per pen) were randomly allotted by initial weight to 1 of 7 dietary treatments with 5 or 6 replications per treatment. Treatments were arranged in a 2 × 3 factorial plus control with main effects of added CWG (0 or 3%) during the fiber reduction period (d 73 to 92) and fiber levels of low (corn-soybean meal diet), medium (9.5% midds and 15% DDGS) or high (19% midds and 30% DDGS) during the reduction period. Prior to the reduction period all pigs, except those on the control diet, were fed high fiber (19% midds and 30% DDGS) diets from d 0 to 73. Control pigs were fed low fiber corn-soybean meal diets from d 0 to 92. Dietary treatments were corn-soybean meal-based and fed in 4 phases from approximately 46 to 67, 67 to 81, 81 to 108, 108 to 125 kg BW for phases 1 to 4 respectively (Tables 3.1 and 3.2). All diets were fed in meal form and balanced to similar SID lysine levels within each phase. Energy level was allowed to be reduced when DDGS and midds were added to the diet. Due to the high level of available P in DDGS, no supplemental P was required in diets containing high levels of DDGS. Phytase was added to all diets at a constant level of 0.13% of the diet which provided 778.4 FTU/kg of complete diet and a 0.12% P release.

Wheat middling and DDGS samples were collected at the time of feed manufacturing and a composite sample was analyzed (Table 3.3) for moisture (AOAC 934.01, 2006), CP (AOAC 990.03, 2006), crude fat (AOAC 920.39 A, 2006), crude fiber (AOAC 978.10, 2006), ash (AOAC 942.05, 2006), Ca (AOAC 965.14/985.01, 2006), and P (AOAC 965.17/985.01, 2006) as well as a complete AA profile (AOAC 982.30 Ea,b, chp. 45.3.05, 2006.) at the University of Missouri Agricultural Experiment Station Chemical Laboratories (Columbia, MO). Also, feed samples were collected from each feeder during each phase and combined for a single composite sample by treatment for each phase to measure bulk density (Table 3.4).

Pigs and feeders were weighed on d 0, 23, 43, 73, and 92 to calculate ADG, ADFI, and G:F. On d 92, all pigs were weighed individually, the second heaviest gilt in each pen (1 pig per pen, 5 pigs per treatment) was identified to be harvested at the Kansas State University Meats Lab (KSU), and all others were then transported to Triumph Foods LLC., St. Joseph, MO. The pigs selected for harvest at KSU were blocked by treatment and randomly allotted to a harvest order to equalize the withdrawal time from feed before slaughter. Feeders were removed from pigs at 18:00 the night before harvest and harvest began at 06:00 the following morning. Hot carcass weights were measured immediately after evisceration. Following evisceration, the entire pluck (heart, lungs, liver, kidneys, spleen, stomach, cecum, large intestine, small intestine, and reproductive tract) was weighed and then the individual organs were weighed. After full organ weights were recorded, the large intestine, stomach, and cecum were physically stripped of contents and reweighed; then were flushed with water, physically stripped of contents, and weighed again. For pigs harvested at the commercial packing plant, pigs were individually tattooed in sequential order with a unique tattoo number to allow for carcass data collection at the packing plant and individual data retrieval. Hot carcass weights were measured immediately after evisceration and each carcass was evaluated for percentage yield, back fat, loin depth, and percentage lean. Percentage carcass yield was calculated by dividing HCW by live weight obtained before transport to the packing plant. Fat depth and loin depth were measured with an optical probe inserted between the 3^{rd} and 4^{th} last rib (counting from the ham end of the carcass) at a distance approximately 7.1 cm from the dorsal midline. Fat-free lean index was calculated according to National Pork Producers Council (1991) equations for lean containing 5% fat where Lean (5% fat), lb = 2.83 + (0.469 × HCW, lb) – (18.47 × last rib fat thickness, in.) + (9.824 × loin muscle depth, in.). Jowl samples were collected and analyzed by Near Infrared Spectroscopy (NIR; Bruker MPA; Multi-Purpose Analyzer) for fat iodine value using the equation of Cocciardi et al. (2009). Because there were differences in HCW, it was used as a covariate for back fat, loin depth, and percentage lean.

Statistical analysis

Data were analyzed as a completely randomized design using the PROC-MIXED procedure of the Statistical Analysis System (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. The main effects of fiber level and CWG prior to market were tested. Linear and quadratic contrasts were used to determine the effects of fiber level (low, medium, high) during the reduction period. Differences between treatments were determined by using least squares means. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results

Bulk density tests showed that adding dietary fiber from midds and DDGS dramatically decreased diet bulk density (Table 3.4) which agrees with previous work by Salyer et al. (2012) and Asmus et al. (2011b) who found a reduction in bulk density when midds or DDGS were included in the diet.

Feeding high fiber diets during the first 73 d of the experiment had no impact ($P > 0.44$) on ADG (Table 3.5 and 3.6); however, pigs fed higher fiber diets tended ($P < 0.10$) to have poorer feed efficiency when compared to pigs fed the low fiber (control) diet. Adding CWG to the diet during the fiber reduction period (d 73 to 92) increased ($P < 0.02$) ADG and improved ($P < 0.006$) G:F.

Overall (d 0 to 92), the fiber reduction strategies did not influence ($P > 0.39$) ADG, ADFI or G:F; however, the addition of CWG during the 19 d reduction period did result in an overall (d 0 to 92) improvement ($P < 0.002$) in G:F.

Carcass yield and backfat depth increased (linear, $P < 0.05$) as the fiber level in the reduction diets decreased from d 73 to 92 (Table 3.7 and 3.8). Removing the DDGS and midds for the 19-d period returned yield to similar levels as the control diet. There were no CWG × fiber interactions ($P < 0.13$) except for jowl IV which increased (linear, $P < 0.03$) when increasing DDGS and Midds were fed during the reduction period with a greater response when CWG was added to the diet (linear, $P < 0.001$), than when the diet did not contain CWG (linear, $P < 0.09$).

Feeding decreasing levels of DDGS and midds during the last 19 d of the experiment decreased (linear, $P < 0.01$) whole intestine weights whether calculated on a weight basis (Table 3.9 and 3.10) or percentage of live weight basis (Table 3.11 and 3.12). Much of the difference was due to a reduction in ($P < 0.01$) full large intestine weight when dietary fiber was reduced, with a greater response when CWG was added to the diet resulting in a tendency ($P > 0.09$) for an interactive effect. The fiber level fed had no impact ($P > 0.21$) on the actual intestine weight.

No differences ($P > 0.18$) were detected in full stomach weights, however, rinsed (empty) stomach weights tended ($P < 0.06$) to be reduced when calculated on a weight basis and were reduced ($P < 0.02$) when calculated as a percentage of body weight when low fiber diets were fed during the reduction period.

Cecum weights were not influenced by the addition of CWG, or dietary fiber level during the reduction period; however, there were minor ($P < 0.11$) reductions in full cecum weights when the low fiber diet was fed during the reduction period. These differences were not maintained in stripped or rinsed cecum weights indicating the change was due to an increase in gut fill and not related to an increase in actual organ weight. Other organs were not influenced by diet other than a quadratic effect ($P < 0.05$) on reproductive tract weight as dietary fiber changed during the withdrawal period in diets containing CWG.

Discussion

Feeding high levels of dietary fiber from DDGS and midds had no negative overall effect on growth; however G:F tended to be reduced when pigs were fed the high fiber diet from d 0 to 73 when compared to pigs fed the control diet. These results agree with previous work by Asmus et al., (2011b) who reported no differences in ADG or ADFI when DDGS and midds were included in the diet at 30% and 19% respectively; however Asmus et al. (2011a,b) showed reductions in G:F. The current trial also disagrees with work by Salyer et al., (2012) who found that as midds were increased (up to 20%) in diets containing 30% DDGS that pigs had decreased ADG and worse feed efficiency. A possible explanation for the difference between findings by Salyer et al. (2012) could be that the stocking density in our trial was slightly lower, although floor space was equalized by adjusting pen size, less pigs per pen allowed pigs more feeder space and therefore a greater amount of time at the feeder to allow them to intake enough feed to meet energy needs. Reducing fiber levels for the final 19 d before harvest (d 73 to 92) had no impact on ADG, ADFI, or G:F which agrees with work by Asmus et al. (2011b). Jacela et al. (2009) also reported no overall differences in growth performance when 30% DDGS was removed from diets containing 3% added fat at 3 and 6 wk prior to harvest. However, other data reported by Gaines et al. (2007) found that G:F was decreased when pigs were fed 30% DDGS with no reduction prior to market. These results could vary due to the variation found within DDGS source and quality (Stein and Shurson, 2009). The addition of 3% CWG during the 19-d reduction period had no effect on ADFI; however, it improved ADG and G:F. This improvement during the 19-d reduction period was large enough that it resulted in an overall improvement in G:F. The improvement in growth with CWG addition agrees with work by Salyer et al. (2012) who also reported increased ADG and G:F when CWG was added to diets containing both DDGS and midds. Although there are no reported studies that utilize added CWG in combination with a fiber reduction strategy to improve carcass yield, the current trial agrees with other studies finding improvement in feed efficiency when CWG was added to the diet (Benz et al., 2007; De la Llata et al., 2001; Linneen et al., 2008).

Reducing the fiber level in the diet for 19 d prior to harvest for pigs previously fed high fiber diets was successful at returning carcass yield to levels similar to that of pigs fed the control diet throughout the trial. Similar to previous work by Asmus et al. (2011b), the pigs switched from high fiber diets to low fiber diets had the greatest improvement with the pigs switched to the medium fiber diets having an intermediate response. This improvement in yield agrees with studies where DDGS (Gaines et al., 2007) or DDGS and midds (Asmus et al., 2011b) were removed from the diet prior to market. Gaines et al. (2007) however, reported that a 6 wk reduction strategy was required to fully recover the yield loss, whereas in our trial the entire loss in yield was recovered in the 19-d reduction period. Other data reported by Xu et al., (2010), Hill et al., (2008), and Jacela et al., (2009) found no improvements in carcass yield when DDGS were removed from the diet. Previous studies summarized by Stein and Shurson (2009) reported in a review inconsistency in yield responses to DDGS inclusion in the diet. Of the 18 trials summarized in their review, 10 studies found no significant change in yield while 8 studies found significant reductions in yield. It can be speculated that the variation in response could be closely linked to variation in DDGS source and quality (Spiehs et al., 2002). It also should be noted that the diets used in the current trial included 19% dietary midds which have shown consistent reductions in carcass yield (Salyer et al., 2012) and could have a more significant effect than DDGS (Asmus et al., 2011a). This could also be partly attributed to the increased gut fill associated with feeding diets high in fiber (Shaw et al., 2002; Just, 1982; Asmus et al., 2011b). The addition of CWG did not improve carcass yield in the current trial which differs from work by Benz et al. (2007) who reported increased carcass yield when 5% CWG or soybean oil was added to corn-soybean meal based diets for increasing lengths of time (26, 54, 68, or 82 d). However, the current study agrees with work by De la Llata et al. (2001), Engel et al. (2001), and Baudon et al. (2003) who saw no differences in carcass yield with the addition of dietary CWG in low fiber diets. Furthermore, Shaw et al. (2002) and Salyer et al. (2012) added CWG to diets that included a constant level (no reduction) of 30% or 20% dietary midds until marketing, respectively, and saw reduction in carcass yield.

For other carcass traits, pigs fed the diet with added CWG had increased loin depth when fiber level was reduced for 19 d. Salyer et al. (2012) also reported reduced loin depth when dietary midds levels increased. Backfat depth was increased when pigs were fed the low fiber (corn-soybean meal-based) diet regardless of dietary fat inclusion; however the effect was more significant when 3% CWG was included in the diet during the last 19 d. Carcass backfat depth was increased linearly when fiber was reduced in the diet from d 73 to 92. This is supported by Jacela et al. (2009) who also reported an increase in backfat depth when pigs were switched from high DDGS diets to a corn-soybean meal based diet. This could be attributed to the energy difference between the control (low fiber) and negative control (high fiber) diet, with midds having a greater reduction in energy causing less backfat to be deposited (Salyer et al., 2012).

With soft and off-white fat a main factor associated with price reductions of processed products like bacon (Carr et al., 2005), some packers have begun setting price reductions for pigs that have increased levels of soft off-white fat. Therefore, it is crucial to find methods to improve fat quality of pigs fed unsaturated fat sources, such as DDGS. Consistent increases in fat IV have been documented when pigs are fed high levels of DDGS (Benz et al., 2010; Whitney et al., 2006). In the current trial, jowl fat IV was reduced when the level of DDGS and midds were reduced in the diet and lower fiber levels were fed during the reduction period regardless of CWG inclusion. These results agree with Hill et al. (2008). In the current experiment, the response to lowering fiber was larger when pigs were fed diets that contained 3% CWG for the 19 d prior to market causing an interactive effect to occur. When pigs were switched to the low or medium fiber diet 19 d prior to market jowl fat IV were similar; however, when pigs remained on high fiber diets, pigs fed 3% added CWG had jowl fat IV much higher than pigs fed high fiber diets without CWG. This could possibly be explained by the fact that pigs preferentially deposit C 18:2 (main source of unsaturation) at the expense of other fatty acids (Koch et al., 1968); consequently, due to the extra energy from the addition of CWG, pigs deposited a greater percentage of 18:2 resulting in elevated IV. Benz et al. (2007) reported increased carcass IV when CWG was added to corn-soybean meal-based diets.

The greatest impact of fiber reduction treatments on organ weights was on full large intestine weight and rinsed stomach weights with the response accounting for roughly 50% (diets without CWG) to 80% (diets with 3% CWG) of the difference in yield response. This finding agrees with research by Agyekum et al. (2012) that reported pigs fed DDGS diets for 28 d had heavier colon plus rectum and portal-drained viscera than pigs fed the control diet; however, no differences were detected in stomach weights. Similarly Asmus et al. (2011b) reported that reducing the dietary fiber level fed during the reduction period accounted for roughly 50% of the yield response when pigs were switched to a corn-soybean meal based diet during the 23 d fiber reduction period. Lowering the fiber level during the 19-d reduction period had a greater yield response when CWG was added to the diet. Although no significant differences were detected in full stomach weights, rinsed (empty) stomach weights were reduced when calculated on a percentage of body weight when fiber levels were reduced during the reduction period indicating a reduction in actual organ size. Small reductions were detected in full cecum weights when fiber was removed from the diet during the 19-d reduction period, however, the differences were not maintained in rinsed (empty) weights, implying the change was due to fill and not an actual increase in organ weight.

In previous trials by Asmus et al. (2011b), increases were detected in liver and kidney weights as fiber levels increased. It was speculated that the increases could possibly be attributed to increased CP levels in the diet (Anugwa et al., 1989). However, there were no differences detected in the current trial with the exception of a tendency for reduced liver weights when CWG was added to the diet. This agrees with work by Agyekum et al. (2012) that found no differences in liver weights with diets similar in CP (18.2% vs 18.1%) even though the diets used in the current trial had significant differences in CP 13.5% vs. 17.0%.

In summary, lowering the fiber level for 19 d prior to market improved carcass yield through reductions in large intestine content and rinsed stomach weight. Lowering the fiber level, was also associated with a decreased jowl IV. The addition of CWG for the last 19 d prior to market improved G:F; however, CWG worsened jowl IV and did not further improve carcass yield or carcass characteristics.

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Figures and tables

Table 3-1. Phase 1, 2, and 3 diet composition (as-fed basis)[1]

	Phase 1		Phase 2		Phase 3	
Fiber level:	Low	High	Low	High	Low	High
Wheat midds, %:	0	19	0	19	0	19
Item DDGS,[2] %:	0	30	0	30	0	30
Ingredient, %						
Corn	73.70	34.90	78.95	40.00	82.65	43.55
Soybean meal, 46.5% CP	23.80	13.75	18.85	8.70	15.30	5.20
DDGS	---	30.00	---	30.00	---	30.00
Wheat middlings	---	19.00	---	19.00	---	19.00
Monocalcium P, 21% P	0.45	---	0.35	---	0.25	---
Limestone	1.05	1.30	1.00	1.28	0.98	1.29
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.15	0.15	0.13	0.13	0.10	0.10
Trace mineral premix[4]	0.15	0.15	0.13	0.13	0.10	0.10
L-Lys HCL	0.17	0.31	0.15	0.29	0.14	0.28
DL-Met	0.02	---	---	---	---	---
L-Thr	0.03	---	0.01	---	---	---
Phytase[5]	0.13	0.13	0.13	0.13	0.13	0.13
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standardized ileal digestible (SID) AA						
Lys, %	0.93	0.93	0.79	0.79	0.69	0.69
Met:Lys, %	30	34	30	37	32	40
Met & Cys:Lys, %	59	70	62	77	66	83
Thr:Lys, %	63	66	63	69	64	72
Trp:Lys, %	19	19	19	19	19	19
Total Lys, %	1.04	1.09	0.89	0.94	0.78	0.83
CP, %	17.5	20.8	15.6	18.9	14.3	17.6
SID Lys:ME, g/Mcal	2.8	2.8	2.4	2.4	2.1	2.1
ME, kcal/kg	3,329	3,265	3,335	3,269	3,344	3,271
Ca, %	0.59	0.58	0.53	0.56	0.49	0.55
Available P, %	0.27	0.39	0.25	0.38	0.22	0.38
Crude fat, %	3.2	5.6	3.4	5.7	3.5	5.8
Crude fiber, %	2.5	4.9	2.5	4.9	2.4	4.8
NDF, %	9.2	18.9	9.3	19.0	9.3	19.0
ADF, %	3.3	6.7	3.2	6.6	3.1	6.5

[1]Dietary treatment fed in meal form from 105 to 127 kg BW for phase 4.

[2]Corn distillers dried grains with solubles.

[3]Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B12.

[4]Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 778.4 FTU/kg of feed and 0.11% available P released.

Table 3-2. Phase 4 diet composition (as-fed basis)[1]

Item	Fiber level:	Low	Low	Med	High	Low	Med	High
	Wheat midds, %:	0	0	15	30	0	15	30
	DDGS,[2] %:	0	0	9.5	19	0	9.5	19
	Choice white grease, %:	0	0	0	0	3	3	3
Ingredient, %								
Corn		84.95	84.95	65.60	45.80	80.65	61.25	41.45
Soybean meal, 46.5% CP		13.15	13.15	8.05	3.05	14.45	9.35	4.35
DDGS		---	---	15.00	30.00	---	15.00	30.00
Wheat middlings		---	---	9.50	19.00	---	9.50	19.00
Monocalcium P, 21% P		0.20	0.20	---	---	0.20	---	---
Limestone		0.93	0.93	1.05	1.28	0.93	1.05	1.28
Salt		0.35	0.35	0.35	0.35	0.35	0.35	0.35
Choice white grease		---	---	---	---	3.00	3.00	3.00
Vitamin premix[3]		0.08	0.08	0.08	0.08	0.08	0.08	0.08
Trace mineral premix[4]		0.08	0.08	0.08	0.08	0.08	0.08	0.08
L-Lys HCL		0.13	0.13	0.20	0.27	0.13	0.20	0.27
DL-Met		---	---	---	---	---	---	---
L-Thr		---	---	---	---	---	---	---
Phytase[5]		0.13	0.13	0.13	0.13	0.13	0.13	0.13
Total		100.0	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis								
Standardized ileal digestible (SID) AA								
Lys, %		0.63	0.63	0.63	0.63	0.66	0.66	0.66
Met:Lys, %		33	33	38	43	32	37	41
Met & Cys:Lys, %		69	69	78	88	66	76	85
Thr:Lys, %		66	66	70	74	65	69	73
Trp:Lys, %		19	19	19	19	19	19	19
Total Lys, %		0.72	0.72	0.74	0.77	0.75	0.77	0.79
CP, %		13.5	13.5	15.1	16.8	13.7	15.3	17.0
SID Lys:ME, g/Mcal		1.88	1.88	1.90	1.92	1.88	1.90	1.92
ME, kcal/kg		3,348	3,348	3,318	3,274	3,485	3,452	3,410
Ca, %		0.46	0.46	0.46	0.54	0.46	0.47	0.54
Available P, %		0.21	0.21	0.27	0.37	0.21	0.27	0.37
Crude fat, %		3.5	3.5	4.7	5.8	6.4	7.5	8.7
Crude fiber, %		2.4	2.4	3.6	4.8	2.3	3.5	4.7
NDF, %		9.3	9.3	14.2	19.0	9.0	14.0	18.7
ADF, %		3.1	3.1	4.8	6.4	3.0	4.7	6.4

[1]Dietary treatment fed in meal form from 105 to 127 kg BW for phase 4.

[2]Corn distillers dried grains with solubles.

[3]Provided per kg of premix: 4,409,200 IU vitamin A; 551,150 IU vitamin D3; 17,637 IU vitamin E; 1,764 mg vitamin K; 3,307 mg riboflavin; 11,023 mg pantothenic acid; 19,841 mg niacin; and 15.4 mg vitamin B12.

[4]Provided per kg of premix: 26.5 g Mn from manganese oxide, 110 g Fe from iron sulfate, 110 g Zn from zinc sulphate, 11 g Cu from copper sulfate, 198 mg I from calcium iodate, and 198 mg Se from sodium selenite.

[5]Phyzyme 600 (Danisco Animal Nutrition, St Louis, MO) provided 778.4 FTU/kg of feed and 0.11% available P released.

Table 3-3. Chemical analysis of dried distillers grains with solubles and wheat middlings (as-fed basis)

Nutrient, %	DDGS	Wheat middlings
DM	90.97	89.39
CP	27.2 (27.2)[1]	15.5 (15.9)
Fat (oil)	11.48	3.26
Crude fiber	9.1 (7.7)	8.09 (7.0)
ADF	12.4 (9.9)	10.5 (10.7)
NDF	31.1 (25.3)	32.1 (35.6)
Ash	4.22	5.68

[1]Values in parenthesis indicate those used in diet formulation.

Table 3-4. Bulk density of experimental diets (as-fed basis)

		Treatments						
	Fiber level:	Low	Low	Med	High	Low	Med	High
	Wheat midds, %:	0	0	15	30	0	15	30
	DDGS,[1] %:	0	0	9.5	19	0	9.5	19
Bulk density, g/L[2,3]	CWG,[4] %:	0	0	0	0	3	3	3
Phase 1		686	---	---	523	---	---	---
Phase 2		678	---	---	503	---	---	---
Phase 3		644	---	---	476	---	---	---
Phase 4		654	654	556	470	640	557	483

[1] Dried distillers grains with solubles.

[2] Diet samples collected from the tops of each feeder during each phase.

[3] Phase 1 = d 0 to 23; Phase 2 = d 23 to 43; Phase 3 = d 43 to 73; Phase 4 = d 73 to 92.

[4] Choice white grease.

Table 3-5. Effect of dietary fiber and added fat prior to marketing on growth performance[1]

Treatment:	1	2	3	4	5	6	7	
d 0 to 73:	Low[2]	High[3]	High	High	High	High	High	
					3% added fat			
d 73 to 90:	Low	Low	Med[4]	High	Low	Med	High	SEM
Weight, kg								
d 0	45.9	46.0	46.0	46.0	46.0	45.9	45.9	0.90
d 23	66.7	66.5	66.2	67.2	66.6	66.4	66.5	0.95
d 43	81.5	81.8	81.8	81.8	81.3	81.8	81.7	1.17
d 73	108.5	107.8	107.8	107.7	107.9	108.0	107.7	1.38
d 92	124.5	123.0	123.8	124.0	124.9	124.8	124.5	1.50
d 0 to 73								
ADG, kg	0.86	0.85	0.85	0.85	0.85	0.84	0.85	0.01
ADFI, kg	2.40	2.44	2.47	2.45	2.40	2.43	2.39	0.06
G:F	0.36	0.35	0.34	0.35	0.35	0.34	0.35	0.005
d 73 to 92								
ADG, kg	0.84	0.80	0.84	0.82	0.89	0.88	0.88	0.03
ADFI, kg	2.80	2.84	2.90	2.78	2.89	2.80	2.76	0.07
G:F	0.30	0.28	0.29	0.29	0.31	0.31	0.32	0.01
d 0 to 92								
ADG, kg	0.85	0.84	0.85	0.84	0.86	0.84	0.85	0.01
ADFI, kg	2.49	2.53	2.56	2.52	2.50	2.50	2.46	0.05
G:F	0.34	0.33	0.33	0.33	0.34	0.34	0.35	0.004

[1] A total of 225 pigs (PIC 327 × 1050, initial BW= 45.5 kg) were used in this 92-d study.
[2] Refers to a low fiber corn-soybean meal based diet without dried distillers grains with solubles (DDGS) or wheat middlings (midds).

[3] Refers to a high fiber diet with 30% DDGS and 19.0% midds.

[4] Refers to a medium fiber diet with 15% DDGS and 9.5% midds.

Table 3-6. Effect of dietary fiber and added fat prior to marketing on growth performance.

	Probability, *P* <								
		Fiber[3]		Interaction[4]		Fiber no fat[5]		Fiber with 3% fat[6]	
	Fat[2]	Linear	Quad	Linear	Quad	Linear	Quad	Linear	Quad
Weight, kg									
d 0	0.97	0.99	1.00	0.99	0.95	1.00	0.97	0.99	0.96
d 23	0.87	0.80	0.65	0.70	0.82	0.65	0.63	0.92	0.88
d 43	0.86	0.87	0.87	0.87	0.90	1.00	0.98	0.81	0.84
d 73	0.92	0.93	0.90	0.97	0.95	0.97	0.97	0.93	0.90
d 92	0.42	0.85	0.86	0.66	0.94	0.66	0.86	0.86	0.94
d 0 to 73									
ADG, kg	0.79	0.90	0.69	0.95	0.68	0.97	0.99	0.89	0.57
ADFI, kg	0.39	0.93	0.62	0.87	0.91	0.96	0.79	0.86	0.67
G:F	0.25	0.96	0.19	0.80	0.46	0.83	0.68	0.88	0.15
d 73 to 92									
ADG, kg	0.02	0.92	0.61	0.65	0.50	0.70	0.40	0.80	0.91
ADFI, kg	0.64	0.22	0.62	0.67	0.37	0.56	0.33	0.24	0.78
G:F	0.005	0.30	0.88	0.87	0.87	0.39	0.82	0.53	0.99
d 0 to 92									
ADG, kg	0.39	0.95	0.87	0.78	0.45	0.88	0.67	0.81	0.52
ADFI, kg	0.39	0.68	0.61	0.81	0.86	0.90	0.63	0.64	0.81
G:F	0.02	0.54	0.31	0.91	0.50	0.72	0.80	0.60	0.23

[1] A total of 225 pigs (PIC 327 × 1050, initial BW= 45.5 kg) were used in a 92-d study.
[2] Main effect of fat regardless of fiber level (treatments 2, 3, and 4 vs. 5, 6, and 7).
[3] Main effect of fiber regardless of fat inclusion (treatments 2, 3, 4 and 5, 6, 7).
[4] Interaction effect of fat × fiber (treatments 2, 3, 4 and 5, 6, 7).
[5] Effect of fiber level on diets without fat (treatments 2, 3, 4).
[6] Effect of fiber level on diets with fat (treatments 5, 6, 7).

Table 3-7. Effect of dietary NDF levels with or without the addition of fat prior to marketing on finishing pig carcass characteristics[1]

Treatment:	1	2	3	4	5	6	7	
d 0 to 73:	Low[2]	High[3]	High	High	High	High	High	
					3% Added Fat			
d 73to 92:	Low	Low	Med[4]	High	Low	Med	High	SEM
Carcass yield, %[5]	72.6	72.6	71.8	71.9	73.0	72.3	71.5	0.31
HCW, kg	90.6	89.4	89.0	89.2	91.2	90.6	88.9	1.33
Backfat depth,[6] mm	18.9	17.5	17.0	17.0	18.6	17.7	16.5	0.60
Loin depth,[6] mm	58.1	56.2	56.8	57.6	58.9	54.7	56.7	1.07
Lean,[6] %	52.8	53.0	53.3	53.4	53.0	52.6	53.4	0.30
Jowl IV	69.4	77.8	78.5	79.2	77.3	78.6	81.2	0.50

[1] A total of 225 pigs (PIC 327 × 1050, initial BW= 45.5 kg) were used in a 92-d study.
[2] Refers to a low fiber corn-soybean meal based diet without dried distillers grains with solubles (DDGS) or wheat middlings (midds).
[3] Refers to a high fiber diet with 30% DDGS and 19.0% midds.
[4] Refers to a medium fiber diet with 15% DDGS and 9.5% midds.
[5] Percentage yield was calculated by dividing HCW by live weight obtained at the farm before transport to the packing plant.
[6] Carcass characteristics other than yield and iodine value were adjusted by using HCW as a covariate.

Table 3-8. Effect of dietary NDF levels with or without the addition of fat prior to marketing on finishing pig carcass characteristics[1]

	Probability, $P <$								
	Fat[2]	Fiber[3]		Interaction[4]		Fiber no fat[5]		Fiber with fat[6]	
		Linear	Quadratic	Linear	Quadratic	Linear	Quadratic	Linear	Quadratic
Carcass yield, %	0.50	0.003	0.53	0.23	0.44	0.16	0.32	0.003	0.91
HCW, kg	0.38	0.40	0.91	0.49	0.72	0.91	0.86	0.28	0.74
Backfat depth, mm	0.40	0.05	0.92	0.22	0.73	0.59	0.75	0.03	0.86
Loin depth, mm	0.91	0.74	0.13	0.15	0.16	0.42	0.94	0.21	0.04
Lean, %	0.48	0.23	0.38	0.95	0.22	0.42	0.80	0.38	0.14
Jowl IV	0.24	0.001	0.54	0.03	0.46	0.09	0.93	0.001	0.35

[1] A total of 225 pigs (PIC 327 × 1050, initial BW= 45.5 kg) were used in a 92-d study.

[2] Main effect of fat regardless of fiber level (treatments 2, 3, and 4 vs. 5, 6, and 7).

[3] Main effect of fiber regardless of fat inclusion (treatments 2, 3, 4 and 5, 6, 7).

[4] Interaction effect of fat × fiber (treatments 2, 3, 4 and 5, 6, 7).

[5] Effect of fiber level on diets without fat (treatments 2, 3, 4).

[6] Effect of fiber level on diets with fat (treatments 5, 6, 7).

Table 3-9. Effect of dietary fiber and added fat prior to marketing on intestinal weights, kg[1]

Treatment:	1	2	3	4	5	6	7	
d 0 to 73:	Low[2]	High[3]	High	High	High	High	High	
					3% added fat			
d 73 to 90:	Low	Low	Med[4]	High	Low	Med	High	SEM
Full pluck	14.00	13.34	13.71	14.31	13.27	13.09	14.77	0.52
Whole intestine	8.97	8.19	8.67	9.08	8.01	8.36	9.71	0.42
Stomach								
Full	1.20	0.98	0.91	1.21	1.02	0.97	1.12	0.11
Stripped	0.69	0.65	0.69	0.73	0.70	0.68	0.75	0.03
Rinsed	0.69	0.64	0.68	0.70	0.69	0.67	0.75	0.03
Cecum								
Full	1.01	0.65	0.79	0.84	0.75	0.66	0.82	0.07
Stripped	0.31	0.27	0.27	0.29	0.31	0.27	0.30	0.02
Rinsed	0.28	0.25	0.26	0.27	0.30	0.26	0.27	0.02
Large intestine								
Full	3.50	3.52	3.89	3.85	3.25	3.81	4.75	0.30
Stripped	1.61	1.67	1.74	1.68	1.62	1.81	1.90	0.09
Rinsed	1.56	1.56	1.64	1.56	1.59	1.61	1.75	0.08
Small intestine								
Full	2.92	2.77	2.54	2.75	2.73	2.67	2.75	0.11
Heart	0.44	0.44	0.41	0.41	0.41	0.43	0.40	0.02
Lungs	0.98	1.01	0.99	1.04	0.96	1.02	1.01	0.04
Liver	2.06	2.09	2.07	2.05	1.98	1.90	2.03	0.07
Kidneys	0.41	0.40	0.41	0.39	0.40	0.38	0.40	0.02
Spleen	0.23	0.24	0.23	0.23	0.23	0.23	0.23	0.02
Reproductive tract	0.70	0.77	0.77	0.90	1.00	0.60	0.84	0.12

[1] A total of 225 pigs (PIC 327 × 1050, initial BW= 45.5 kg) were used in this 92-d study.
[2] Refers to a low fiber corn-soybean meal based diet without dried distillers grains with solubles (DDGS) or wheat middlings (midds).

[3] Refers to a high fiber diet with 30% DDGS and 19.0% midds.

[4] Refers to a medium fiber diet with 15% DDGS and 9.5% midds.

Table 3-10. Effect of dietary fiber and added fat prior to marketing on intestinal weights, kg[1]

	Probability, *P* <								
		Fiber[3]		Interaction[4]		Fiber no fat[5]		Fiber with fat[6]	
	Fat[2]	Linear	Quad	Linear	Quad	Linear	Quad	Linear	Quad
Full pluck	0.87	0.04	0.30	0.64	0.41	0.24	0.87	0.07	0.19
Whole intestine	0.90	0.01	0.57	0.39	0.51	0.18	0.95	0.01	0.39
Stomach									
Full	0.95	0.18	0.19	0.61	0.68	0.20	0.22	0.54	0.51
Stripped	0.44	0.06	0.41	0.84	0.50	0.15	0.91	0.21	0.29
Rinsed	0.22	0.06	0.43	0.94	0.27	0.16	0.81	0.19	0.18
Cecum									
Full	0.81	0.11	0.50	0.49	0.20	0.09	0.65	0.52	0.17
Stripped	0.24	0.90	0.26	0.36	0.41	0.46	0.83	0.58	0.17
Rinsed	0.30	0.70	0.51	0.25	0.60	0.59	0.92	0.28	0.40
Large intestine									
Full	0.51	0.01	0.99	0.09	0.51	0.50	0.65	0.00	0.63
Stripped	0.35	0.17	0.53	0.20	0.98	0.95	0.64	0.06	0.67
Rinsed	0.42	0.38	0.87	0.38	0.41	1.00	0.48	0.21	0.63
Small intestine									
Full	0.75	0.99	0.19	0.87	0.50	0.92	0.16	0.90	0.65
Heart	0.61	0.38	0.72	0.53	0.22	0.29	0.54	0.86	0.26
Lungs	0.69	0.40	0.98	0.88	0.38	0.63	0.55	0.49	0.52
Liver	0.14	0.98	0.46	0.56	0.46	0.70	1.00	0.67	0.30
Kidneys	0.62	0.69	1.00	0.84	0.30	0.67	0.46	0.89	0.46
Spleen	0.69	0.80	0.78	0.80	0.78	0.73	0.69	1.00	1.00
Reproductive tract	0.98	0.89	0.09	0.25	0.26	0.47	0.68	0.36	0.05

[1] A total of 225 pigs (PIC 327 × 1050, initial BW= 45.5 kg) were used in a 92-d study.

[2] Main effect of fat regardless of fiber level (treatments 2, 3, and 4 vs. 5, 6, and 7).

[3] Main effect of fiber regardless of fat inclusion (treatments 2, 3, 4 and 5, 6, 7).

[4] Interaction effect of fat × fiber (treatments 2, 3, 4 and 5, 6, 7).

[5] Effect of fiber level on diets without fat (treatments 2, 3, 4).

[6] Effect of fiber level on diets with fat (treatments 5, 6, 7).

Table 3-11. Effect of dietary NDF levels with or without the addition of fat prior to marketing on finishing pig intestinal and organ weights, %[1,2]

Treatment:	1	2	3	4	5	6	7	
d 0 to 73:	Low[3]	High[4]	High	High	High	High	High	
					3% Added fat			
d 73to 92	Low	Low	Med[5]	High	Low	Med	High	SEM
Full pluck	10.98	10.61	10.96	11.69	10.51	10.52	11.74	0.42
Whole Intestine	7.03	6.51	6.93	7.42	6.35	6.72	7.73	0.35
Stomach								
Full	0.94	0.78	0.72	0.99	0.81	0.78	0.90	0.09
Stripped	0.54	0.52	0.55	0.59	0.55	0.55	0.60	0.02
Rinsed	0.54	0.51	0.54	0.57	0.55	0.54	0.60	0.02
Cecum								
Full	0.79	0.52	0.63	0.68	0.60	0.53	0.65	0.06
Stripped	0.24	0.21	0.22	0.23	0.24	0.22	0.23	0.01
Rinsed	0.22	0.20	0.21	0.22	0.23	0.21	0.21	0.01
Large intestine								
Full	2.75	2.80	3.21	3.12	2.58	3.06	3.79	0.25
Stripped	1.26	1.33	1.39	1.37	1.28	1.46	1.51	0.07
Rinsed	1.22	1.24	1.31	1.28	1.26	1.30	1.39	0.06
Small intestine								
Full	2.29	2.20	2.03	2.24	2.16	2.14	2.18	0.08
Heart	0.35	0.35	0.33	0.34	0.32	0.35	0.32	0.01
Lungs	0.77	0.80	0.79	0.85	0.77	0.82	0.80	0.04
Liver	1.61	1.66	1.65	1.67	1.57	1.52	1.61	0.06
Kidneys	0.32	0.32	0.33	0.32	0.32	0.30	0.31	0.01
Spleen	0.18	0.19	0.18	0.19	0.18	0.18	0.18	0.01
Reproductive tract	0.55	0.61	0.62	0.74	0.78	0.49	0.66	0.09

[1] A total of 225 pigs (PIC 327 × 1050, initial BW= 45.5 kg) were used in a 92-d study.

[2]All values are a percent of live weight ((ex. (reproductive tract/ live weight) × 100)).

[3]Refers to a low fiber corn-soybean meal based diet without dried distillers grains with solubles (DDGS) or wheat middlings (midds).

[4]Refers to a high fiber diet with 30% DDGS and 19.0% midds.

[5]Refers to a medium fiber diet with 15% DDGS and 9.5% midds.

Table 3-12. Effect of dietary NDF levels with or without the addition of fat prior to marketing on finishing pig intestinal and organ weights, %[1]

	Probability, P <									
	Fat[2]	Fiber[3]		Interaction[4]		Fiber no fat[5]		Fiber with fat[6]		
		Linear	Quad	Linear	Quad	Linear	Quad	Linear	Quad	
Full pluck	0.66	0.02	0.32	0.87	0.61	0.11	0.73	0.07	0.29	
Whole Intestine	0.94	0.006	0.60	0.55	0.67	0.11	0.94	0.02	0.50	
Stomach										
Full	0.98	0.15	0.19	0.56	0.58	0.16	0.19	0.51	0.59	
Stripped	0.52	0.02	0.39	0.63	0.78	0.05	0.68	0.16	0.42	
Rinsed	0.24	0.02	0.41	0.73	0.44	0.05	0.96	0.13	0.26	
Cecum										
Full	0.73	0.12	0.57	0.40	0.28	0.08	0.70	0.62	0.25	
Stripped	0.33	0.74	0.26	0.22	0.52	0.27	0.73	0.53	0.22	
Rinsed	0.40	0.85	0.51	0.16	0.71	0.39	0.83	0.26	0.47	
Large intestine										
Full	0.68	0.01	0.79	0.13	0.46	0.43	0.50	0.004	0.72	
Stripped	0.43	0.10	0.50	0.25	0.84	0.71	0.74	0.05	0.54	
Rinsed	0.53	0.25	0.81	0.49	0.55	0.74	0.56	0.19	0.80	
Small intestine										
Full	0.97	0.71	0.13	0.91	0.26	0.73	0.07	0.86	0.77	
Heart	0.38	0.46	0.64	0.69	0.06	0.42	0.30	0.81	0.09	
Lungs	0.62	0.33	0.99	0.85	0.27	0.41	0.43	0.58	0.44	
Liver	0.08	0.71	0.43	0.80	0.66	0.93	0.81	0.66	0.39	
Kidneys	0.39	0.80	0.99	0.98	0.34	0.88	0.49	0.84	0.51	
Spleen	0.63	0.91	0.74	0.95	0.66	0.90	0.58	0.97	0.94	
Reproductive tract	0.86	1.00	0.11	0.22	0.31	0.39	0.67	0.39	0.07	

[1] A total of 225 pigs (PIC 327 × 1050, initial BW= 45.5 kg) were used in a 92-d study.

[2] Main effect of fat regardless of fiber level (treatments 2, 3, & 4 vs. 5, 6, & 7).

[3] Main effect of fiber regardless of fat inclusion (treatments 2, 3, 4 and 5, 6, 7).

[4] Interaction effect of fat × fiber (treatments 2, 3, 4 and 5, 6, 7).

[5] Effect of fiber level on diets without fat (treatments 2, 3, 4).

[6] Effect of fiber level on diets with fat (treatments 5, 6, 7).

Chapter 4 - The Effects of Immunocastration and Dried Distillers Grains with Solubles Withdrawal on Growth Performance, Carcass Characteristics, Fatty Acid Analysis, and Iodine Value of Pork Fat Depots

Abstract

The objectives of this research were to determine the effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration (IC; Improvest®, Pfizer Animal Health, Kalamazoo, MI) on growth performance and carcass fat quality of growing-finishing pigs. A total of 1,360 pigs (337 × 1050: PIC Hendersonville, TN; initially 24 kg) were used in a 125-d study. Pens of pigs were randomly allotted by initial BW and gender (barrows or IC) to 1 of 3 dietary treatments with 8 replications per treatment for a total of 48 pens with 27 to 29 pigs per pen. Treatments were arranged in a 2 × 3 factorial with the main effects of gender (barrow or IC) and diet (0% DDGS throughout, 30% DDGS throughout, or 30% DDGS through d 75 then withdrawn to 0% to d 125). Immunocastrates were created by injecting boars with Improvest on d 39 and 74 of the study. Dietary treatments were corn-soybean meal–based diets and fed in 5 phases. No gender × diet interactions ($P > 0.12$) were observed. For the entire period before the second Improvest injection (d 0 to 74), barrows had increased ($P < 0.001$) ADFI, but were less efficient ($P < 0.001$) than boars. During the same time period, pigs fed 30% DDGS had reduced ($P < 0.003$) ADG an G:F. For the period after the second Improvest injection until the first marketing event (d 74 to 107), IC pigs had improved ($P < 0.01$) ADG and G:F ($P < 0.001$) compared to barrows. From d 0 to 107, IC pigs had improved ($P < 0.03$) ADG, G:F, and lower ADFI than barrows. The inclusion of 30% DDGS regardless of withdrawal or gender decreased ($P < 0.001$) G:F compared to pigs fed the control diet. For the period after the second Improvest injection (d 74 to 125), IC pigs had increased ($P < 0.01$) ADG, ADFI, and G:F then barrows. Overall (d 0 to 125), IC pigs had improved ($P < 0.003$) ADG and G:F and lower ADFI than barrows. The inclusion of 30% DDGS regardless of withdrawal or gender decreased ($P < 0.001$) G:F. Carcass yield was lower ($P < 0.001$) for IC pigs than barrows regardless of dietary DDGS or withdrawal strategy. Pigs fed 30% DDGS throughout had decreased ($P < 0.001$) carcass yield;

however, withdrawing DDGS from the diet on d 74 was effective at fully recovering the yield loss. Carcass fat iodine values (IV) were consistently higher ($P < 0.001$) regardless of fat depot or harvest time when 30% DDGS were included in the diet. No three or four-way interactions were detected ($P < 0.09$), however, multiple two-way interactions ($P < 0.05$) were detected including sex × DDGS, sex × depot, sex × time, DDGS × depot, DDGS × time, and time × depot. The majority of the interactions were caused by the fact that fatty acid profiles changed more rapidly in backfat and belly fat than jowl fat from d 107 to 125 and the fact that IC pigs improved more rapidly from d 107 to 125 than barrows. This dramatic improvement from d 107 to 125 could be caused by the dilution of unsaturated fatty acids, specifically C18:2 and C18:3, due to the rapid deposition of fat from de novo synthesis in IC pigs.

Key words: carcass, DDGS, fatty acids, Improvest, finishing pigs, withdrawal

Introduction

By-products such as dried distillers grains with solubles (DDGS) are often used as alternatives to corn and soybean meal in swine diets. Although these ingredients are used with the intent of lowering feed costs, they have been shown to negatively affect performance and carcass characteristics (Whitney et al., 2006; Linneen et al., 2008; Stein and Shurson et al., 2009) compared to feeding corn soybean meal based diets. The main areas of concern are the reduction in carcass yield with pigs fed high DDGS diets as well as the negative effect of DDGS on fat quality. A high carcass fat iodine value (IV) is associated with more unsaturated fat and has consistently been observed in pigs fed high levels of DDGS (Hill et al., 2008; Asmus et al., 2011a); however, removing DDGS as the source of unsaturated fat from the diet prior to harvest lowers carcass fat IV (Xu et al., 2010; Jacela et al., 2009; Asmus et al., 2011b).

Improvest (Pfizer Animal Health, Kalamazoo, MI), an immunocastration technology, allows pigs to perform as boars until the second immunization injection (Dunshea et al., 2001). Pigs are administered a primer dose of Improvest (protein compound) any time after nine weeks of age, then given a second dose at least 4 weeks after the primer dose and three to ten weeks prior to harvest. After the second immunization, IC pigs rapidly increase feed intake and growth rate (Dunshea et al., 2001; Cronin et al., 2003; Zamaratskaia et al., 2008). Since boars deposit less fat than barrows (Knudson et al., 1985) our hypothesis was that boars would deposit less fat prior to the second dose with a greater portion of their total fat deposition occurring late in the finishing stage (Rikard-Bell et al., 2009). Thus, we speculated that feeding high levels of unsaturated fat prior to the second dose may have less overall impact on carcass fat iodine value (IV) when less unsaturated fat (from DDGS) is fed during the post–second dose phase prior to market.

Previous research has shown that reducing the level of DDGS in the diet before harvest has been successful in improving carcass yield and improving fat quality (Gaines et al., 2007b; Hill et al., 2008; Xu et al., 2010); however, no studies are available to determine the impact of the DDGS withdrawal strategy in combination with immunocastration. The objective of this trial was to determine the effects of withdrawing DDGS from the diets of barrows and immunocastrates prior to market on growth performance and carcass fat quality of growing-finishing pigs.

Materials and methods

General

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at a commercial research-finishing barn in southwestern Minnesota. The facility was double curtain sided with pit fans for minimum ventilation and completely slatted flooring over a deep pit for manure storage. Individual pens were 3.0 × 5.5 m. Each pen was equipped with a single-sided, 152.4-cm-wide, 5-hole, stainless steel dry feeder (STACO, Inc., Schaefferstown, PA) and a cup waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished through a robotic feeding system (FeedPro; Feedlogic Corp., Willmar, MN) that delivered and recorded diets as specified. The equipment provided pigs with ad libitum access to feed and water.

Animals and diets

A total of 1,360 pigs (337 × 1050: PIC Hendersonville, TN; initially 24.0 kg) were used in a 125-d study. All pigs used in the study were individually tagged and tattooed at birth in sequential order; to minimize maternal effects, even numbers of pigs were used from each sow. To create gender differences, all odd-numbered pigs were left intact and even-numbered pigs were surgically castrated at 2 d of age per standard farm procedures. At weaning (~19 d of age), all pigs were transported to the commercial wean-to-finish barn and double-stocked in pens by gender. Pens on one half of the barn were randomly assigned to house boars or barrows and the other half of the barn was stocked with gilts. When pigs reached ~24 kg BW, all gilts were removed and half the pigs within each pen (barrow or boar) were moved to a pen across the aisle. Thus, each double stocked pen was split into 2 replicate pens. Pens of pigs (~28 barrows per pen or ~28 boars per pen) were randomly allotted by initial weight within gender to 1 of 3 dietary treatments with 8 boar and 8 barrow replications per dietary treatment. Dietary treatments were based on DDGS feeding (0% throughout, 30% throughout, or 30% from d 0 to 74 and no DDGS fed from d 74 to market). Dietary treatments were corn-soybean meal–based and fed in 5 phases (Tables 4.1 and 4.2). All diets were fed in meal form and balanced to similar SID lysine:ME ratios. Due to the high level of available P in DDGS, no supplemental P was required in diets containing high levels of DDGS. Phytase was added to all diets at a constant level of 0.01% of the diet which provided 998.8 FTU/kg of complete diet. Therefore, treatments for the overall period were arranged in a 2 × 3 factorial with the main effects of gender (barrow vs. immunocastrate) and DDGS feeding (0, 30%, or 30% then 0% DDGS).

On d 39 (~110 d of age), all boar pigs were administered a 2-ml primer dose of Improvest (Pfizer Animal Health, Kalamazoo, MI) in the high lateral aspect of the neck by a Pfizer Animal Health certified injection team (PAH), who also administered the second 2-ml dose on d 74 (~145 d of age). A PAH quality assurance check was performed on d 88 to ensure all pigs received both doses and did not exhibit any signs of typical boar behavior. Any pig thought to be a “suspect pig” (21 total) was re-dosed with an additional 2 ml of Improvest in the high lateral aspect of the neck, and the individual pig ID was recorded.

Pens of pigs were weighed and feed disappearance was recorded on d 0, 25, 53, 74, 87, 107, and 125 to determine ADG, ADFI, and G:F. On d 107 (~180 d of age), all pigs were weighed individually and the 9 heaviest pigs per pen were tattooed by pen to be transported to Natural Food Holdings (Sioux Center, IA). At d 107 the 4 pigs closest to the pen median weight in each pen (32 pigs per treatment) were also identified to gain representative fat samples over time. These pigs were individually tattooed with a unique number (1 through 192), and the 2 heaviest median pigs per pen (16 per treatment) were transported with the 9 topped pigs to Natural Food Holdings for harvest. During harvest, the 2 selected median weight pigs were sequenced with a unique number corresponding to the tattoo given at the farm to allow for further tracking. The day after harvest, the left side of each carcass was transported by refrigerated truck to the University of Illinois Meat Sciences Laboratory (Urbana, IL) for full carcass breakdown. Standard carcass criteria of HCW and percentage carcass yield were collected on all pigs harvested. The other 2 median-weight pigs remained in their respective pens and were harvested on d 125, then transported to the University of Illinois Meat Sciences Laboratory for carcass processing. Fat samples were collected for both harvest dates from 4 fat depots (jowl, backfat between 10^{th} and 11^{th} rib, clear plate between 1^{st} and 2^{nd} rib, and belly) at the University of Illinois Meat Sciences Laboratory. These fat samples were then transported frozen to the K-State Analytical Lab (Manhattan, KS) for full fatty acid analyses. Iodine value was calculated using the equation IV= [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723. Backfat depth was measured at the 10^{th} rib and percentage lean was calculated using the equation FFL= 58.86 – (backfat × 0.61) + (loin depth × 0.12). All pigs harvested where utilized in calculating percentage yield, which was calculated by dividing HCW at the plant by live weight at the plant.

Statistical analysis

Data were analyzed as a completely randomized design using the PROC MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit. The main effects of gender and DDGS during withdrawal, as well as interactive effects, were tested.

Interactive effects of DDGS, harvest time, fat depot, and gender were tested using repeated measures. Differences between treatments were determined by using least squares means. Results were considered significant at $P \leq 0.05$ and considered a trend at $P \leq 0.10$.

Results

No gender × diet interactions ($P > 0.12$) occurred with the exception of a tendency ($P < 0.07$) for carcass yield on d 107, where there was a greater reduction in carcass yield for IC pigs compared with barrows when fed DDGS throughout than when fed the control diet throughout or when DDGS was withdrawn from the diet on d 74. Barrows had greater ($P < 0.01$) ADG (0.87 vs. 0.84 kg) than boars from d 0 to 25 (Tables 4.3 and 4.4), which resulted in a tendency for barrows to have greater ($P < 0.08$) ADG (0.90 vs. 0.89 kg) than boars prior to the second Improvest immunization (d 0 to 74; Table 4.5 and 4.6). Boars had decreased ($P < 0.001$) ADFI and improved ($P < 0.001$) G:F for all periods prior to the second immunization. Immediately after the second immunization (d 74 to 87), IC pigs continued to have lower ($P < 0.001$) ADFI (2.71 vs. 3.01 kg), but grew faster ($P < 0.03$) than barrows (1.02 vs. 0.98 kg), resulting in improved ($P < 0.001$) G:F (0.38 vs. 0.33). After this 2-wk period, feed intake increased in IC pigs such that they had greater ($P < 0.001$) ADFI for the last two phases of the trial (d 87 to 107 and d 107 to 125) than barrows. The higher feed intake allowed IC pigs to have greater ($P < 0.001$) ADG during the last two phases than barrows. Feed efficiency also improved ($P < 0.01$) from d 87 to 107 for IC pigs but was similar to barrows from d 107 to 125.

For the period after the second Improvest injection until the first marketing event (d 74 to 107), IC pigs had increased ($P < 0.01$) ADG (1.04 vs. 0.95 kg) and were more feed efficient ($P < 0.01$; 0.33 vs. 0.31) than barrows. From d 0 to 107, IC pigs had improved ($P < 0.03$) ADG (0.93 vs. 0.92 kg), G:F (0.43 vs. 0.40), and lower ($P < 0.001$) ADFI (2.18 vs. 2.30 kg) than barrows. The inclusion of 30% DDGS regardless of withdrawal or gender did not influence ADG or ADFI, but did reduce ($P < 0.001$) G:F.

For the period after the second Improvest injection to the end of the trial (d 74 to 125; 51 d after the second dose), IC pigs had increased ($P < 0.01$) ADG (1.04 vs. 0.95 kg) and ADFI (3.22 vs. 3.10 kg) and were more feed efficient ($P < 0.01$; 0.33 vs. 0.31) than barrows. Overall (d

0 to 125), IC pigs had improved (*P* < 0.003) ADG (0.94 vs. 0.92 kg) and G:F (0.41 vs. 0.39) and lower ADFI (2.30 vs. 2.37 kg) than barrows. The inclusion of 30% DDGS regardless of withdrawal or gender again did not influence ADG or ADFI, but reduced (*P* < 0.001) G:F.

Regardless of gender, pigs fed 30% DDGS had decreased (*P* < 0.02) ADG compared with pigs fed the control diet without DDGS from d 0 to 25, d 25 to 53, and for the entire period prior to the second Improvest immunization (d 0 to 74; 0.84 vs. 0.89, 0.81 vs. 0.79, and 0.90 vs 0.89 kg, respectively). Withdrawing DDGS from the diet on d 74 did not influence pig performance from d 74 to 107 but resulted in lower (*P* < 0.001) ADFI and improved (*P* < 0.001) G:F from d 107 to 125. The inclusion of 30% DDGS did not influence (*P* > 0.12) overall ADG or ADFI, but reduced (*P* = 0.001) G:F regardless of withdrawal strategy.

Carcass yield was lower (*P* < 0.001) for IC pigs than barrows regardless of diet type or withdrawal strategy. Pigs fed the 30% DDGS diet throughout had decreased (*P* < 0.001) carcass yield; however, withdrawing DDGS from the diet on d 74 was effective at fully recovering the yield loss, returning yield to levels similar to that of the pigs fed the corn-soybean meal diet throughout. Final HCW were not influenced (*P* > 0.11) by treatment. Immunocastrates tended (*P* < 0.07) to have a reduced amount of backfat when compared to barrows as well as an interaction of DDGS × time where pigs withdrawn from DDGS tended (*P* < 0.08) to have increased fat deposition. However, no differences (*P* > 0.16) were detected for DDGS, time, or interactions. There were no significant differences (*P* > 0.12) for loin area, loin depth, or percent lean regardless of gender, DDGS, or time with the exception of an interaction (*P* < 0.06) of DDGS × time for percent lean where at d 107 pigs fed DDGS throughout had a lower percent lean, but by d 125 had a higher percent lean.

There were no three or four way interactions (*P* > 0.07) with the exception of a DDGS×time×depot interaction (*P* < 0.03) for PUFA where PUFA levels were lowered at d 125 compared to d 107 in belly and backfat samples, however, jowl and clearplate fat samples had similar or increased PUFA at d 125 when compared to d 107. The reduction in PUFA was also greater for belly and backfat samples when DDGS was withdrawn leading to the 3-way interaction.

Gender×DDGS. There were multiple gender×DDGS interactions (*P* < 0.04) for C18:2n-6, C18:3n-3, MUFA, PUFA, PUFA:SFA, and IV (Tables 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16, and 4.17). These interactions were caused by IC pigs having a greater decrease in unsaturated fatty acids and increase in saturated fatty acids than barrows when DDGS were withdrawn from the diet, resulting in a greater improvement in fatty acid profiles for IC pigs.

Gender×Depot. There were multiple interactions ($P < 0.03$) detected for gender (barrow or IC) × depot (belly, backfat, clearplate, jowl). Interactions were detected in C16:0, C18:0, C18:1*cis*-9, C18:2n-6, C18:3n-3, C20:2, C20:4n-6, all other fatty acids, MUFA, trans fatty acids, UFA:SFA, and IV. The interactive effects ($P < 0.05$) were caused by differences in fatty acid profiles for the depots with values being similar between barrows and IC pigs in backfat and belly samples, but IC pigs had increased values for unsaturated fatty acids and decreased values for saturated fatty acids when compared to barrows in jowl and clearplate samples.

Gender×Time. Several gender×time interactions ($P < 0.05$) occurred in fatty acid analysis. Immunocastrates had higher concentrations of unsaturated fatty acids and lower concentrations of saturated fatty acids at d 107 compared to barrows, but those levels of C14:0, C16:0, C18:2n-6, C18:3n-3, C20:4n-6, MUFA, UFA:SFA, and IV were significantly reduced ($P < 0.05$) by d 125 compared to barrows resulting in an interaction of gender (barrow or IC) and harvest time (d 107 or 125). Similarly the rapid improvement in fat quality from d 107 to 125 for IC pigs resulted in a tendency ($P < 0.08$) for an interaction for C20:2, all other, and total trans fatty acids compared to barrows.

DDGS×Depot. Numerous interactive effects were detected between DDGS level (0% throughout, 30% withdrawal, and 30% throughout) and fat sample depot (backfat, belly, clearplate, and jowl). All depots showed improvements in C14:0, C16:0, C18:0, C18:1 *cis*-9, C18:1n-7, and IV as DDGS were withdrawn from the diet; however, jowl fat responded less than all other depots resulting in an interaction.

DDGS×Time. An interaction was detected ($P < 0.02$) for the fatty acid C18:2n-6 due to the fact that the concentration of C18:2n-6 in the fat was lower at d 125 than 107 for pigs withdrawn from DDGS at d 74 regardless of gender. There also was an interaction as MUFA increased at d 125 for pigs fed the corn-soy diet throughout and the withdrawal strategy while the pigs fed DDGS had similar MUFA concentrations at d 107 and 125.

Time×Depot. There were multiple interactions ($P < 0.001$) for time (d107 and 125) and depot (backfat, belly, clearplate, and jowl) including for concentrations of C14:0, C16:0, C17:0, C18:0, C18:1*cis*-9, C18:2n-6, C18:3n-3, C20:0, C20:1, C20:2, C20:4n-6, other fatty acids, SFA, MUFA, PUFA, trans fatty acids, UFA:SFA, PUFA:SFA, and IV. These were caused by jowl fat samples showing very little to no change over time, whereas fat samples from the belly, clearplate, and back all showed similar responses with increasing saturated fatty acids and decreasing unsaturated fatty acids causing an interaction.

Fatty acid analysis on d 107. All fat depots responded similarly to treatment on d 107, so results will be discussed together (Tables 4.18, and 4.19). Including 30% DDGS reduced (P < 0.001) SFA and MUFA proportions regardless of fat depot. Of the predominant SFA (P < 0.02), myristic (14:0), palmitic (16:0), and stearic (18:0) acid concentrations were reduced (P < 0.01) as well as MUFA concentrations of palmitoleic (16:1), oleic (18:1c9), and vaccenic (18:1n7) acids. Total *trans* and PUFA, however, were increased (P < 0.04) due to increases in linoleic (18:2n6), α-linoleic (18:3n3), eicosadienoic (20:2), and arachidonic (20:4n-6) acid concentrations, resulting in overall increases (P < 0.001) in UFA:SFA and PUFA:SFA ratios as well as IV. Withdrawing DDGS from the diet on d 74 reduced (P < 0.03) SFA concentrations through reductions in 16:0 and 18:0 and tended to reduce MUFA by reducing 18:1c9. Total *trans* and PUFA concentration increased (P < 0.05) by 18:2n6, 18:3n3, and 20:2 concentration, which resulted in overall increases (P < 0.02) in UFA:SFA, PUFA:SFA, and IV. The IC pigs had reduced (P < 0.04) MUFA proportions as a result of reductions in 18:1c9 and 20:1 concentrations. The IC pigs also had lower (P < 0.02) 14:0 concentrations but no difference in overall SFA; however, total PUFA was increased (P < 0.01) through increases (P < 0.04) in 18:2n6, 18:3n3, 20:2, and 20:4n6, causing an overall increase (P < 0.02) in PUFA:SFA ratio. Carcass IV were increased (P < 0.02) in backfat and clear plate and tended to increase (P < 0.07) in jowl fat for IC pigs compared with barrows, but no difference was detected in IV for belly fat samples.

Fatty acid analyses on d 125. The change in fatty acid profile and IV between fat stores and by days post–second injection of Improvest are shown in Figure 4.1. From (d 107 to d 125) fatty acid profiles of immunocastrates changed dramatically through reductions in PUFA, mainly 18:2n6, 18:3n3, 20:2, and 20:4n6 (Tables 4.9, 4.10, 4.13, 4.14, 4.17, 4.18, 4.21, and 4.22). These reductions in unsaturated fatty acid concentration resulted in improved IV, resulting in values that were not statistically different, and in some cases numerically better than that of barrows. Despite increases (P < 0.05) in 17:0, including 30% DDGS in the diet reduced (P < 0.001) SFA and MUFA proportions through reductions (P < 0.01) in SFA concentrations of 14:0 and 16:0

and MUFA concentrations (*P* < 0.01) of 16:1, 18:1c9, and 18:1n7. Total *trans* and PUFA were increased (*P* < 0.003) by increases (*P* < 0.004) in 18:2n6, 18:3n3, 20:2, and 20:4n6, which resulted in overall increases (*P* < 0.001) in UFA:SFA, PUFA:SFA, and IV when 30% DDGS were included in the diet. Withdrawing DDGS from the diet on d 74 reduced (*P* < 0.002) SFA and MUFA proportions through reductions (*P* < 0.001) in SFA concentrations of 16:0 and 18:0 (except in jowl fat samples) and MUFA concentrations (*P* < 0.05) of 16:1, 18:1c9, and 18:n7; however, PUFA was increased (*P* < 0.001) through increases (*P* < 0.04) in 18:2n6, 18:3n3, and 20:2, which resulted in overall increases (*P* < 0.04) in UFA:SFA, PUFA:SFA, and IV. The IC pigs tended (*P* < 0.10) to have reduced MUFA proportions as a result of reductions (*P* < 0.09) in 18:1c9 and 18:1n7 concentrations, but no differences were detected in UFA:SFA, PUFA:SFA, or IV between IC pigs and barrows.

Discussion

The current experiment found that immunocastration of boars resulted in pigs that had increased ADG, reduced ADFI, and improved feed efficiency compared to barrows. This agrees with research by Dunshea et al. (2001) and Turkstra et al. (2002). Morales et al. (2011) reported no overall differences in ADG, however, similarly they reported an overall reduction in ADFI and improvement in feed efficiency for IC pigs when compared to barrows. Immunocastrates (still boars) tended to have reduced ADG prior to the second injection due to reductions in feed intake, which improved feed efficiency; however, the tendency for reduced ADG was driven by the significant reduction from d 0 to 25, with no differences in ADG from d 25 to 53 or 53 to 74 of the study. This agrees with Morales et al. (2011) who reported barrows having increased ADG when compared to IC pigs. It is reported that increased testosterone levels in boars cause reductions in feed intake (Weiler et al., 1996) which could explain the reduced feed intake seen in our study from d 0 to 74. These results also agree with Campbell and Taverner (1988) and Bonneau et al. (1994) who reported that barrows have increased levels of feed intake when compared to boars. Similarly, Quiniou et al. (1996) have reported that boars reach maximum protein deposition at a lower energy intake which could allow IC pigs to be more efficient possibly due to the fact that lean muscle deposition is more energetically efficient than fat deposition (NRC, 1998).

For the 13 d immediately following second Improvest injection (d 74 to 87), IC pigs had lower ADFI, and improved ADG and feed efficiency. This matches well with Lealiifano et al. (2011) who reported no significant difference (~1% increase) in ADFI for 2 wk immediately following the second dose of Improvest; however, during the following 2 wk (2 to 4 wk post second injection) the authors reported a 32% increase in ADFI for IC pigs compared to barrows. Similar to work by Dunshea et al. (2001), Rikard-Bell et al. (2011), McCauley et al. 2003, and Oliver et al. (2003), IC pigs had increased ADFI from 2 wk post 2nd injection through harvest. This could partly be explained by the fact that when IC pigs transition from a boar to an immunocastrated state they will spend less time engaged in fighting and sexual behavior (Dunshea et al., 2001) and spend more time at the feeder (Cronin et al., 2003). This increase in ADFI resulted in increased ADG from d 87 to 125.

Although no data exists reporting the inclusion of dietary DDGS in diets fed to immunocastrates, there is a large amount of work reported on the dietary inclusion of DDGS for barrows. For growth performance, both genders responded similarly to dietary treatments. The addition of 30% DDGS to the diet reduced ADG through numeric reductions in feed intake and feed efficiency from d 0 to 25 for pigs fed 30% DDGS. This initial reduction in ADFI could be explained by the fact that pigs have reduced preference to diets that include DDGS (Hastad et al., 2005). Including 30% DDGS to the diet reduced ADG and feed efficiency for the entire period from d 0 to 74, with no difference in ADFI which agrees with previous research by Whitney et al. (2006), and is most likely attributed to the reduced energy and increased fiber level in DDGS. From d 74 to 125 (period after 2nd injection), ADFI was increased by the inclusion of 30% DDGS when compared to pigs fed the control diet with the pigs withdrawn from DDGS having intermediate consumption. This data agrees with Asmus et al. (2011b) who saw increased feed intake when pigs remained on dietary DDGS compared to pigs fed a corn-soybean meal control diet, with pigs withdrawn from high fiber having intermediate intake levels. These differences within phase resulted in no overall (d 0 to 125) differences in ADG or ADFI; however, the inclusion of 30% DDGS reduced G:F, which agrees with data by Gaines et al. (2008). The effect of DDGS on growth performance has been shown to be highly variable as Hill et al. (2008) and

Xu et al. (2009) saw no differences in G:F. The variability in response could be attributed to high variability between DDGS sources. Also, we had a greater number of pigs and replications in our experiment than in some of the previous experiments which would allow us to detect smaller differences in feed efficiency.

In the current trial, there was a reduction in carcass yield for IC pigs regardless of dietary inclusion of DDGS. Yield has been shown to be lower in boars and IC than barrows possibly due in part to the presence of testicles and other accessory tissues (Hansen and Lewis, 1993; Babol and Squired, 1995). Although immunocastration has been shown to reduce the weight of testes and bulbo-urethral glands when compared to intact boars (Pauly et al., 2009; Gispert et al., 2010), IC pigs still have increased testes which are absent from barrows. It has also been hypothesized that the reduction in yield could be due to increased amounts of gut fill due to the large increase in ADFI exhibited after the second injection of Improvest, as well as increased amounts of abdominal fat (Dunshea et al., 2001; Zamaratska, et al., 2008). Another possible cause for the reduction in yield could be due to the fact that boars have heavier kidneys, and intestines when compared to barrows (Hansen and Lewis, 1993; Babol and Squires, 1995). It has also been reported that liver weights tended to be heavier in IC pigs when compared with barrows (Pauly et al., 2009).

In the current trial, DDGS inclusion reduced saturated fatty acid (SFA) and mono unsaturated fatty acid (MUFA) proportions regardless of fat depot; however, total trans and poly unsaturated fatty acids (PUFA) were increased mainly though increases in C18:2 and C18:3 fatty acid concentrations resulting in increased carcass fat IV. This agrees with work by Xu et al. (2008) and Hill et al. (2008) who reported increased fat IV when pigs were fed increasing levels of DDGS. Immunocastrated pigs had reduced MUFA, however, PUFA was increased again through C18:2 and C18:3 causing increases in IV for backfat, clear plate, and jowl fat but no difference in IV in belly fat. Concentration of SFA increased and decreased polyunsaturated fatty acid for IC compared to barrows (Lealiifano et al., 2011). Similarly it has been reported that the degree of unsaturation is higher in boars than barrows and IC should be intermediate (EFSA, 2004). The IV of jowl fat was considerably greater than the IV of backfat, belly fat, or clear plate regardless of gender or dietary regimen. Increasing feeding duration from 33 to 51 d post–second injection reduced IV for backfat and belly fat for IC pigs but did not influence IV of jowl or clear plate fat. These results would be expected, because more of the fat in the late finishing period is being deposited in the belly and backfat. The data also demonstrate the difference in conclusion depending on which fat source is being measured. For jowl fat, IV was greater for IC pigs than barrows regardless of diet and did not decrease with days on feed. For backfat and belly fat, increasing days on feed from d 107 to d 125 reduced IV, with IC pigs having a much greater reduction in IV than barrows. Carcass fat IV regardless of depot was greater when 30% DDGS were included in the diet. The withdrawal strategy was successful at lowering the IV compared with pigs fed DDGS throughout; however, as observed in previous studies, it was not successful at fully lowering IV to values similar to pigs fed the control diet throughout.

The withdrawal of dietary DDGS prior to marketing, regardless of gender, helped reduce IV which agrees with work by Asmus et al. (2011b). However, more interestingly IC pigs had dramatic changes in fatty acid profiles with improved IV that was similar to barrows and in some cases numerically better. This could be caused by the rapid deposition of backfat that occurs after 2nd injection (Lealiifano et al., 2011) which causes increased backfat depths and a dilution effect for unsaturated fatty acids.

In summary, withdrawing DDGS from the diet prior to harvest, regardless of gender, can regain yield loss and improve carcass IV; however, regardless of withdrawal strategy or gender, feed efficiency was poorer when feeding DDGS. Immunocastrates had reduced carcass yield and ADFI regardless of diet type, but they also had improved ADG which resulted in improved G:F compared to barrows. Although Improvest can increase IV of fat depots when pigs are harvested at 5 wk post–second injection, extending the length of feeding duration prior to harvest after the second injection returns IV values to levels similar to those of barrows, probably caused by a dilution effect of unsaturated fatty acids coming from dietary sources.

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Figures and tables

Table 4-1. Phase 1 and 2 diet composition (as-fed basis)[1]

	Phase 1		Phase 2	
Item DDGS,[2] %:	0	30	0	30
Ingredient, %				
Corn	67.85	45.25	72.90	50.20
Soybean meal, 46.5% CP	29.45	22.40	24.70	17.55
DDGS	---	30.00	---	30.00
Monocalcium P, 21% P	0.60	---	0.45	---
Limestone	0.90	1.20	0.90	1.20
Salt	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.09	0.09	0.09	0.09
L-thr	0.09	0.04	0.08	0.03
DL-met	0.12	0.01	0.07	---
L-lys sulfate	0.51	0.64	0.45	0.58
Phytase[4]	0.01	0.01	0.01	0.01
Total	100.0	100.0	100.0	100.0
Calculated analysis				
Standardized ileal digestible (SID) AA				
Lys, %	1.14	1.14	1	1
Met:lys, %	32	29	30	30
Met & cys:lys, %	56	56	56	60
Thr:lys, %	62	62	63	63
Trp:lys, %	18	18	18	18
Total lys, %	1.26	1.33	1.11	1.18
CP, %	19.9	22.9	18.1	21
SID lys:ME, g/Mcal	3.41	3.39	2.98	2.98
ME, kcal/kg	3,340	3,353	3,346	3,355
Ca, %	0.57	0.55	0.53	0.54
Available P, %	0.3	0.32	0.27	0.32
Crude fat, %	3.1	5.3	3.2	5.4
Crude fiber, %	2.6	4.1	2.6	4

[1] Phase 1 diets were fed from approximately 24 to 45 kg; Phase 2 diets were fed from 45 to 68 kg.

[2] Dried distillers grains with solubles.

[3] VTM = Vitamin and trace mineral premix.

[4] Optiphos 2000 (Enzyvia LLC, Sheridan, IN) provided per pound of diet: 998.8 (FTU)/kg and 0.11% available P released.

Table 4-2. Phase 3, 4, and 5 diet composition (as-fed basis)[1]

	Phase 3		Phase 4		Phase 5	
Item DDGS,[2] %	0	30	0	30	0	30
Ingredient, %						
Corn	75.75	53.00	80.10	57.15	85.30	62.25
Soybean meal, 46.5% CP	22.00	14.75	17.80	10.70	12.75	5.65
DDGS	---	30.00	---	30.00	---	30.00
Monocalcium P, 21% P	0.35	---	0.30	---	0.30	---
Limestone	0.90	1.20	0.85	1.20	0.85	1.20
Salt	0.35	0.35	0.35	0.35	0.35	0.35
Vitamin premix[3]	0.09	0.09	0.09	0.09	0.09	0.09
L-thr	0.07	0.02	0.06	0.02	0.03	---
DL-met	0.04	---	0.03	---	---	---
L-lysine sulfate	0.42	0.55	0.37	0.50	0.31	0.44
Phytase[4]	0.01	0.01	0.01	0.01	0.01	0.01
Total	100.0	100.0	100.0	100.0	100.0	100.0
Calculated analysis						
Standardized ileal digestible (SID) AA						
Lys, %	0.92	0.92	0.8	0.8	0.65	0.65
Met:lys, %	29	31	30	34	31	39
Met & cys:lys, %	56	63	59	68	63	78
Thr:lys, %	64	64	66	66	66	69
Trp:lys, %	18	18	18	18	18	18
Total lys, %	1.03	1.09	0.9	0.96	0.73	0.8
CP, %	17	20	15.4	18.4	13.4	16.4
SID lys:ME, g/Mcal	2.74	2.74	2.38	2.38	1.93	1.93
ME, kcal/kg	3,351	3,355	3,355	3,357	3,355	3,357
Ca, %	0.5	0.53	0.46	0.52	0.45	0.5
Available P, %	0.24	0.31	0.23	0.31	0.22	0.3
Crude fat, %	3.3	5.5	3.4	5.6	3.5	5.7
Crude fiber, %	2.5	3.9	2.5	3.9	2.4	3.8

[1] Phase 3 diets were fed from approximately 68 to 90 kg; Phase 4 diets were fed from 90 to 103 kg: Phase 5 diets were fed from 103 to 133 kg.

[2] Dried distillers grains with solubles.

[3] VTM = Vitamin and trace mineral premix.

[4] Optiphos 2000 (Enzyvia LLC, Sheridan, IN) provided per pound of diet: 998.8 FTU/kg and 0.11% available P released.

Table 4-3. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on growth performance[1]

Gender:	Barrow	Barrow	Barrow	Improvest	Improvest	Improvest	
d 0 to 74:	Corn-soy	30% DDGS	30% DDGS	Corn-soy	30% DDGS	30% DDGS	
d 74 to 125:	Corn-soy	Corn-soy	30% DDGS	Corn-soy	Corn-soy	30% DDGS	SEM
d 0 to 25							
ADG, kg	0.90	0.86	0.85	0.87	0.82	0.84	0.013
ADFI, kg	1.58	1.54	1.52	1.47	1.43	1.45	0.032
G:F	0.57	0.56	0.57	0.60	0.57	0.58	0.010
d 25 to 53[2]							
ADG, kg	0.81	0.78	0.79	0.81	0.79	0.79	0.014
ADFI, kg	1.84	1.94	1.81	1.63	1.67	1.68	0.040
G:F	0.44	0.40	0.43	0.50	0.47	0.47	0.008
d 53 to 74[3]							
ADG, kg	1.07	1.08	1.08	1.08	1.06	1.05	0.019
ADFI, kg	2.63	2.60	2.65	2.38	2.35	2.32	0.040
G:F	0.41	0.41	0.41	0.45	0.45	0.45	0.005
d 74 to 87							
ADG, kg	0.98	0.97	1.00	1.03	1.03	1.00	0.018
ADFI, kg	2.99	3.01	3.02	2.67	2.77	2.69	0.051
G:F	0.33	0.32	0.33	0.39	0.37	0.37	0.005
d 87 to 107							
ADG, kg	0.91	0.92	0.96	1.02	1.06	1.09	0.030
ADFI, kg	3.03	3.21	3.23	3.34	3.44	3.55	0.078
G:F	0.30	0.29	0.30	0.31	0.31	0.31	0.007
d 107 to 125							
ADG, kg	0.94	0.97	0.96	1.04	1.06	1.04	0.030
ADFI, kg	3.05	3.04	3.25	3.31	3.42	3.67	0.060
G:F	0.31	0.32	0.30	0.31	0.31	0.28	0.006

[1] A total of 1,360 pigs (PIC 337 × 1050, initially 24 kg) were used in a 125-d study.

[2] First Improvest injection was given on d 39.

[3] Second Improvest injection was given on d 74.

Table 4-4. Main effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on growth performance[1]

	Probability, $P <$				
	Interaction[2]	Gender[3]	Diet[4]	DDGS before[5]	DDGS withdrawal[6]
d 0 to 25					
ADG, kg	0.66	0.01	0.001	0.001	
ADFI, kg	0.71	0.001	0.35	0.15	
G:F	0.75	0.06	0.14	0.05	
d 25 to 53[2]					
ADG, kg	0.95	0.78	0.08	0.03	
ADFI, kg	0.22	0.001	0.20	0.27	
G:F	0.12	0.001	0.001	0.001	
d 53 to 74[3]					
ADG, kg	0.61	0.42	0.86	0.64	
ADFI, kg	0.63	0.001	0.73	0.46	
G:F	0.78	0.001	0.69	0.79	
d 74 to 87					
ADG, kg	0.22	0.03	0.98	0.85	0.93
ADFI, kg	0.64	0.001	0.51	0.35	0.49
G:F	0.22	0.001	0.22	0.12	0.41
d 87 to 107					
ADG, kg	0.88	0.001	0.13	0.09	0.26
ADFI, kg	0.84	0.001	0.04	0.01	0.41
G:F	0.47	0.03	0.66	0.64	0.44
d 107 to 125					
ADG, kg	0.93	0.001	0.62	0.45	0.54
ADFI, kg	0.39	0.001	0.001	0.003	0.001
G:F	0.24	0.25	0.001	0.14	0.001

[1] A total of 1,360 pigs (PIC 337 × 1050, initially 24 kg) were used in a 125-d study.

[2] Interaction gender × diet.

[3] Main effect of gender (treatments 1, 2, and 3 – (barrows) vs. 4, 5, and 6 – (Immunocastrates)).

[4] Main effect of diet type (corn-soy or 30% DDGS).

[5] Effect of DDGS before 2nd injection (treatments 1 and 4 vs. 2, 3, 5, and 6).

[6] Effect of withdrawing DDGS after 2nd injection (treatments 2 and 5 vs. 3 and 6).

Table 4-5. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on overall growth performance[1]

Gender:	Barrow	Barrow	Barrow	Improvest	Improvest	Improvest	
d 0 to 74:	Corn-soy	30% DDGS	30% DDGS	Corn-soy	30% DDGS	30% DDGS	
d 74 to 125:	Corn-soy	Corn-soy	30% DDGS	Corn-soy	Corn-soy	30% DDGS	SEM
Weight, kg							
d 0	24.2	24.3	24.3	24.0	24.1	24.0	0.526
d 25	46.8	45.8	45.6	45.9	44.6	45.0	0.793
d 53[2]	69.7	67.7	67.7	68.8	67.0	67.2	0.927
d 74[3]	92.3	90.4	90.4	91.5	89.4	89.5	0.968
d 87	105.0	103.0	103.4	104.9	102.8	102.6	1.003
d 107	117.1	115.6	115.9	119.9	117.8	118.1	1.358
d 125	133.9	133.7	133.2	138.6	137.0	137.0	1.458
d 0 to 74							
ADG, kg	0.92	0.89	0.89	0.91	0.87	0.88	0.009
ADFI, kg	1.97	1.99	1.94	1.78	1.77	1.78	0.026
G:F	0.47	0.45	0.46	0.51	0.49	0.49	0.005
d 74 to 107							
ADG, kg	0.94	0.94	0.98	1.02	1.05	1.05	0.021
ADFI, kg	3.01	3.13	3.14	3.07	3.17	3.20	0.063
G:F	0.31	0.30	0.31	0.33	0.33	0.33	0.005
d 74 to 125							
ADG, kg	0.94	0.95	0.97	1.03	1.05	1.05	0.017
ADFI, kg	3.02	3.11	3.17	3.13	3.23	3.31	0.052
G:F	0.31	0.31	0.31	0.33	0.33	0.32	0.004
d 0 to 107							
ADG, kg	0.92	0.91	0.92	0.94	0.93	0.93	0.010
ADFI, kg	2.28	2.33	2.30	2.16	2.18	2.20	0.033
G:F	0.40	0.39	0.40	0.44	0.42	0.42	0.004
d 0 to 125							
ADG, kg	0.92	0.91	0.92	0.95	0.94	0.94	0.009
ADFI, kg	2.35	2.39	2.38	2.27	2.29	2.33	0.031
G:F	0.39	0.38	0.39	0.42	0.41	0.40	0.004

[1] A total of 1,360 pigs (PIC 337 × 1050, initially 24 kg) were used in a 125-d study.

[2] First Improvest injection was given on d 39.

[3] Second Improvest injection was given on d 74.

Table 4-6. Main effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on overall growth performance[1]

	Probability, P <				
	Interaction[2]	Gender[3]	Diet[4]	DDGS before[5]	DDGS withdrawal[6]
Weight, kg					
d 0	1.00	0.64	1.00	0.96	
d 25	0.95	0.17	0.26	0.10	
d 53[2]	0.98	0.36	0.08	0.03	
d 74[3]	1.00	0.29	0.07	0.02	
d 87	0.93	0.67	0.08	0.02	0.90
d 107	0.96	0.04	0.37	0.16	0.85
d 125	0.89	0.002	0.70	0.41	0.87
d 0 to 74					
ADG, kg	0.92	0.08	0.002	0.001	0.74
ADFI, kg	0.60	0.001	0.77	0.74	0.52
G:F	0.34	0.001	0.003	0.001	0.25
d 74 to 107					
ADG, kg	0.78	0.001	0.24	0.16	0.35
ADFI, kg	0.99	0.35	0.10	0.03	0.72
G:F	0.51	0.001	0.40	0.30	0.38
d 74 to 125					
ADG, kg	0.81	0.001	0.24	0.11	0.55
ADFI, kg	0.93	0.01	0.01	0.01	0.15
G:F	0.44	0.001	0.19	0.11	0.36
d 0 to 107					
ADG, kg	0.91	0.03	0.22	0.13	0.41
ADFI, kg	0.80	0.001	0.58	0.30	0.88
G:F	0.37	0.001	0.01	0.002	0.29
d 0 to 125					
ADG, kg	0.89	0.003	0.37	0.21	0.53
ADFI, kg	0.76	0.003	0.26	0.12	0.59
G:F	0.29	0.001	0.004	0.001	0.93

[1] A total of 1,360 pigs (PIC 337 × 1050, initially 24 kg) were used in a 125-d study.

[2] Interaction gender × diet.

[3] Main effect of gender (treatments 1, 2, and 3 – (barrows) vs. 4, 5, and 6 – (Immunocastrates)).

[4] Main effect of diet type (corn-soy or 30% DDGS).

[5] Effect of DDGS before 2nd injection (treatments 1 and 4 vs. 2, 3, 5, and 6).

[6] Effect of withdrawing DDGS after 2nd injection (treatments 2 and 5 vs. 3 and 6).

Table 4-7. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on carcass characteristics

Gender:	Barrow	Barrow	Barrow	Improvest	Improvest	Improvest	
Day 0 to 74:	Corn-soy	30% DDGS	30% DDGS	Corn-soy	30% DDGS	30% DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	30% DDGS	Corn-soy	Corn-soy	30% DDGS	SEM
HCW, kg[1]							
d 107	94.7	93.6	93.1	95.0	94.5	92.9	0.94
d 125	97.0	96.7	95.5	98.4	97.2	96.3	1.04
Yield, %[1]							
d 107	76.6	76.4	75.9	74.8	74.8	73.6	0.13
d 125	76.3	76.2	75.8	74.9	74.8	74.0	0.16
Backfat depth, mm[2]							
d 107[3]	20.02	20.65	21.45	17.31	17.97	20.35	1.14
d 125[3]	25.98	22.81	24.21	24.34	24.69	23.22	1.14
Loin depth, mm[2]							
d 107[3]	68.17	68.11	66.60	66.22	67.77	65.64	1.25
d 125[3]	66.24	68.18	69.13	68.27	67.47	67.64	1.25
Loin area, mm[2]							
d 107[3]	49.49	47.95	48.43	51.10	48.79	48.86	1.24
d 125[3]	55.32	54.47	55.56	54.61	53.98	54.66	1.25
Percent lean[2]							
d 107[3]	54.83	54.44	53.77	56.25	56.03	54.32	0.74
d 125[3]	50.96	53.13	52.39	52.20	51.89	52.82	0.74

[1] Data includes all pigs harvested on d 107 (528 pigs) and on d 125 (739 pigs).
[2] Data includes only pigs sent to University of Illinois for carcass analysis (96 pigs on d 107 and 96 pigs on d 125).
[3] Values on d 107 are adjusted to 87.73 kg HCW, and on d 125 to 101.44 kg HCW.

Table 4-8. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on main effects of carcass characteristics[1]

	Gender×Time[2]	Gender×DDGS[3]	DDGS×Time[4]	Gender[5]	DDGS[6]	Time[7]
HCW, kg	0.64	0.92	1.00	0.28	0.04	0.001
Yield, %	0.03	0.05	0.43	0.001	0.001	0.56
Backfat depth	0.16	0.53	0.08	0.07	0.63	0.97
Loin depth	0.49	0.77	0.34	0.43	0.71	0.38
Loin area	0.26	0.92	0.58	0.86	0.33	0.16
Percent lean	0.23	0.52	0.06	0.12	0.58	0.89

[1] No three or four way interactions occurred ($P > 0.34$).

[2] Gender (barrow or IC) × time (d 107 or 125) interaction.

[3] Gender (barrow or IC) × DDGS (0% throughout, 30% then withdraw, 30% throughout) interaction.

[4] DDGS (0% throughout, 30% then withdraw, 30% throughout) × time (d 107 or 125) interaction.

[5] Main effect of gender (barrow or IC).

[6] Main effect of DDGS (0% throughout, 30% then withdraw, 30% throughout).

[7] Main effect of time (d 107 or 125).

Table 4-9. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on belly fatty acid analysis for pigs harvested at d 107[1,2,3]

Gender:	Barrow	Barrow	Barrow	Improvest	Improvest	Improvest	
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.40	1.36	1.31	1.35	1.29	1.22	0.03
Palmitic acid (C16:0), %	24.50	23.28	22.56	23.60	23.38	22.27	0.29
Palmitoleic acid (C16:1), %	2.59	2.38	2.26	2.52	2.16	2.11	0.09
Margaric acid (C17:0), %	0.55	0.58	0.63	0.54	0.54	0.57	0.03
Stearic acid (C18:0), %	12.43	11.40	10.85	12.67	12.82	11.11	0.34
Oleic acid (C18:1 *cis*-9), %	39.12	37.44	36.13	37.89	36.29	35.58	0.44
Vaccenic acid (C18:1n-7), %	3.77	3.50	3.34	3.71	3.35	3.22	0.08
Linoleic acid (C18:2n-6), %	11.63	15.64	18.37	13.49	15.89	19.32	0.52
α-Linoleic acid (C18:3n-3), %	0.52	0.59	0.64	0.60	0.60	0.65	0.02
Arachidic acid (C20:0), %	0.25	0.24	0.25	0.23	0.26	0.24	0.01
Gadoleic acid (C20:1), %	0.82	0.82	0.78	0.75	0.77	0.77	0.02
Eicosadienoic acid (C20:2), %	0.66	0.85	0.93	0.74	0.83	1.00	0.03
Arachidonic acid (C20:4n-6), %	0.23	0.26	0.27	0.29	0.30	0.30	0.01
Other fatty acids, %	1.54	1.65	1.66	1.62	1.53	1.62	0.05
Total SFA, %[4]	39.39	37.12	35.83	38.66	38.54	35.67	0.56
Total MUFA, %[5]	46.37	44.22	42.59	44.96	42.64	41.76	0.56
Total PUFA, %[6]	13.24	17.57	20.44	15.35	17.82	21.50	0.57
Total *trans* fatty acids, %[7]	0.79	0.91	0.94	0.88	0.85	0.94	0.03
UFA:SFA ratio[8]	1.52	1.67	1.77	1.58	1.59	1.79	0.04
PUFA:SFA ratio[9]	0.34	0.48	0.58	0.40	0.47	0.61	0.02
Iodine value, g/100g[10]	62.07	67.41	70.86	64.32	66.40	71.79	0.81

[1] All values are on a DM basis.

[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.

[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[4] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]0 Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8] UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9] PUFA:SFA = total PUFA/total SFA.

[10] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 4-10. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on clearplate fatty acid analysis for pigs harvested at d 107[1,2,3]

Gender:	Barrow	Barrow	Barrow	Improvest	Improvest	Improvest	
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.36	1.32	1.27	1.31	1.23	1.17	0.03
Palmitic acid (C16:0), %	25.24	23.89	23.04	24.16	23.52	22.26	0.29
Palmitoleic acid (C16:1), %	1.99	1.85	1.75	1.94	1.64	1.60	0.09
Margaric acid (C17:0), %	0.65	0.70	0.74	0.66	0.67	0.70	0.03
Stearic acid (C18:0), %	14.91	13.41	12.43	14.52	14.21	12.30	0.34
Oleic acid (C18:1 *cis*-9), %	36.01	34.29	33.54	35.36	33.47	32.76	0.44
Vaccenic acid (C18:1n-7), %	3.02	2.84	2.72	3.03	2.68	2.62	0.08
Linoleic acid (C18:2n-6), %	12.78	17.24	19.91	14.90	18.18	21.81	0.51
α-Linoleic acid (C18:3n-3), %	0.56	0.64	0.68	0.64	0.67	0.73	0.02
Arachidic acid (C20:0), %	0.27	0.27	0.27	0.24	0.26	0.26	0.01
Gadoleic acid (C20:1), %	0.81	0.78	0.75	0.71	0.74	0.76	0.02
Eicosadienoic acid (C20:2), %	0.68	0.87	0.95	0.73	0.88	1.07	0.03
Arachidonic acid (C20:4n-6), %	0.22	0.25	0.26	0.28	0.30	0.30	0.01
Other fatty acids, %	1.50	1.65	1.70	1.52	1.54	1.67	0.05
Total SFA, %[4]	42.68	39.83	37.98	41.13	40.14	36.93	0.55
Total MUFA, %[5]	41.89	39.82	38.83	41.11	38.60	37.81	0.55
Total PUFA, %[6]	14.43	19.25	22.04	16.74	20.26	24.17	0.56
Total *trans* fatty acids, %[7]	0.82	0.97	1.01	0.90	0.94	1.04	0.03
UFA:SFA ratio[8]	1.33	1.49	1.61	1.42	1.48	1.69	0.04
PUFA:SFA ratio[9]	0.34	0.48	0.58	0.41	0.51	0.66	0.02
Iodine value, g/100g[10]	60.23	66.52	70.39	63.45	67.09	72.94	0.80

[1] All values are on a DM basis.

[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.

[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[4] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]0 Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8] UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9] PUFA:SFA = total PUFA/total SFA.

[10] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 4-11. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on jowl fatty acid analysis for pigs harvested at d 107[1,2,3]

Gender:	Barrow	Barrow	Barrow	Improvest	Improvest	Improvest	
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.35	1.30	1.25	1.28	1.22	1.20	0.03
Palmitic acid (C16:0), %	23.23	21.74	21.17	22.02	21.64	21.05	0.29
Palmitoleic acid (C16:1), %	2.50	2.36	2.15	2.40	2.12	2.12	0.09
Margaric acid (C17:0), %	0.60	0.66	0.72	0.62	0.62	0.67	0.03
Stearic acid (C18:0), %	11.67	10.21	9.95	11.53	11.52	10.23	0.34
Oleic acid (C18:1 *cis*-9), %	39.62	37.36	36.20	38.05	35.76	35.31	0.44
Vaccenic acid (C18:1n-7), %	3.84	3.62	3.35	3.77	3.36	3.32	0.08
Linoleic acid (C18:2n-6), %	12.70	17.73	19.99	15.53	18.85	20.77	0.51
α-Linoleic acid (C18:3n-3), %	0.58	0.69	0.73	0.71	0.72	0.74	0.02
Arachidic acid (C20:0), %	0.23	0.22	0.24	0.21	0.23	0.21	0.01
Gadoleic acid (C20:1), %	0.88	0.85	0.83	0.80	0.80	0.84	0.02
Eicosadienoic acid (C20:2), %	0.75	0.97	1.07	0.84	1.00	1.13	0.03
Arachidonic acid (C20:4n-6), %	0.26	0.31	0.31	0.34	0.36	0.36	0.01
Other fatty acids, %	1.80	1.98	2.04	1.90	1.81	2.06	0.05
Total SFA, %[4]	37.34	34.39	33.59	35.93	35.49	33.64	0.55
Total MUFA, %[5]	46.94	44.31	42.64	45.12	42.14	41.72	0.55
Total PUFA, %[6]	14.57	20.01	22.44	17.73	21.20	23.38	0.56
Total *trans* fatty acids, %[7]	0.90	1.07	1.13	1.03	1.00	1.12	0.03
UFA:SFA ratio[8]	1.66	1.88	1.95	1.76	1.80	1.96	0.04
PUFA:SFA ratio[9]	0.39	0.58	0.67	0.50	0.61	0.71	0.02
Iodine value, g/100g[10]	64.70	71.54	74.15	68.43	71.53	74.78	0.80

[1] All values are on a DM basis.

[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.

[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[4] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]0 Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8] UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9] PUFA:SFA = total PUFA/total SFA.

[10] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 4-12. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on backfat fatty acid analysis for pigs harvested at d 107[1,2,3]

Gender:	Barrow	Barrow	Barrow	Improvest	Improvest	Improvest	
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.36	1.34	1.29	1.34	1.25	1.22	0.03
Palmitic acid (C16:0), %	25.41	24.30	23.22	24.53	23.80	22.95	0.29
Palmitoleic acid (C16:1), %	2.10	1.95	1.79	2.07	1.82	1.76	0.09
Margaric acid (C17:0), %	0.65	0.66	0.75	0.65	0.64	0.67	0.03
Stearic acid (C18:0), %	14.76	13.57	12.32	14.48	14.03	12.33	0.34
Oleic acid (C18:1 *cis*-9), %	35.83	34.43	32.84	34.66	33.35	32.52	0.44
Vaccenic acid (C18:1n-7), %	3.11	2.93	2.71	3.07	2.82	2.69	0.08
Linoleic acid (C18:2n-6), %	12.76	16.45	20.46	15.01	17.93	21.27	0.51
α-Linoleic acid (C18:3n-3), %	0.54	0.61	0.68	0.64	0.66	0.69	0.02
Arachidic acid (C20:0), %	0.30	0.28	0.29	0.27	0.29	0.28	0.01
Gadoleic acid (C20:1), %	0.80	0.78	0.72	0.72	0.72	0.73	0.02
Eicosadienoic acid (C20:2), %	0.66	0.82	0.95	0.71	0.85	0.99	0.03
Arachidonic acid (C20:4n-6), %	0.23	0.25	0.27	0.28	0.29	0.28	0.01
Other fatty acids, %	1.50	1.63	1.70	1.58	1.55	1.62	0.05
Total SFA, %[4]	42.72	40.38	38.12	41.54	40.26	37.70	0.55
Total MUFA, %[5]	41.92	40.18	38.14	40.58	38.79	37.77	0.55
Total PUFA, %[6]	14.37	18.35	22.60	16.85	19.95	23.48	0.56
Total *trans* fatty acids, %[7]	0.80	0.93	1.01	0.92	0.92	0.97	0.03
UFA:SFA ratio[8]	1.32	1.45	1.60	1.39	1.47	1.64	0.04
PUFA:SFA ratio[9]	0.34	0.46	0.60	0.41	0.50	0.63	0.02
Iodine value, g/100g[10]	60.17	65.34	70.76	63.24	66.78	71.82	0.80

[1] All values are on a DM basis.

[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.

[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[4] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]0 Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8] UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9] PUFA:SFA = total PUFA/total SFA.

[10] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 4-13. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on belly fatty acid analysis for pigs harvested at d 125[1,2,3]

Gender:	Barrow	Barrow	Barrow	Improvest	Improvest	Improvest	
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.38	1.32	1.28	1.42	1.30	1.28	0.03
Palmitic acid (C16:0), %	24.64	23.35	21.99	24.67	23.79	22.42	0.29
Palmitoleic acid (C16:1), %	2.46	2.40	2.20	2.56	2.31	2.12	0.09
Margaric acid (C17:0), %	0.52	0.56	0.59	0.52	0.57	0.54	0.03
Stearic acid (C18:0), %	12.80	11.85	10.13	12.88	12.54	11.33	0.34
Oleic acid (C18:1 *cis*-9), %	39.70	37.95	37.19	38.56	38.25	36.16	0.44
Vaccenic acid (C18:1n-7), %	3.72	3.54	3.38	3.71	3.49	3.22	0.08
Linoleic acid (C18:2n-6), %	10.83	14.72	18.63	11.67	13.55	18.57	0.51
α-Linoleic acid (C18:3n-3), %	0.47	0.54	0.63	0.51	0.51	0.60	0.02
Arachidic acid (C20:0), %	0.26	0.26	0.26	0.25	0.28	0.26	0.01
Gadoleic acid (C20:1), %	0.86	0.80	0.82	0.81	0.83	0.75	0.02
Eicosadienoic acid (C20:2), %	0.63	0.79	0.99	0.64	0.76	0.94	0.03
Arachidonic acid (C20:4n-6), %	0.22	0.26	0.27	0.24	0.25	0.27	0.01
Other fatty acids, %	1.52	1.66	1.65	1.57	1.58	1.53	0.05
Total SFA, %[4]	39.85	37.60	34.48	40.01	38.72	36.06	0.55
Total MUFA, %[5]	46.83	44.77	43.66	45.73	44.97	42.33	0.55
Total PUFA, %[6]	12.36	16.56	20.77	13.29	15.29	20.61	0.56
Total *trans* fatty acids, %[7]	0.77	0.88	0.93	0.81	0.81	0.88	0.03
UFA:SFA ratio[8]	1.49	1.64	1.88	1.49	1.56	1.76	0.04
PUFA:SFA ratio[9]	0.31	0.44	0.61	0.34	0.40	0.58	0.02
Iodine value, g/100g[10]	60.95	66.21	72.21	61.60	64.19	70.82	0.80

[1] All values are on a DM basis.

[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.

[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[4] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]0 Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8] UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9] PUFA:SFA = total PUFA/total SFA.

[10] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 4-14. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on clearplate fatty acid analysis for pigs harvested at d 125[1,2,3]

Gender:	Barrow	Barrow	Barrow	Improvest	Improvest	Improvest	
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.32	1.26	1.21	1.34	1.22	1.19	0.03
Palmitic acid (C16:0), %	25.06	23.62	22.41	25.02	23.71	22.50	0.29
Palmitoleic acid (C16:1), %	1.95	1.88	1.63	1.95	1.78	1.47	0.09
Margaric acid (C17:0), %	0.62	0.66	0.72	0.62	0.69	0.67	0.03
Stearic acid (C18:0), %	15.00	13.63	12.15	14.92	14.00	13.04	0.34
Oleic acid (C18:1 *cis*-9), %	36.46	34.61	33.28	35.07	34.96	31.54	0.44
Vaccenic acid (C18:1n-7), %	2.98	2.88	2.63	2.95	2.81	2.42	0.08
Linoleic acid (C18:2n-6), %	12.72	17.19	21.46	14.14	16.60	22.70	0.52
α-Linoleic acid (C18:3n-3), %	0.55	0.61	0.69	0.60	0.60	0.72	0.02
Arachidic acid (C20:0), %	0.24	0.25	0.25	0.25	0.25	0.24	0.01
Gadoleic acid (C20:1), %	0.79	0.76	0.75	0.75	0.77	0.72	0.02
Eicosadienoic acid (C20:2), %	0.67	0.84	1.02	0.70	0.84	1.03	0.03
Arachidonic acid (C20:4n-6), %	0.21	0.24	0.25	0.23	0.24	0.27	0.01
Other fatty acids, %	1.43	1.55	1.56	1.48	1.55	1.49	0.05
Total SFA, %[4]	42.46	39.64	36.95	42.37	40.08	37.88	0.56
Total MUFA, %[5]	42.24	40.20	38.34	40.78	40.39	36.21	0.56
Total PUFA, %[6]	14.32	19.09	23.61	15.84	18.46	24.91	0.57
Total *trans* fatty acids, %[7]	0.80	0.93	0.97	0.87	0.89	0.98	0.03
UFA:SFA ratio[8]	1.34	1.50	1.68	1.34	1.47	1.62	0.04
PUFA:SFA ratio[9]	0.34	0.49	0.64	0.37	0.46	0.66	0.02
Iodine value, g/100g[10]	60.36	66.61	72.56	61.73	65.65	72.91	0.81

[1] All values are on a DM basis.

[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.

[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[4] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]0 Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8] UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9] PUFA:SFA = total PUFA/total SFA.

[10] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 4-15. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on jowl fatty acid analysis for pigs harvested at d 125[1,2,3]

Gender:	Barrow	Barrow	Barrow	Improvest	Improvest	Improvest	
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.33	1.25	1.22	1.35	1.20	1.21	0.03
Palmitic acid (C16:0), %	22.60	20.95	20.50	22.44	20.99	20.63	0.29
Palmitoleic acid (C16:1), %	2.53	2.46	2.17	2.56	2.31	2.02	0.09
Margaric acid (C17:0), %	0.60	0.63	0.66	0.59	0.65	0.61	0.03
Stearic acid (C18:0), %	10.82	9.64	9.01	10.83	10.04	9.88	0.34
Oleic acid (C18:1 *cis*-9), %	40.44	38.36	37.26	38.94	37.94	35.74	0.44
Vaccenic acid (C18:1n-7), %	3.84	3.66	3.34	3.78	3.52	3.13	0.08
Linoleic acid (C18:2n-6), %	13.43	18.24	20.84	15.02	18.51	21.93	0.52
α-Linoleic acid (C18:3n-3), %	0.61	0.70	0.73	0.67	0.71	0.75	0.02
Arachidic acid (C20:0), %	0.21	0.22	0.21	0.21	0.21	0.21	0.01
Gadoleic acid (C20:1), %	0.90	0.82	0.84	0.85	0.84	0.80	0.02
Eicosadienoic acid (C20:2), %	0.79	0.98	1.13	0.83	1.03	1.15	0.03
Arachidonic acid (C20:4n-6), %	0.26	0.30	0.30	0.27	0.31	0.31	0.01
Other fatty acids, %	1.64	1.79	1.79	1.67	1.74	1.62	0.05
Total SFA, %[4]	35.81	32.91	31.81	35.66	33.33	32.78	0.56
Total MUFA, %[5]	47.76	45.37	43.67	46.20	44.68	41.75	0.56
Total PUFA, %[6]	15.31	20.50	23.26	17.00	20.80	24.39	0.57
Total *trans* fatty acids, %[7]	0.90	1.06	1.06	0.98	1.03	1.02	0.03
UFA:SFA ratio[8]	1.77	2.01	2.11	1.78	1.97	2.03	0.04
PUFA:SFA ratio[9]	0.43	0.63	0.73	0.48	0.63	0.75	0.02
Iodine value, g/100g[10]	66.65	73.31	76.37	68.24	73.11	76.56	0.81

[1] All values are on a DM basis.

[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.

[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[4] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]0 Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8] UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9] PUFA:SFA = total PUFA/total SFA.

[10] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 4-16. Effect of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on backfat fatty acid analysis for pigs harvested at d 125[1,2,3]

Gender:	Barrow	Barrow	Barrow	Improvest	Improvest	Improvest	
Day 0 to 74:	Corn-soy	DDGS	DDGS	Corn-soy	DDGS	DDGS	
Day 74 to 125:	Corn-soy	Corn-soy	DDGS	Corn-soy	Corn-soy	DDGS	SEM
Myristic acid (C14:0), %	1.35	1.33	1.27	1.38	1.29	1.28	0.03
Palmitic acid (C16:0), %	25.60	24.51	23.19	25.86	24.80	23.52	0.29
Palmitoleic acid (C16:1), %	2.10	2.05	1.73	2.03	1.95	1.68	0.09
Margaric acid (C17:0), %	0.53	0.57	0.65	0.52	0.58	0.60	0.03
Stearic acid (C18:0), %	14.97	13.99	12.48	15.52	14.49	13.27	0.34
Oleic acid (C18:1 *cis*-9), %	37.29	35.48	33.54	35.92	36.31	32.60	0.44
Vaccenic acid (C18:1n-7), %	3.08	2.94	2.64	2.94	2.91	2.53	0.08
Linoleic acid (C18:2n-6), %	11.27	14.97	20.15	12.08	13.73	20.28	0.51
α-Linoleic acid (C18:3n-3), %	0.48	0.53	0.64	0.49	0.49	0.63	0.02
Arachidic acid (C20:0), %	0.30	0.31	0.28	0.30	0.30	0.27	0.01
Gadoleic acid (C20:1), %	0.83	0.79	0.76	0.82	0.82	0.72	0.02
Eicosadienoic acid (C20:2), %	0.62	0.77	0.96	0.62	0.72	0.94	0.03
Arachidonic acid (C20:4n-6), %	0.20	0.23	0.24	0.20	0.22	0.25	0.01
Other fatty acids, %	1.37	1.51	1.48	1.31	1.39	1.45	0.05
Total SFA, %[4]	43.01	40.96	38.11	43.82	41.69	39.19	0.55
Total MUFA, %[5]	43.38	41.34	38.73	41.77	42.06	37.59	0.55
Total PUFA, %[6]	12.75	16.72	22.18	13.56	15.33	22.28	0.56
Total *trans* fatty acids, %[7]	0.71	0.84	0.89	0.74	0.74	0.89	0.03
UFA:SFA ratio[8]	1.31	1.42	1.61	1.27	1.38	1.54	0.04
PUFA:SFA ratio[9]	0.30	0.41	0.59	0.31	0.37	0.57	0.02
Iodine value, g/100g[10]	58.65	63.58	70.45	58.69	61.79	69.69	0.80

[1] All values are on a DM basis.

[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.

[3] Pigs selected for fat analyses represented the median for each pen (2 pigs/pen).

[4] Total SFA = ([C8:0] + [C10:0] + [C12:0] + [C14:0] + [C16:0] + [C17:0] + [C18:0] + [C20:0] + [C22:0] + [C24:0]); brackets indicate concentration.

[5] Total MUFA = ([C14:1] + [C16:1] + [C18:1cis-9] + [C18:1n-7] + [C20:1] + [C24:1]); brackets indicate concentration.

[6] Total PUFA = ([C18:2n-6] + [C18:3n-3] + [C18:3n-6] + [C20:2] + [C20:4n-6]); brackets indicate concentration.

[7]0 Total trans fatty acids = ([C18:1trans] + [C18:2trans] + [C18:3trans]); brackets indicate concentration.

[8] UFA:SFA = (total MUFA + total PUFA)/total SFA.

[9] PUFA:SFA = total PUFA/total SFA.

[10] Calculated as IV value (IV) = [C16:1] × 0.95 + [C18:1] × 0.86 + [C18:2] × 1.732 + [C18:3] × 2.616 + [C20:1] × 0.785 + [C22:1] × 0.723; brackets indicate concentration.

Table 4-17 Interactive effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on fatty acid analysis for pigs harvested at d 107 and 125[1]

	Gender×DDGS[2]	Gender×Depot[3]	Gender×Time[4]	DDGS×Depot[5]	DDGS×Time[6]	Time×Depot[7]	Gender	DDGS	Time	Depot
Myristic acid (C14:0), %	0.45	0.35	0.05	0.02	0.72	0.001	0.02	0.001	0.95	0.001
Palmitic acid (C16:0), %	0.34	0.03	0.02	0.001	0.29	0.001	0.22	0.001	0.58	0.001
Palmitoleic acid (C16:1), %	0.55	0.59	0.62	0.44	0.34	0.08	0.06	0.001	0.76	0.001
Margaric acid (C17:0), %	0.42	0.78	0.68	0.17	0.70	0.001	0.24	0.01	0.03	0.001
Stearic acid (C18:0), %	0.19	0.03	0.55	0.001	0.87	0.001	0.02	0.001	0.92	0.001
Oleic acid (C18:1 *cis*-9), %	0.31	0.03	0.67	0.002	0.11	0.001	0.001	0.001	0.001	0.001
Vaccenic acid (C18:1n-7), %	0.69	0.60	0.92	0.03	0.19	0.17	0.01	0.001	0.72	0.001
Linoleic acid (C18:2n-6), %	0.04	0.002	0.04	0.001	0.02	0.001	0.001	0.001	0.01	0.001
α-Linoleic acid (C18:3n-3), %	0.01	0.01	0.03	0.003	0.20	0.001	0.004	0.001	0.001	0.001
Arachidic acid (C20:0), %	0.33	0.32	0.26	0.04	0.65	0.001	0.16	0.36	0.87	0.001
Gadoleic acid (C20:1), %	0.26	0.84	0.32	0.001	0.39	0.001	0.01	0.05	0.13	0.001
Eicosadienoic acid (C20:2), %	0.44	0.001	0.08	0.001	0.30	0.001	0.07	0.001	0.11	0.001
Arachidonic acid (C20:4n-6), %	0.52	0.01	0.001	0.15	0.61	0.001	0.001	0.001	0.001	0.001
Other fatty acids, %	0.20	0.03	0.08	0.001	0.53	0.001	0.53	0.001	0.98	0.001
Total SFA, %	0.61	0.08	0.64	0.01	0.08	0.001	0.001	0.001	0.003	0.001
Total MUFA, %	0.04	0.001	0.03	0.001	0.03	0.001	0.001	0.001	0.01	0.001
Total PUFA, %	0.001	0.25	0.28	0.06	0.88	0.001	0.66	0.001	0.001	0.001
Total *trans* fatty acids, %	0.24	0.05	0.08	0.001	0.55	0.001	0.60	0.001	0.71	0.001
UFA:SFA ratio	0.07	0.001	0.02	0.001	0.14	0.001	0.02	0.001	0.10	0.001
PUFA:SFA ratio	0.02	0.86	0.62	0.41	0.07	0.001	0.07	0.001	0.001	0.001
Iodine value, g/100g	0.04	0.002	0.03	0.001	0.16	0.001	0.11	0.001	0.15	0.001

[1] No three or four way interactions occurred ($P > 0.09$) with the exception of DDGS×time×depot ($P < 0.03$) for total PUFA.
[2] Gender (barrow or IC) × DDGS (0% throughout, 30% then withdraw, 30% throughout) interaction.
[3] Gender (barrow or IC) × depots (belly, clearplate, jowl, backfat) interaction.
[4] Gender (barrow or IC) × time (d 107 or 125) interaction.
[5] DDGS (0% throughout, 30% then withdraw, 30% throughout) × depots (belly, clearplate, jowl, backfat) interaction.
[6] DDGS (0% throughout, 30% then withdraw, 30% throughout) × time (d 107 or 125) interaction.
[7] Time (d 107 or 125) × depots (belly, clearplate, jowl, backfat) interaction.

Table 4-18. Effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on fatty acid concentrations for pigs harvested at d 107[1,2]

	Jowl			Belly			Backfat			Clear plate		
	Gender[3]	DDGS[4]	Withdraw[5]	Gender	DDGS	Withdraw	Gender	DDGS	Withdraw	Gender	DDGS	Withdraw
Myristic acid (C14:0)	↓	↓	~	↓	↓	↓*	↓	↓	~	↓	↓	↓*
Palmitic acid (C16:0)	↓*	↓	↓*	~	↓	↓	↓	↓	↓	↓	↓	↓
Palmitoleic acid (C16:1)	~	↓	~	~	↓	~	~	↓	~	↓*	↓	~
Margaric acid (C17:0)	~	↑	~	~	~	~	~	~	~	~	~	~
Stearic acid (C18:0)	~	↓	↓	↑*	↓	↓	~	↓	↓	~	↓	↓
Oleic acid (C18:1 *cis*-9)	↓	↓	↓*	↓	↓	↓	↓	↓	↓	↓	↓	↓*
Vaccenic acid (C18:1n-7)	~	↓	~	~	↓	~	~	↓	↓	~	↓	~
Linoleic acid (C18:2n-6)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
α-Linoleic acid (C18:3n-3)	↑	↑	~	↑	↑	↑	↑	↑	↑	↑	↑	↑
Arachidic acid (C20:0)	↓*	~	~	~	~	~	~	~	~	↓	~	~
Gadoleic acid (C20:1)	↓	~	~	↓	~	~	↓	~	~	↓	~	~
Eicosadienoic acid (C20:2)	↑	↑	↑	↑*	↑	↑	~	↑	↑	↑	↑	↑
Arachidonic acid (C20:4n-6)	↑	↑	~	↑	↑	~	↑*	↑*	~	↑	↑	~
Other fatty acids	~	↑	↑	~	~	~	~	↑	↑*	~	↑	↑*
Total SFA[7]	~	↓	↓	~	↓	↓	~	↓	↓	~	↓	↓
Total MUFA[8]	↓	↓	↓*	↓	↓	↓*	↓	↓	↓	↓	↓	↓*
Total PUFA[9]	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Total *trans* fatty acids[10]	~	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑
UFA:SFA ratio[11]	~	↑	↑	~	↑	↑	~	↑	↑	↑*	↑	↑
PUFA:SFA ratio[12]	↑	↑	↑	↑*	↑	↑	↑	↑	↑	↑	↑	↑
Iodine value, g/100g[13]	↑*	↑	↑	~	↑	↑	↑	↑	↑	↑	↑	↑

[1] Symbols (↓↑) mean significant differences ($P < 0.05$); symbols with (*) mean trend ($P < 0.10$); ~ means no difference ($P > 0.10$).
[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.
[3] Effect of gender (Immunocastrate vs. Barrow); ↑ means value was higher for IC pigs; ↓ means value was lower for IC pigs.
[4] Effect of DDGS for first 74 d; ↑ means value was higher for pigs fed DDGS; ↓ means value was lower for pigs fed DDGS.
[5] Effect of DDGS during withdrawal; ↑ means value was higher for pigs fed DDGS throughout; ↓ means value was lower for pigs fed DDGS throughout.

Table 4-19. Effects of dried distillers grains with solubles (DDGS) withdrawal post-immunocastration on fatty acid concentrations for pigs harvested at d 125[1,2]

	Jowl			Belly			Backfat			Clear plate		
	Gender[3]	DDGS[4]	Withdraw[5]	Gender	DDGS	Withdraw	Gender	DDGS	Withdraw	Gender	DDGS	Withdraw
Myristic acid (C14:0)	~	↓	~	~	↓	~	~	↓	~	~	↓	~
Palmitic acid (C16:0)	~	↓	~	~	↓	↓	~	↓	↓	~	↓	↓
Palmitoleic acid (C16:1)	~	↓	↓	~	↓	↓*	~	↓	↓	~	↓	↓
Margaric acid (C17:0)	~	~	~	~	↑	~	~	↑	~	~	↑	~
Stearic acid (C18:0)	↑	↓	~	↑	↓	↓	↑	↓	↓	~	↓	↓
Oleic acid (C18:1 *cis*-9)	↓	↓	↓	↓*	↓	↓	~	↓	↓	↓	↓	↓
Vaccenic acid (C18:1n-7)	↓	↓	↓	~	↓	↓	↓*	↓	↓	↓	↓	↓
Linoleic acid (C18:2n-6)	↑	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑
α-Linoleic acid (C18:3n-3)	↑*	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑
Arachidic acid (C20:0)	~	~	~	~	~	~	~	~	↓	~	~	~
Gadoleic acid (C20:1)	~	↓	~	~	~	~	~	↓	↓	~	~	~
Eicosadienoic acid (C20:2)	~	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑
Arachidonic acid (C20:4n-6)	~	↑	~	~	↑	↑*	~	↑	↑*	~	↑	↑*
Other fatty acids	↓*	↑	~	~	~	~	↓	↑	~	~	↑	~
Total SFA[7]	~	↓	↓*	↑	↓	↓	↑	↓	↓	~	↓	↓
Total MUFA[8]	↓	↓	↓	↓*	↓	↓	↓*	↓	↓	↓	↓	↓
Total PUFA[9]	↑	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑
Total *trans* fatty acids[10]	~	↑	~	~	↑	↑*	~	↑	↑	~	↑	↑
UFA:SFA ratio[11]	~	↑	↑	↓*	↑	↑	↓	↑	↑	~	↑	↑
PUFA:SFA ratio[12]	~	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑
Iodine Value, g/100g[13]	~	↑	↑	~	↑	↑	~	↑	↑	~	↑	↑

[1] Symbols (↓↑) mean significant differences ($P < 0.05$); symbols with (*) mean trend ($P < 0.10$); ~ means no difference ($P > 0.10$).
[2] First Improvest injection was given on d 39; second Improvest injection was given on d 74.
[3] Effect of gender (Immunocastrate vs. Barrow); ↑ means value was higher for IC pigs; ↓ means value was lower for IC pigs.
[4] Effect of DDGS for first 74 d; ↑ means value was higher for pigs fed DDGS; ↓ means value was lower for pigs fed DDGS.
[5] Effect of DDGS during withdrawal; ↑ means value was higher for pigs fed DDGS throughout; ↓ means value was lower for pigs fed DDGS throughout.

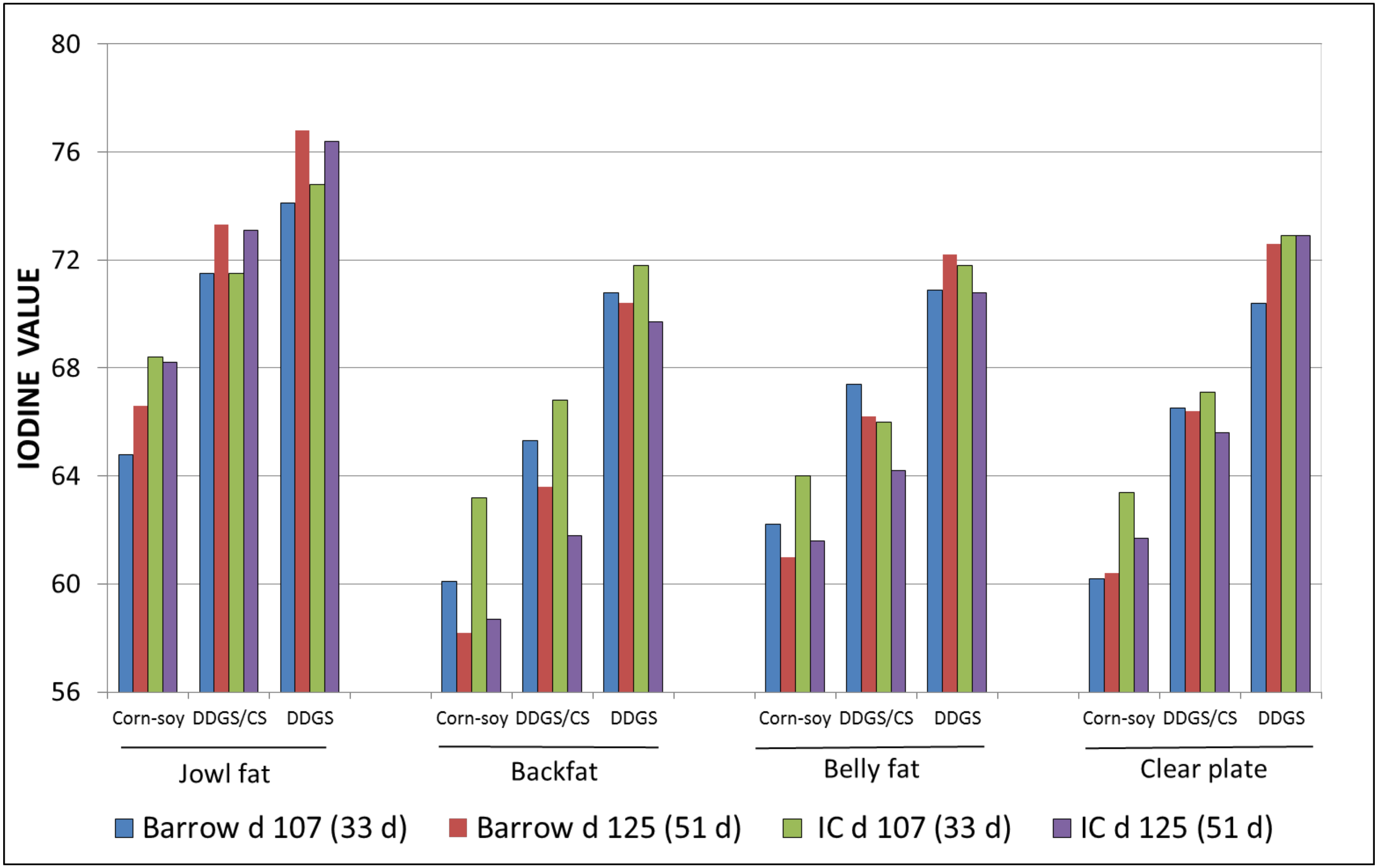

Figure 4-1 Differences in fat depot iodine values and changes between genders and time post-second injection