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The effects of feeding diets containing corn distillers dried grains with solubles (DDGS), and DDGS withdrawal period, on growth performance and pork quality in grower-finisher pigs[1]

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ABSTRACT: A study was conducted to determine the quantitative effects of feeding levels and withdrawal period of corn distillers dried grains with solubles (**DDGS**) from the diet on growth performance, carcass quality, and pork fat fatty acid profile. A total of 432 pigs (29.8 ± 0.2 kg BW) were randomly allotted to 1 of 9 dietary treatments in a completely randomized arrangement. The 9 treatments were: control (D0), D15-0wk, D15-3wk, D15-6wk, D15-9wk, D30-0wk, D30-3wk, D30-6wk, and D30-9 wk — where D0, D15, and D30 indicates the dietary DDGS level (0, 15, and 30%, respectively) and 0, 3, 6, 9 wk indicate the withdrawal period of DDGS from the diets prior to harvest. Dietary DDGS inclusion rate of 15 or 30%, without or with a withdrawal period, had no effect (P = 0.76) on ADG, ADFI and G:F except for a slight reduction (0.87 vs. 0.92 kg/d; P < 0.05) in ADG when pigs received D30-0wk compared with the control treatment. Carcass quality, LM quality, and Japanese fat color scores for backfat and belly fat were not affected by dietary DDGS level (backfat, P = 0.47; belly fat, P =0.17) or withdrawal period (backfat, P = 0.33; belly fat, P = 0.95). Compared with pigs fed the control diet, a lower belly firmness score was observed (P = 0.04) in pigs that received D30-0wk treatment, but belly firmness in pigs fed the other treatments was not different (P = 0.26) from pigs fed the control diet. Linoleic acid content (C18:2; P < 0.001) and iodine value (**IV**; P < 0.001) of belly fat increased with increasing DDGS level. Withdrawal of DDGS from the diet for 0 wk to 9 wk prior to harvest resulted in a linear reduction in the content of C18:2 and IV of belly fat in pigs fed the 15% DDGS diets (C18:2 content: 14.6, 13.3, 12.6, and 10.9%; P = 0.001; IV: 67.3, 64.4, 64.1, and 62.7; P = 0.02; for wk 0, 3, 6, and 9 withdrawal, respectively) and the 30% DDGS diets (C18:2 content: 17.3, 16.1, 14.2, and 12.4%; P < 0.001; IV: 71.2, 68.2, 64.5, and 62.7; P < 0.001; for wk 0, 3, 6, and 9 withdrawal, respectively). These results indicate that inclusion rate of DDGS up to 30% in grower-finisher diets has minor effects on growth

performance and the desired effect of reducing C18:2 content and iodine value of pork fat could be elicited in as little as 3 wk of withdrawing DDGS from the diet prior to harvest.

Key words: DDGS withdrawal, pork quality, pigs

INTRODUCTION

Corn dried distillers grains with solubles (**DDGS**) contains approximately 10% oil which is rich in linoleic acid (C18:2; Xu, 2007). Whitney et al. (2006) showed that when the level of DDGS increased to 20% or 30% of the diet, pork belly firmness was reduced. More recently, results from a field trial (Xu et al., 2007) showed that the C18:2 content of belly fat was higher in pigs fed diets containing 10% DDGS than in pigs fed corn-soybean meal diets.

Soft and off-white fat is one of main factors associated with downgrading and price reduction of processed products such as bacon (Carr et al., 2005). Some U.S. pork processing companies are concerned about the potential for reduced belly firmness and lower pork fat quality when grower-finisher pigs are fed diets containing DDGS.

Withdrawing DDGS from the diet for a period of time before harvest is one alternative strategy to improve pork fat quality while feeding diets containing DDGS. Researchers have shown that 60 to 70% of the theoretical capacity for change, including incorporation and elimination of C18:2 content of pork fat, can be achieved in the first 2 wk following dietary changes, and nearly 100% of the changes in carcass fat composition can be realized in 6 to 8 wk after a change in dietary fat (Wiseman and Agunbiade, 1998; Warnants et al., 1999). Gaines et al. (2007) showed that carcass dressing percentage was improved in pigs fed diets containing 30% DDGS with a 3 or 6 wk DDGS withdrawal period prior to marketing compared with a 0 wk withdrawal period in grower-finisher pigs. To date, no studies have evaluated various withdrawal times for DDGS feeding on pork fat quality. The objective of this study was to determine the quantitative effects of feeding level (0, 15, or 30% DDGS) and withdrawal period (0, 3, 6, or 9 wk before harvest) of DDGS from the diet on growth performance, carcass quality, and fatty acid profile of pork fat.

MATERIALS AND METHODS

All animal procedures were approved by the Institutional Animal Care and Use Committee of the University of Minnesota. Pigs used in this experiment were terminal offspring of sows (Landrace × Yorkshire; Genetically Advanced

Pigs, Winnipeg, Manitoba) sired by Duroc boars (Compart's Boar Store, Nicollet, MN). The experiment was conducted at the West Central Research and Outreach Center in Morris, MN.

Experimental Design

A total of 432 pigs with an initial BW of 29.8 ± 0.2 kg were allotted randomly to 48 pens, with 9 pigs (5 barrows and 4 gilts) per pen. Pens were assigned to 1 of 9 dietary treatments according to a completely randomized design. The 9 treatments were: control (D0), D15-0wk, D15-3wk, D15-6wk, D15-9wk, D30-0wk, D30-3wk, D30-6wk, and D30-9 wk — where D0, D15, and D30 indicates the dietary DDGS level (0, 15, and 30%, respectively), and 0, 3, 6, or 9 wk indicate the period of withdrawal of DDGS from the diet before harvest. All pigs were fed the control diets after the DDGS diets were removed. There were 8 pens assigned to the control treatment and 5 pens assigned to each of the other treatments.

Housing and Animal Management

Pigs were housed in an environmentally controlled, total confinement building. Each pen measured 1.6 × 4.5 m and contained 1, 4-space self-feeder, 1 nipple drinker, and a totally slatted-floor. Pigs were fed 1 of 3 diets within each phase of production in a 3-phase grower-finisher feeding program (20 to 50 kg BW, 50 to 80 kg BW, and 80 kg to harvest). Diet changes were made on an individual pen basis when the average BW of pigs in the pen reached the target BW for the start of each phase. The average number of days pigs consumed each treatment during phase I, II, and III, respectively, was as follows: D0 = 27, 40, and 38 d; D15-0 = 28, 41, and 36 d; D15-3wk = 28, 36, and 40 d; D15-6wk = 28, 38, and 39 d; D15-9wk = 28, 41, and 36 d; D30-0wk = 28, 41, and 36 d; D30-3wk = 28, 39, and 38 d; D30-6wk = 27, 39, and 39 d; D30-9 wk = 28, 38, and 39 d.

Pigs had ad libitum access to experimental diets and water throughout the study. Pigs were monitored daily to ensure that they were healthy and their feeders were functioning properly. A total of 11 pigs (D0, 5 pigs; D15-0wk, 2 pigs; D15-6wk, 2 pigs; D30-3wk, 1 pig; D30-9 wk, 1 pig) were removed from the experiment because of poor health (leg problems and tail biting) during the 15-wk feeding period.

Diet Composition and Growth Performance Measurements

Diet composition and nutrient concentrations are presented for the 3 diet phases used during the grower-finisher period in Table 1. All diets were formulated on a standardized ileal digestible (**SID**) AA basis according to nutrient requirements of growing pigs with a carcass lean tissue gain of 325 g/d (NRC, 1998). All diets met or exceeded a minimum ratio relative to SID Lys 27, 60, and 19% for SID Met, Thr, and Trp (NRC, 1998), respectively. The DDGS used in this study was obtained from Golden Grain Energy, LLC (Mason City, IA). The SID AA values for the source of DDGS used in this experiment were: 0.47, 0.39, 0.99, 0.62, and 0.12% for Lys, Met, Thr, and Trp (as-is basis), respectively. These values were obtained from a recent study conducted in our laboratory (Urriola, 2006). Metabolizable energy and SID Lys were maintained similarly across all diets within phase. All diets were fed in meal form. No supplemental fat was added to the diets in order to evaluate the direct effects of fat source and level (provided by DDGS), without the interactive effects of other types and levels of supplemental fat in the diet. Individual pig BW and pen feed disappearance were recorded at 1-wk periods to determine ADG, ADFI, and G:F.

Carcass Measurements

At the end of the experiment, pigs were tattooed and harvested at a commercial abattoir on the same day. Hot carcass weight was determined immediately after harvest before the pigs were skinned. A total of 345 carcasses were retrieved and subjected to carcass measurements. During the harvest process 76 pigs could not be retrieved due to mixing with other non-experimental carcasses or could no longer be identified because their tattoo number was lost after skin was removed from the carcass. Last rib backfat depth at the midline was measured on the right side of the carcass using a ruler in the cooler after the skin was removed, and was adjusted to a skin-on basis by adding 0.1 inch to the fat depth of the skinned carcasses (NPPC, 2000). Fat-free lean percentage was calculated as: (23.568 – 0.84 × last rib back fat thickness, mm + 1.109 × warm carcass wt., kg) / 2.205 × warm carcass wt in kg × 100 (NPPC, 2000). Before carcasses were separated into primal cuts, 96 pigs (1 barrow and 1 gilt from each pen) were selected randomly from the first 200 pigs harvested and marked for belly and LM quality evaluation. Carcasses were chilled for 24 h, and then carcasses were ribbed and fabricated. The whole LM and bellies were separated and trimmed. After processing, 85 bellies and 87 LM were retrieved and subjected to quality tests. Of the original 96 pigs identified for belly and LM quality evaluation, 11 bellies and 9 LM were mixed with non-experimental bellies and LM during further processing and could not be retrieved. The right side of each LM was cut in the middle into two equal length sections. After allowing a minimum 30 min of bloom time, the cut surface of the anterior section of LM were evaluated by 2 experts for color using the 6 point NPPC color standard scale (1 = pale pinkish gray to white to 6 = dark purplish red), firmness standards (1 = extremely soft to 5 = extremely firm), and marbling standards (1 = 1% i.m fat to 10=10% i.m. fat; NPPC, 2000). Color scores were determined independently by each evaluator and their scores were averaged.

The retrieved bellies (n = 85) from the left side of the carcass were laid on a flat surface of the table, placed skin-side down, and belly length was measured. Belly thickness, not including skin, was measured by inserting a rule at the scribe line midway between the cranial and caudal ends. These measurements were obtained in the cooler at the packing plant at the same room temperature. The degree of belly firmness was measured using the procedure described by Whitney et al. (2006) by draping the center of the belly over, and perpendicular to, a smoke stick, with the skin-side facing down. The distance between the 2 ends of the belly while hanging over the smoke stick was measured and used to calculate flop angle = $\cos^{-1} \{[0.5 \times L^2) - D^2] \div (0.5 \times L^2)]\}$ where L = ½ the belly length and D = distance between the belly ends while hanging over the smoke stick.

LM, Backfat, and Belly Sample Collection and Measurements

Two pigs (1 barrow and 1 gilt) with final BW closest to the mean pen BW were selected before processing for tissue sampling. At 24 h postmortem, carcasses from the selected pigs were retrieved for sample collection. A 2.54-cm-diameter core sample of belly tissue from each belly was collected at the midline opposite of the last rib for a visual fat color and fatty acids analysis, and the same sized backfat and LM core samples were collected at 10th rib location on the right side of the carcasses for objective (Minolta) and subjective (visual) fat color measurements. Belly fat, backfat, and LM cores were measured for color lightness (L*), redness (a*), and yellowness (b*) using a CM-508-d chromameter (Minolta, Ramsey, NJ). Chromameter settings were 8-mm light apperture, D65 light source, and 10^{o} standard observer.

Samples were packaged, placed in a cooler with ice, and delivered to the laboratory. The fat samples were evaluated for visual fat color independently by 8 trained panelists using the NPPC Japanese fat color scale from 1 to 4 (1 = white, 4 = yellow) after the samples allowed a minimum 10 min of bloom time at 20˚ C room temperature. A composite fat color score was obtained by averaging individual scores for each sample. Belly samples were packed and stored at -18˚C until fatty acid analysis was performed. Fatty acid analysis and IV calculation were performed commercially (Lipid Technologies, LLC, Austin, MN) using gas chromatography to separate fatty acid methyl esters according to the AOCS (1998) method Ce 1-62. Iodine value of fat was calculated using the following equation (AOCS, 1998): (C16:1 × 0.95) + (C18:1 × 0.86) + (C18:2 × 1.732) + (C18:3 × 2.616) + (C20:1 × 0.785) + (C22:1 × 0.723).

Statistical Analysis

The control treatment served as the standard and was included in every comparison with each treatment when analyzing response data. The number of replications in the control treatment was larger than each of the other treatments to estimate the means of the control treatment more precisely.

Pen was used as the experimental unit for all responses except for the measurement of LM characteristics (subjective color, marbling, and firmness) and belly traits (thickness and firmness). Pig was used as the experimental unit for LM characteristics and belly traits. All analyses were conducted using the MIXED procedure (SAS Inst. Inc., Cary, NC). Analysis of variance (ANOVA) for performance responses (ADG, ADFI, and G:F) was conducted following a complete 2 × 4 factorial plus 1 control, which consisted of 3 DDGS levels (0, 15, and 30%) and 4 withdrawal times (0, 3, 6, and 9 wks), with repeated measures in time. Heterogeneous compound symmetry was used to fit the covariance structure in the model. The ANOVA for post-harvest carcass quality and fatty acid profile of pork fat was analyzed as a 2 × 4 factorial plus 1 control. Least-squares treatment means were obtained assuming fixed models that included the effects of DDGS level, withdrawal time, and DDGS level × withdrawal time. Pen nested within DDGS level × withdrawal time was included when data involved individual pigs and it was a random error term used for the fixed effects. Multiple comparisons with a control using Dunnett's adjustment were performed to compare control with the other treatments. Linear and quadratic effects of withdrawal time (0, 3, 6, and 9 wk) within DDGS levels (15 and 30%) were evaluated. The significance level was set at $P < 0.05$. All reported means are least squares means.

RESULTS AND DISCUSSION

Growth Performance

Initial BW of pigs (29.8 ± 0.2 kg) did not differ ($P = 0.22$) among treatments (Table 2). Final harvest weights and overall ADG were not affected by dietary DDGS levels ($P = 0.31$ and $P = 0.11$, respectively) and DDGS withdrawal periods ($P = 0.61$ and $P = 0.76$, respectively), but there were interactions ($P = 0.04$ and $P = 0.02$, respectively) between DDGS level × withdrawal period. The interaction between DDGS and withdrawal period indicated that final harvest weights and overall ADG were not different for pigs fed D15 diets without or with withdrawal periods compared with pigs fed the control diets, whereas pigs receiving D30-0wk treatment, but not D30 with 3, 6, or 9 wk DDGS withdrawal period, had lower final weight, and lower ADG compared with pigs fed the control treatment. Dietary treatment did not affect ADFI and G:F (*P* = 0.40 and *P* = 0.94, respectively). No linear or quadratic effects of DDGS withdrawal period ($P \geq 0.05$) were observed for ADG, ADFI and G:F when pigs were fed diets containing 15% DDGS or 30% DDGS. In a similar study, Gaines et al. (2007) reported ADG and ADFI for pigs fed diets containing 30% DDGS, with a DDGS withdrawal period 0, 3, or 6 wk prior to marketing of pigs, were not different from pigs fed corn-soybean meal control diets. Hill et al. (2008) showed that ADG did not differ in pigs fed 20 or 30% DDGS diets when DDGS was withdrawn from the diet 30 d prior to harvest. The ADG results from the current study for pigs fed diets containing 30% DDGS with a DDGS withdrawal period for 3, 6, or 9 wk are consistent with those 2 studies. However, the ADG in pigs fed D30-0 wk is not consistent with that reported by Gaines et al. (2007). Since diets in the Gaines et al. (2007) and the current study were formulated on a SID Lys basis with the same ME levels, the reasons for the difference in these results is not clear, but it may be due to quality differences between the DDGS sources used in these studies.

Carcass, LM, and Fat Color Characteristics

Consistent with final harvest weights, carcass weights were not affected by dietary DDGS level (*P* = 0.39; Table 2) or withdrawal period (*P* = 0.55). The interaction between DDGS level and withdrawal period (*P* = 0.04) indicated that carcass weights were not different for pigs fed D15 diets without or with a withdrawal period compared with pigs fed the control diets, whereas pigs receiving D30-0wk treatment, but not D30 with 3, 6, or 9 wk DDGS withdrawal period, had lower (*P* = 0.02) carcass weight compared with pigs fed the control treatment. No effects of dietary DDGS level, withdrawal period, or DDGS level × withdrawal period were detected for dressing percentage, last rib backfat depth, and carcass lean percentage ($P \geq 0.05$).

Longissimus muscle firmness, marbling, and visual color score were not affected by DDGS level or withdrawal period, and there were no interactions ($P \geq 0.05$, Table 3). Similarly, no effect of DDGS level or withdrawal interval was detected for Minolta color L*, a* and b* ($P >$ 0.1) of LM (data not shown). The fat color (Table 3) by visual assessment (Japanese color score) for both backfat and belly fat was not different among dietary treatments ($P = 0.17$). Objective measurement of color in backfat and belly fat showed that Minolta L*, a*, and b* were unaffected by dietary DDGS level or withdrawal interval (data not shown).

Results from previous studies have been summarized by Stein and Shurson (2009) that evaluated the effects of increasing levels of dietary DDGS on carcass dressing percentage have shown inconsistent results. Of the 18 studies reporting carcass dressing percentage data, results from 10 studies showed no change in dressing percentage while 8 studies showed a reduction in dressing percentage when increasing dietary levels of DDGS were fed to grower-finisher pigs. Cook et al. (2005) and Whitney et al. (2006) showed that feeding diets containing 0 to 30% DDGS to grower-finisher pigs resulted in a reduced dressing percentage. However, studies conducted by Fu et al. (2004) and Widmer et al. (2008) showed that dressing percentage was similar in pigs fed diets containing 30% and 20% DDGS compared with those fed control diets, respectively. Gaines et al. (2007) reported that dressing percentage was lower in pigs fed diets containing 30% DDGS with a 0 wk withdrawal period compared with pigs fed control diets, but carcass yield was improved in pigs diets containing 30% DDGS with a 3 or 6 wks DDGS withdrawal period prior to marketing. In the current study, dressing percentage was similar for pigs fed diets containing 0, 15, and 30% DDGS, and there were no effects of DDGS withdrawal period. The reason for the inconsistent response in dressing percentage is uncertain, but it might be due to differences in fiber content of various DDGS sources (Spiehs et al., 2002) or formulation technique. The similarity of carcass lean percentage, LM marbling, and LM subjective color scores of pigs fed up to 30% DDGS in the current study are similar to the results reported by Whitney et al. (2006) and Widmer et al. (2007).

Fatty Acid Composition of Belly Fat

The fatty acid profile of porcine fat generally reflects the dietary fat composition, and fat quality of pigs can be altered through changing dietary fat (Wood, 1984; Gatlin et al., 2002). Corn DDGS contains approximately 10% fat, which is about 54% C18:2. In the current study, dietary C18:2 content increased from 1.74 to 2.74% for diets containing 0 to 30% DDGS, respectively.

As expected, increasing levels of dietary DDGS linearly increased ($P < 0.001$) the total PUFA content (Table 4). Iodine value (**IV**) is a measure of the degree of unsaturation of fat. Consequently, pigs had a higher IV ($P < 0.001$) in belly fat when fed increasing dietary DDGS levels. An increased PUFA content of belly fat was at the expense of the levels of SFA and MUFA. Consequently, SFA ($P < 0.001$) and MUFA concentrations of belly fat were reduced linearly ($P < 0.01$) as the level of dietary DDGS increased. With increasing dietary DDGS withdrawal period from 0 to 9 wks before harvest, the IV and C18:2 content of belly fat were reduced linearly ($P < 0.01$), and the rate of reduction in C18:2 content of belly fat was 45, 31, and 24% of the total reduction following a DDGS withdrawal period of 3, 6, and 9 wks before harvest, respectively. However, belly fat C18:2 concentration in pigs fed diets containing 30% DDGS with a 9-wk withdrawal period was not reduced to a similar level compared with pigs fed the control treatment ($P = 0.006$). Total SFA content in belly fat was increased linearly ($P < 0.05$) with increasing DDGS withdrawal periods only when feeding the 30% DDGS diet. Mono-unsaturated fatty acid content was not influenced by withdrawal period ($P = 0.36$). In comparison with bellies from pigs fed the control treatment, belly fat achieved a similar level of IV in pigs fed diets containing 15 to 30% DDGS with a 9-wk withdrawal period ($P = 0.15$).

However, belly fat IV in pigs assigned to the other dietary treatments was higher ($P < 0.05$) than in pigs fed the control diets.

High concentrations of unsaturated fatty acids (**UFA**) in porcine fat are associated with soft fat, which is an undesirable characteristic of pork fat. One strategy to improve pork fat firmness is to feed pigs diets that contain high levels of UFA in the growing phase followed by feeding diets containing more saturated fatty acids in the finishing phase. Linoleic acid (C18:2) in pork fat is the primary UFA that contributes to soft pork (Whittington et al., 1986). The rate of change in C18:2 content of pork fat following a change in dietary fat source has been investigated in a few studies (Warnants et al. 1999; Gatlin et al., 2002). Koch et al. (1968) and Warnants et al. (1999) showed that a 50% reduction of C18:2 concentration of backfat occurred within the first 2 wks, and the amount of C18:2 reduction reached a plateau at 4 to 6 wks following a dietary fat source change from unsaturated fat to saturated fat.

Wiseman and Agunbiade (1998) estimated that the rate of change in C18:2 of belly fat reached 60 to 70% in the first 2 wks, and over 90% within 6 wks following a dietary fat source change. Gatlin et al. (2002) showed that the rate of decline in C18:2 was 2 percentage units and 2.5 IV units per week following a dietary fat source change for 4, 6, or 8 wks prior to harvest. In addition, those studies demonstrated that the increase in C18:2 concentration in backfat occurs with a reduction in the other fatty acids such as C18:0, C18:1 and C16:1. The current results are in agreement with previous report that C18:2 and IV of body fat can be reduced in pigs fed diets containing a high level of C18:2 followed by feeding diets containing low levels of C18:2, and most of this change can be achieved within a 6 to 8 wk feeding period.

Wiseman and Agunbiade (1998) reported that the relative concentration of a particular fatty acid at a given time following a dietary fat change also depends on a number of factors including initial concentration within the tissues and the capacity for depletion or deposition within a specific fat depot. We observed that the rate of change in C18:2 and IV of belly fat is different in pigs fed diets containing different dietary levels of DDGS. In pigs fed the D15 diets, the rate of reduction in C18:2 content of belly fat was 36, 18, and 46% of the total reduction following DDGS withdrawal period at 3, 6, or 9 wks before harvest, respectively. In pigs fed D30 diets, the rate of reduction in C18:2 content of belly fat was 25, 38, and 37% of total reduction following a DDGS withdrawal period of 3, 6, and 9 wks before harvest, respectively. The IV was reduced approximately 0.6 and 1 unit per week during the withdrawal period in pigs receiving D15-9 wk and D30-9wk compared with pigs receiving D15-0wk and D30-0wk treatments, respectively. In comparison with bellies from pigs fed the control treatment, total PUFA content of belly fat decreased to a similar level of pigs fed the control diets when pigs were fed the D15-9 wk treatment, while PUFA content of belly fat in pigs receiving the other dietary treatments were all higher ($P < 0.01$) than in pigs receiving the D0 treatment.

In the current study, the belly fat IV in pigs increased linearly ($P < 0.05$) with increase dietary DDGS level, which is in agreement with previous reports (Whitney et al., 2006; Hill et al., 2008) that the IV of belly fat increased with increased DDGS level in grower-finisher pig diets. The Danish Meat Research Institute (Barton-Gade, 1987) has established a maximum IV of 70 for acceptable pork fat quality. In the U.S., according to Pork Composition and Quality Assessment Procedures (NPPC, 2000), acceptable pork fat quality has an IV of less than 70. It is worth noting that the IV of belly fat was greater than 70 only in pigs fed diets containing 30% DDGS without a withdrawal period. However, the IV of belly fat was reduced to 68.2 after a 3-wk withdrawal period before harvest in pigs fed 30% DDGS diet, which meets the current NPPC (2000) standards for pork fat quality. Similarly, Hill et al. (2008) showed that removal of DDGS from the diet during the final 3 to 4 wk prior to harvest resulted in acceptable IV of pork fat. In addition, IV for belly fat was below 70 for pigs fed the other DDGS dietary treatments.

Belly Quality

With increasing content of C18:2 or IV of pork fat, fat firmness is reduced (Gatlin et al., 2002; Nishioka and Irie, 2006). In the current study, C18:2 content and IV of belly fat increased, but C18:0 content was reduced when pigs were fed increased levels of dietary DDGS. In addition, IV of belly fat decreased linearly when the dietary DDGS withdrawal period increased from 0 to 9 wks before harvest. As expected, pigs fed D30-0wk had a significantly lower (P = 0.04; Table 4) belly firmness score, while pigs fed the D15 diets, without or with withdrawal period, or pigs fed D30 with a 3 wk or more withdrawal period, had similar belly firmness scores compared with pigs fed the control diets. Our results are in agreement with those from previous studies (Gatlin et al., 2002; Nishioka and Irie, 2006). A higher firmness score describes a firmer belly. Results from this study showed that belly firmness similar to that in pigs fed the control diet can be achieved when diets containing 10 or 30% DDGS are withdrawn during the final 3, 6, or 9 wk before harvest. In addition, belly thickness was not affected by dietary DDGS level (P = 0.99) or withdrawal period (P = 0.53).

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Table 1. Composition and analyzed nutrient concentration of experimental diets

	Phase I			Phase II			Phase III		
Ingredient, %	D0[1]	D15[1]	D30[1]	D0	D15	D30	D0	D15	D30
Corn	73.44	62.92	52.42	81.3	70.78	60.65	87.03	76.25	65.99
Soybean meal, 47.5% CP	23.90	19.50	15.10	16.50	12.10	7.30	10.80	6.70	2.00
DDGS	0.00	15.00	30.00	0.00	15.00	30.00	0.00	15.00	30.00
Limestone	0.91	1.12	1.31	0.75	0.96	1.13	0.70	0.90	1.10
Monocalcium phosphate	0.80	0.41	0.02	0.75	0.36	0.00	0.77	0.36	0.00
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamin trace mineral premix[2]	0.50	0.50	0.50	0.25	0.25	0.25	0.25	0.25	0.25
L-Trp	0.00	0.01	0.02	0.00	0.01	0.03	0.00	0.01	0.03
L-Lys HCl	0.15	0.24	0.33	0.15	0.24	0.34	0.15	0.23	0.33
Analyzed composition:									
ME[4], Mcal/kg	3.05	3.12	3.15	3.16	3.18	3.20	3.17	3.31	3.21
CP, %	16.31	17.80	19.20	13.42	14.70	16.78	11.13	11.69	13.95
Fat, %	2.52	3.76	5.14	2.90	3.31	5.17	3.19	5.15	6.11
Calcium, %	0.62	0.53	0.58	0.58	0.56	0.55	0.36	0.43	0.39
Total Phosphorus, %	0.54	0.46	0.45	0.37	0.33	0.35	0.36	0.35	0.32
Lys, %	0.98	1.06	1.09	0.78	0.80	0.90	0.62	0.67	0.73
Met and Cys , %	0.50	0.59	0.66	0.44	0.46	0.53	0.40	0.45	0.51
Thr, %	0.60	0.69	0.73	0.50	0.47	0.57	0.42	0.43	0.48
Trp, %	0.21	0.17	0.21	0.19	0.15	0.17	0.16	0.14	0.15
Calculated composition:									
ME[3], Mcal/kg	3.05	3.12	3.15	3.16	3.18	3.20	3.17	3.31	3.21
CP, %	17.56	18.64	19.73	14.68	15.76	16.69	12.45	13.64	14.61
Fat, %	3.58	4.72	5.85	3.66	4.79	5.92	3.70	4.84	5.97
Lys, %	0.91	0.91	0.91	0.72	0.72	0.72	0.58	0.58	0.58
Met and Cys, %	0.53	0.54	0.57	0.46	0.47	0.49	0.40	0.42	0.44
Thr, %	0.56	0.56	0.56	0.46	0.46	0.45	0.38	0.38	0.38

Trp, %	0.17	0.17	0.17	0.14	0.14	0.14	0.11	0.11	0.11
C18:2[4], %	1.57	2.07	2.56	1.67	2.16	2.66	1.74	2.23	2.72

[1]D0 = corn-soybean meal control diet, D15 = diet containing 15% distillers dried grains with solubles (DDGS), D30 = diet containing 30% DDGS.

[2]Vitamin-trace mineral premix that supplied the following nutrients per kilogram of feed for phase I: 17,640 IU of vitamin A as retinyl acetate; 3,307 IU of vitamin D_3; 66 IU of vitamin E as DL-α-tocopherol acetate; 8.8 mg of vitamin K as menadione dimethylpyrimidinol bisulfite; 13.2 mg of riboflavin; 77.2 mg of niacin; 44.1 mg of pantothenic acid as D-calcium pantothenate; 88.2 µg of vitamin B_{12}; 2.2 mg of iodine as ethylenediamine dihydroiodide; 0.60 mg of selenium as sodium selenite; 121.3 mg of zinc as zinc oxide; 72.8 mg of iron as ferrous sulfate; 7.3 mg of copper as copper sulfate polysaccharide complex; and 24.3 mg of manganese as manganese oxide.

[3]ME was calculated according to Noblet and Perez (1993).

[4]Calculated C18:2 from corn, soybean meal (NRC, 1998), and DDGS (analyzed value).

Table 2. Effects of dietary distillers dried grains with solubles (DDGS) level[1] and withdrawal period[2] on overall growth performance of grower-finisher pigs

		Diets (D)[1]												
		D0	D15				D30					*P*-value		
Trait	Withdrawal, wk[2]	0	0	3	6	9	0	3	6	9	Pooled SEM	D	W	D × W
No. of pens		8	5	5	5	5	5	5	5	5				
Growth performance														
No. of pigs		67	43	45	43	45	45	44	45	44				
Initial wt, kg		29.75	29.68	30.13	29.73	29.42	29.93	30.21	29.97	29.67	0.20	0.17	0.30	0.20
Final wt, kg		125.01	124.77	123.18	125.57	121.32	120.92[b]	124.10	122.46	124.00	1.13	0.31	0.61	0.04
ADG, kg		0.92	0.91	0.90	0.92	0.88	0.87[a]	0.90	0.89	0.91	0.01	0.11	0.76	0.02
ADFI, kg		2.74	2.73	2.69	2.71	2.66	2.63	2.70	2.69	2.71	0.04	0.40	0.91	0.98
G:F, kg/kg		0.33	0.34	0.33	0.34	0.33	0.33	0.34	0.33	0.34	0.003	0.94	0.56	0.17
Carcass characteristics														
No. of pigs		59	37	39	31	39	35	37	36	32	59	37	39	31
Hot carcass wt, kg		94.90	95.56	94.53	95.27	92.62	92.38[a]	95.35	92.80	94.43	0.97	0.39	0.55	0.04
Dressing, %		76.10	76.71	76.66	76.38	76.22	76.71	76.98	75.89	75.75	0.41	0.35	0.14	0.73
Last-rib fat depth, cm		2.82	2.73	2.75	2.56	2.76	2.66	2.74	2.62	2.50	0.09	0.28	0.36	0.38
Lean, %		50.41	50.70	50.65	51.38	50.66	51.05	50.72	51.15	51.63	0.36	0.28	0.40	0.41

[a] Means within a row differ from control ($P < 0.05$).
[b] Means within a row differ from control ($P < 0.1$).

[1] Diet (D): D0 = corn-soybean meal control diet; D15 = diet containing 15% DDGS; D30 = diet containing 30% DDGS.
[2] Withdrawal period (W): 0, 3, 6, and 9 wks DDGS withdrawal period from the diet before harvest and changed to control diets, respectively.

Table 3. Effects of dietary distillers dried grains with solubles (DDGS) level[1] and withdrawal period[2] on LM and fat color characteristics

	Diets (D)[1]										*P*-Values		
	D0	D15				D30							
Trait Withdrawal, wk[2]	0	0	3	6	9	0	3	6	9	Pooled SEM	D	W	D × W
No. of pens	8	5	5	5	5	5	5	5	5				
LM evaluation													
No. of pigs	14	8	11	7	10	7	10	11	8				
Firmness[3]	2.81	3.00	2.80	2.88	2.90	2.90	3.00	3.10	2.90	0.20	0.72	0.96	0.84
Marbling[4]	2.50	2.10	2.20	2.88	2.80	3.10	2.90	2.50	3.00	0.34	0.29	0.73	0.25
Color[5]	3.13	3.20	3.33	3.25	3.30	3.20	3.30	3.00	3.00	0.21	0.62	0.80	0.87
Japanese fat color score[6]													
No. of pigs	16	10	10	10	10	10	10	10	10	16	10	10	10
Backfat	2.64	2.45	2.46	2.54	2.51	2.58	2.33	2.63	2.80	0.14	0.47	0.33	0.55
Belly fat[a]	2.19	1.85	1.85	1.92	1.96	1.93	1.98	1.97	1.99	0.15	0.17	0.95	0.99

[a] Linear effect of withdrawal period ($P < 0.05$).

[1] Diet (D): D0 = corn-soybean meal control diet; D15 = diet containing 15% DDGS; D30 = diet containing 30% DDGS.
[2] Withdrawal period (W): 0, 3, 6, and 9 wk was DDGS withdrawal period from the diet before harvest and changed to control diets, respectively.
[3] Firmness measurements using 5 point scale with 1 = extremely soft and 5 = extremely firm (NPPC, 2000).
[4] Marbling score using 10 point scale with 1.0 = 1% intramuscular fat and 10 = 10% intramuscular fat (NPPC, 2000).
[5] Loin color using 6 point scale with 1.0 = pale pinkish gray to white and 6 = dark purplish red (NPPC, 2000).
[6] Japanese fat color scale using a 4 point scale with 1 = white and 4 = yellow (NPPC, 2000).

Table 4. Effects of diets containing distillers dried grains with solubles (DDGS) level[1] and withdrawal period[2] on fatty acid profile of belly fat

	Diets (D)[1]										*P*-Values		
	D0	D15				D30							
Trait / Withdrawal, wk[2]	0	0	3	6	9	0	3	6	9	Pooled SEM	D	W	D × W
No. of pigs	16	10	10	10	10	10	10	10	10				
No. of pens	8	5	5	5	5	5	5	5	5				
Fatty acids, %													
C14:0	1.46	1.37	1.50	1.44	1.51	1.39	1.49	1.39	1.50	0.06	0.37	0.10	0.94
C16:0[be]	25.71	23.44[d]	24.93	24.54	24.62	23.24[d]	23.78[d]	23.85[d]	24.57[d]	0.42	< 0.001	0.03	0.56
C16:1[a]	3.11	2.88	3.07	2.95	3.20	2.73	2.87	2.89	2.88	0.16	0.08	0.53	0.89
C18:0[bf]	12.69	10.40	11.06	11.15	11.02	9.44[d]	10.77	13.12	12.50	0.89	0.02	0.09	0.33
C18:1[b]	44.39	43.41	42.59	43.78	45.43	42.63	41.44	40.85	42.58	1.14	0.04	0.34	0.71
C18:2[bdf]	9.19	14.62[d]	13.25[d]	12.58[d]	10.87[d]	17.32[d]	16.11[d]	14.22[d]	12.39[d]	0.67	< 0.001	< 0.001	0.67
C18:3	0.52	0.60	0.57	0.56	0.52	0.57	0.59	0.58	0.55	0.03	0.14	0.52	0.78
C20:0	0.19	0.19	0.19	0.18	0.18	0.17	0.17	0.19	0.17	0.012	0.52	0.96	0.60
C20:1	0.66	0.68	0.66	0.68	0.67	0.69	0.60	0.68	0.65	0.03	0.55	0.34	0.75
C20:2[abc]	0.37	0.60	0.50	0.52	0.43	0.68	0.57	0.57	0.47	0.02	< 0.001	< 0.001	0.73
C20:3	0.13	0.19	0.16	0.16	0.15	0.15	0.16	0.15	0.15	0.018	0.18	0.79	0.56
SFA[ac]	40.43	35.73[d]	38.00	37.63	37.60	34.37[d]	36.50	38.87	39.08	1.19	< 0.001	0.04	0.46
MUFA[a]	48.60	47.33	46.68	47.78	49.65	46.38	45.23	44.79	46.49	1.23	0.03	0.36	0.76
PUFA[ac]	10.67	16.56[d]	15.02[d]	14.31[d]	12.48	19.11[d]	17.97[d]	16.04[d]	14.14[d]	0.74	< 0.001	< 0.001	0.80

Iodine value[abc]	58.82	67.33[d]	64.40[d]	64.12[d]	62.74	71.22[d]	68.19[d]	64.47[d]	62.73	1.3	< 0.001	< 0.001	0.30
Belly thickness, cm	1.52	1.42	1.50	1.63	1.42	1.60	1.32	1.47	1.55	0.10	0.99	0.53	0.20
Firmness score, degree	38.22	34.27	25.22	37.21	28.14	19.66[d]	23.85	27.15	27.22	5.17	0.03	0.55	0.50
Adjusted firmness score, degree[3]	37.99	34.53	25.18	36.49	28.43	19.10[d]	24.64	27.19	26.88	5.19	0.04	0.64	0.48

[a] Linear effect of DDGS level ($P < 0.05$).

[b] Linear effect of withdrawal time at 15% DDGS ($P < 0.05$).

[c] Linear effect of withdrawal time at 30% DDGS ($P < 0.05$).

[d] Means with a row differ from Control ($P < 0.05$).

[1] Diet (D): D0 = corn-soybean meal control diet; D15 = diet containing 15% DDGS; D30 = diet containing 30% DDGS.

[2] Withdrawal interval (W): 0, 3, 6, and 9 wks was DDGS withdrawal period from the diet before harvest and changed to control diets, respectively.

[3] Belly firmness score adjusted for belly thickness.