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ASSESSMENT OF ENERGY CONTENT OF LOW-SOLUBLES CORN DISTILLER'S DRIED GRAINS AND ITS EFFECTS ON GROWTH PERFORMANCE, CARCASS CHARACTERISTICS, AND PORK FAT QUALITY IN GROWING-FINISHING PIGS

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ABSTRACT

Two studies were conducted to assess the utility of low-solubles corn distiller's dried grains (LS-DDG) in diets for growing-finishing pigs. The LS-DDG was sourced from the Corn Plus ethanol plant in Winnebago, MN. The first experiment was conducted to assess the energy content of LS-DDG. Crossbred barrows (n = 48; Yorkshire-Landrace X Duroc; 80 to 90 d of age) were housed individually in metabolism stalls and assigned randomly to one of six dietary treatments. The control diet (C) was formulated on a total amino acid basis following NRC (1998) nutrient requirements for pigs gaining 350 g/d of lean tissue. The LS-DDG or distiller′s dried grains with solubles (DDGS) were combined with the control diet to yield five additional diets: LS-DDG30%, LS-DDG40%, and LS-DDG50% (30, 40, and 50% LS-DDG, respectively), and DDGS30% and DDGS40% (30 and 40% DDGS, respectively). Crude fat content of LS-DDG (7.95%) was lower than DDGS (8.87%), as-fed basis. All diets contained chromic oxide (0.25%) as an indigestible marker. Pigs were fed their respective dietary treatments during a 7-d adaptation period and at 3% of initial body weight (BW) during a 5-d collection period. The digestible energy (DE) and metabolizable energy (ME) content of LS-DDG used in this experiment were 3,232 ± 75 and 2,959 ± 100 kcal/kg DM, respectively. These values are

comparable to the DE and ME determined for DDGS in this same study (3,351 ± 122 and 2,964 ± 81 kcal/kg DM, respectively). Similar to typical DDGS, increased dietary level of LS-DDG decreased ($P < 0.01$) ME content (DM basis) of diets (C = 3,615 kcal/kg; LS-DDG30% = 3,455 kcal/kg; LS-DDG40% = 3,333 kcal/kg; LS-DDG50% = 3,271 kcal/kg; PSE = 31.3). In addition, as the level of LS-DDG increased in the diet the nitrogen intake of pigs also increased ($P < 0.01$) (C = 31.3 g/d; LS-DDG30% = 46.1 g/d; LS-DDG40% = 51.8 g/d; LS-DDG50% = 55.2 g/d; PSE = 1.59). However, nitrogen digestibility was not influenced by LS-DDG concentration (C = 77.7%; LS-DDG30% = 77.7%; LS-DDG40% = 75.5%; LS-DDG50% = 77.3%; PSE = 0.80). In contrast, DDGS at 40% of the diet decreased ($P < 0.01$) nitrogen digestibility compared to the control (C = 77.7%¨; DDGS40% = 73.9%; PSE = 0.80).

The second experiment was conducted to assess the effects of LS-DDG on growth performance, carcass characteristics, and pork fat quality in growing-finishing pigs. Crossbred pigs (n = 216; Yorkshire-Landrace X Duroc; 46 to 54 d of age) were blocked by initial body weight (18.8 ± 0.76 kg) and assigned randomly to one of 24 pens (9 pigs/pen). Pens within each weight block were allotted randomly to one of three dietary treatments in a four-phase feeding program (8 pens/trt). Diets were formulated on a standardized ileal digestible amino acid basis following NRC (1998) nutrient requirements for pigs gaining 350 g/d of lean tissue. Diets included a corn-soybean meal control (C); C containing 20% LS-DDG (LS-DDG); and C containing 20% distiller′s dried grains with solubles (DDGS). Weight of pigs and feed intake were determined bi-weekly and harvest occurred at two different times when average weight of pens reached 113.8 ± 0.75 kg and 112.8 ± 0.75 kg. Overall final BW (C = 113.8 kg; LS-DDG = 112.1 kg; DDGS = 114.0 kg; PSE = 0.89), ADG (C = 0.88 kg; LS-DDG = 0.86 kg; DDGS =

0.88 kg; PSE = 0.01), and ADFI (C = 2.32 kg; LS-DDG = 2.35 kg; DDGS = 2.39 kg; PSE = 0.04) were similar among dietary treatments. Pigs fed LS-DDG exhibited similar G:F compared to pigs fed DDGS, but tended ($P = 0.09$) to have lower G:F compared to pigs fed C (C = 0.380; LS-DDG = 0.367; DDGS = 0.370; PSE = 0.004). Hot carcass weight did not differ among treatments but dressing percentage was lower ($P < 0.01$) for pigs fed LS-DDG and DDGS compared to C (C = 73.8%; LS-DDG = 72.8%; DDGS = 72.8%; SEM = 0.22). Pigs fed LS-DDG displayed reduced ($P = 0.02$) 10th-rib back fat depth (C = 15.5 mm; LS-DDG = 14.2 mm; DDGS = 16.0 mm; SEM = 0.47) and increased ($P = 0.02$) carcass lean (C = 54.1%; LS-DDG = 54.8%; DDGS = 53.4%; SEM = 0.33) compared to pigs fed DDGS, but similar to pigs fed C. The belly flop test revealed that bellies from pigs fed DDGS were softer ($P < 0.01$) than those from pigs fed C (C = 17.7°; LS-DDG = 14.1°; DDGS = 12.9°; SEM = 1.07). However, only a tendency ($P = 0.07$) for softer bellies was observed when pigs received LS-DDG compared to C. The PUFA content of belly fat was reduced ($P < 0.01$) by LS-DDG compared with DDGS but was still elevated compared to pigs fed C (C = 9.4%; LS-DDG = 14.0%; DDGS = 15.4%; SEM = 0.34). Thus, pigs fed LS-DDG tended ($P = 0.06$) to have lower iodine value of belly fat compared to pigs fed DDGS (C = 57.8; LS-DDG = 63.1; DDGS = 65.0; SEM = 0.53). Gilts fed LS-DDG had lower ($P = 0.02$) PUFA (13.4%) in belly fat than gilts fed DDGS (15.9%) while there was no difference among barrows (LS-DDG = 14.6%; DDGS = 15.0%, SEM = 0.50).

In conclusion, LS-DDG has similar ME value compared to DDGS and thus, can replace typical DDGS in swine diets without compromising the energy content in diets with improvement in nitrogen digestibility. Inclusion of 20% LS-DDG in diets for growing-finishing pigs supports ADG and ADFI similar to that of diets containing 20% DDGS. However, gain

efficiency of pigs fed 20% LS-DDG may decline slightly compared to pigs fed corn-soybean meal diets. Additionally, LS-DDG may lessen the negative impacts of DDGS on pork fat quality; and pork fat of gilts may be more sensitive to dietary LS-DDG than that of barrows.

Key words: energy, fat quality, growth, low-solubles distiller's dried grain, carcass, swine

INTRODUCTION

Currently, there are more than 160 ethanol plants functioning in the U.S (RFA, 2008). This large number of plants resulted in approximately 14.6 million tonnes of distiller's grains produced in 2007. As a result of the starch removal for the production of ethanol, distiller's dried grains with solubles (DDGS) contain approximately three times the nutrient concentration of corn for fat, protein, fiber, and minerals (Spiehs et al., 2002; Shurson et al., 2004). This characteristic combined with the recent high prices of corn and soybean meal make DDGS a valuable feed ingredient in swine diets (Leibtag, 2008; RFA, 2008).

Typically, during DDGS production the distiller's solubles are added back to the wet distiller's grains before drying to generate traditional DDGS. Several ethanol plants are producing modified co-products as a consequence of new technologies used to increase ethanol yield or add value to existing co-products. One such product is low-solubles distiller's dried grains (LS-DDG) which is produced by drying the wet distiller's grains without the addition of the distiller's solubles. Because the solubles fraction is high in crude fat, ash, calcium, and phosphorus (Knott et al., 2004), LS-DDG has lower fat content than typical DDGS (7.95% vs. 8.87%, respectively). Although little research has been conducted with LS-DDG, its lower amount of solubles may result in reduced ME for swine compared to traditional DDGS. While

research has been completed to evaluate the DE and ME content of DDGS (Spiehs et al., 2002; Stein et al., 2006; Pedersen et al., 2007), the DE and ME content of LS-DDG have not been determined.

Most of the DDGS included in swine diets is used during the growing-finishing phase of production replacing portions of corn, soybean meal, and inorganic phosphorus. Much controversy exists about how much DDGS can be added to diets for growing-finishing pigs (Stein and Shurson, 2008). Pig performance, carcass quality, and pork fat quality must all be considered when selecting a level of ethanol by-products for swine diets. Growth performance of pigs fed diets containing 15% DDGS or less is similar to that of pigs fed diets without DDGS (Augspurger et al., 2008; Linneen et al., 2008). However, higher levels of DDGS may occasionally compromise pig growth (Whitney et al., 2006a; Xu et al., 2008a,b). Many authors have determined that up to 30% DDGS can be included in growing-finishing swine diets without compromising carcass loin eye area, back fat depth, or lean percentage (Whitney et al., 2006a; Xu et al., 2007; Williams et al., 2008). However, producers should be aware of a potential reduction in carcass weight and dressing percentage (Whitney et al., 2006a, Williams et al., 2008) when utilizing such high levels of DDGS in growing-finishing diets.

Fat quality is a concern because of its importance during bacon and sausage processing, as well the role it plays in shelf life of retail products, and in the retail value of pork (Carr et al., 2005). A usual concern when diets are formulated with high amounts of DDGS ($\geq$ 20%) is a possible decrease in belly firmness (Xu et al., 2007; Widmer et al., 2008; Xu et al., 2008a). Soft bellies can cause some difficulty during processing, decrease appearance of retail products to consumers, and decrease shelf-life of retail products (NPPC, 2000). The decrease in belly

firmness that can occur with increased inclusion of DDGS is mostly due to the approximately 10% corn oil present in DDGS (NRC, 1998). Low-solubles distillers dried grains may improve pork fat quality compared to typical DDGS because of its lower fat (corn oil) content.

The nutritional quality of LS-DDG for pigs has not been determined. Consequently, two experiments were conducted to determine the digestible and metabolizable energy content of LS-DDG when fed to late growing pigs (Exp. 1) and to assess the growth performance, carcass characteristics, and pork fat quality of growing- finishing pigs fed LS-DDG (Exp. 2).

MATERIALS AND METHODS

Experiment 1

Animals. To achieve the objective of this experiment, twenty-six crossbred (Yorkshire-Landrace X Duroc) barrows were used (80 to 90 days of age) in two replicated trials. Barrows were housed in an environmentally-controlled metabolism research unit at the Southern Research and Outreach Center (SROC) in Waseca, MN. On the first day of Trial 1, barrows were weighed and housed individually in metabolism stalls. Twenty four pigs were assigned randomly to one of six dietary treatments. Average initial body weight (BW) of all barrows for Trial 1 was 47.9 ± 1.2 kg. Two extra pigs were maintained in case a replacement was necessary. At the end of Trial 1, pigs were removed from the metabolism stalls, weighed, and housed back in their original metabolism stalls. On the following day, these twenty four pigs were reassigned randomly to one of six dietary treatments for Trial 2. Average initial BW for Trial 2 was 56.0 ± 1.2 kg. Pigs in Trial 2 were not reassigned to the same treatment they received previously in Trial 1. At the end of Trial 2, pigs were weighed and returned to the SROC finishing facility.

Management. Pigs were managed according to standard operating procedures that were approved by the University of Minnesota Institutional Animal Care and Use Committee (Protocol number 0611A96347). No illness or injury occurred in any pigs during either replicated trial.

Barrows were housed individually in 84 x 198 cm stainless steel metabolism stalls with plastic-coated, woven wire floors. Underneath the floor of the stalls, a wire screen collected all the fecal material and under the wire screen a stainless steel tray, with a drain in the center, allowed the collection of all urine produced. Each metabolism stall contained a nipple waterer and a single feeder in the pig space. Glass windows in both sides of the stall allowed visual contact among pigs located in adjacent stalls.

Pigs were allowed a 7-day period to adapt to their assigned metabolism stalls and dietary treatments. On the morning of day 7, the floor of the metabolism stalls were thoroughly washed and the wire screen and the stainless steel tray were placed underneath the metabolism stalls to allow the collection of fecal material and urine. During the subsequent 5-day collection period, feces and urine from each pig were collected.

During the adaptation period, pigs were fed twice daily as close to *ad libitum* as possible to satisfy nutrient requirements suggested by NRC (1998) for 60 kg barrows gaining 350 g/d of lean tissue. During the collection period, feed allowance equaled 3% of the pig's initial body weight. Feed not consumed from the previous feeding, was removed, weighed, and subtracted from the added feed to determine daily feed intake. Pigs had *ad libitum* access to water throughout both replicated trials. Chromic oxide (0.25%) was added to diets as an indigestible

marker to aid in measurement of nutrient digestibility. Daily high and low temperatures were recorded in the room. Target room temperature was set at 20 °C.

Dietary treatments. The six experimental diets were: control - a typical corn-soybean meal based diet (C); control containing 30% low-solubles distiller's dried grains (LS-DDG30%); control containing 40% low-solubles distiller's dried grains (LS-DDG40%); control containing 50% low-solubles distiller's dried grains (LS-DDG50%); control containing 30% distiller's dried grains with solubles (DDGS30%); and control containing 40% distiller's dried grains with solubles (DDGS40%). A single lot of LS-DDG and DDGS was used for both replicated experimental trials (Table 1). Both LS-DDG and DDGS were from the Corn-Plus ethanol plant in Winnebago, MN. The control diet was formulated on a total amino acid basis following NRC (1998) nutrient requirements for growing-finishing pigs gaining 350 g/d of lean tissue (Table 2). Diets were formulated on a total amino acid basis because amino acid standardized ileal digestibility (SID) coefficients are not available for LS-DDG. The remaining five dietary treatments were then acquired by the substitution method, in which portions of corn and soybean meal of the control diet were substituted by the respective percentages of LS-DDG (30, 40, or 50%) or DDGS (30 or 40%; Adeola, 2001). Ratio of corn to soybean meal and levels of dicalcium phosphate, limestone, salt, vitamin/mineral premix, and chromic oxide were maintained constant across dietary treatments.

Data collection and laboratory analyses. Samples of individual feed ingredients and mixed experimental diets were collected and stored at -18 °C. At the end of the experiment, feed samples were split by quartering and feed subsamples were sent to the University of Missouri Agricultural Experiment Station Chemical Laboratories in Columbia, MO for chemical analysis

of amino acids (Complete Amino Acid Profile Method 982.30; AOAC, 1995), crude fat (Ether Extraction Method 920.39; AOAC, 2000), crude fiber (Method 978.10; AOAC, 2000), NDF (Hoist, 1973), ADF (Method 973.18; AOAC, 2000), and calcium and phosphorus (inductively coupled plasma atomic emission spectroscopy) content. In addition, feed samples were analyzed for chromium concentration.

Pigs were weighed individually on day zero and day twelve of each replicated trial for determination of initial and final BW.

During the 5-day collection period, feces were collected twice daily, immediately after each meal, sealed in plastic bags, and stored in a freezer at -18˚C. Meals were offered at 08:00h and at 16:00h every day. At each meal, pigs received half of their daily assigned amount of dietary treatment. Extreme care was taken to avoid contact between any wasted feed and fecal material. Feed wastage was minimal. At the end of the collection period, feces from each day were thawed, pooled, mixed, and a subsample of approximately 1.0 kg was dried in a forced-draft oven (model DC-246-E, Blue M Electronic, Watertown, WI) at 60˚C. Dried feces were ground through a 1-mm screen (Wiley mill, Swedesboro, NJ) for further analysis of dry matter, gross energy, nitrogen, and chromium content.

During the collection period, total daily urine output was drained into plastic buckets located under the stainless steel trays placed underneath the metabolism stalls. One hundred milliliters of 10% HCl was added to the urine collection containers to limit microbial growth and to reduce volatilization of ammonia. Immediately after the morning feeding, total urine volume present in each bucket was recorded, mixed, and a subsample of urine was poured into a 50 ml beaker covered with clean gauze to filter out any foreign material. This subsample of urine from

each pig was stored in labeled, capped, plastic containers in a freezer at approximately -18º C. The urine collection procedure was repeated after the afternoon feeding. At the end of the collection period, a subsample (350 ml) of urine was freeze-dried using the Labconco – Stoppering tray dryer (Kansas City, MO) for further analysis of gross energy and nitrogen content.

Gross energy content of experimental diets, feces, and urine was determined using an isoperibol bomb calorimeter (Parr Instrument Co. - Model 1281, Moline, IL), with mineral oil as a standard. Nitrogen content of feed, feces, and urine was determined by the Dumas method (AOAC, 1995) using a Leco nitrogen analyzer (TruSpec N, LECO Corporation, St. Joseph, MI). A subsample of dried feed and feces was dried in a vacuum-oven at 105 ºC for determination of analytical dry matter (Method 934.01; AOAC, 2000). Feed and feces were analyzed chemically for determination of chromium concentration following the procedures of Fenton and Fenton (1979). All analyses of feed, feces, and urine samples were performed in duplicate. Coefficients of variation of the analyses of feed, feces, and urine samples were considered acceptable when lower than 5%. From these data, digestible and metabolizable energy content and N-digestibility of diets were calculated using the difference approach outlined by Adeola (2001).

The DE and ME values for LS-DDG and DDGS were obtained using a substitution method for each pig. Recall that a fixed ratio of corn and soybean meal was removed from each dietary treatment and substituted with a percentage of either LS-DDG (30, 40, or 50%) or DDGS (30 or 40%). Also, levels of vitamins, minerals, and chromic oxide were equal among dietary treatments. With this in mind, 71, 61, or 51% of the total amount of DE and ME in the control diet was assumed to be present in the 30, 40, or 50% LS-DDG dietary treatments, respectively.

Likewise, 71 or 61% of the total amount of DE and ME in the control diet was assumed to be present in the 30 or 40% DDGS dietary treatments, respectively. The DE and ME values for LS-DDG and DDGS were calculated by subtracting the proportion of energy contributed by the control diet from the total DE and ME of each dietary treatment. This value was then divided by the proportion of ingredient in the diet (0.29, 0.39, or 0.49 for 30, 40, or, 50% LS-DDG, respectively, and 0.29 or 0.39 for 30 or 40% DDGS, respectively). As an example, for each pig in the 30% LS-DDG dietary treatment the DE of LS-DDG was calculated as the following: DE, kcal/kg = {[Total dietary DE, kcal/kg – (Control DE, kcal/kg × 0.71)] ÷ 0.29}.

Statistical analysis. The MIXED procedure of SAS (SAS Inst. Inc., Cary, NC; version 9.1) was used in all statistical analysis. Pig was the experimental unit and the statistical model included dietary treatment as the fixed effect and replicated trial as a random effect. All reported means are least squares means. Linear and quadratic contrasts within LS-DDG and DDGS diets were calculated. Mean separation was accomplished using the probability of difference procedure (PDIFF) in SAS with multiple comparisons by the Tukey-Kramer adjustment. Pooled standard errors were calculated as: $\sqrt{Estimate\ of\ residual\ variance} \div \sqrt{Replications}$. Statistical significance was set at $P < 0.05$ and P-values between 0.05 and 0.10 were considered to be trends.

Experiment 2

Animals. To achieve the objectives of this experiment, 216 crossbred (Yorkshire-Landrace X Duroc) pigs were used (46 to 54 days of age). Barrows and gilts were housed in an environmentally-controlled growing-finishing facility at the West Central Research and Outreach Center (WCROC) in Morris, MN. At the initiation of the experiment, pigs were weighed

individually and ear tagged. Pigs were blocked by initial BW (18.8 ± 0.76 kg) and assigned randomly to one of 24 pens (9 pigs/pen). Pens within each weight block were allotted randomly to one of three dietary treatments yielding 8 pens per treatment. Sex ratio within each pen was balanced across all pens (4 barrows and 5 gilts or 5 barrows and 4 gilts).

Pigs were managed according to standard operating procedures that were approved by the University of Minnesota Institutional Animal Care and Use Committee (Protocol number 0611A96347). Farm attendants verified animals' health and comfort daily; and appropriate action was taken according to WCROC standard operating procedures when animals were detected ill or injured. Each pen provided 0.77 m^2 of totally slotted floor space per pig, two nipple waterers, and a four-hole feeder. Waterers and feeders were checked daily and adjustments were made when necessary. Pigs had *ad libitum* access to water and feed throughout the entire experiment.

Pigs were marketed in two different harvest groups according to their final BW. The first group of pigs (4 pens from each treatment) was harvested at Hormel Foods Corporation in Austin, MN when average body weight of pigs in pens reached 113.8 ± 0.75 kg. Seven days later, the second group of pigs (remaining 4 pens from each treatment) was harvested in the same commercial abattoir when average BW of pigs in pens was 112.8 ± 0.75 kg.

Dietary treatments. Experimental diets were: Control - a typical corn-soybean meal based diet; Low-Solubles Distiller's Dried Grains diet (LS-DDG) - control diet containing 20% LS-DDG; and Distiller's Dried Grains with Solubles diet (DDGS) - control diet containing 20% DDGS. A single lot of LS-DDG and DDGS was used for the entire experiment (Table 1). Both LS-DDG and DDGS were sourced from the Corn-Plus ethanol plant in Winnebago, MN.

Composition and nutrient analysis of experimental diets are summarized in Tables 3 to 6. Within each dietary treatment, experimental diets were offered in a four-phase feeding program. Phases were based on average BW of pigs within a pen. Phase weight ranges were: phase 1 (20 to 45 kg), phase 2 (45 to 70 kg), phase 3 (70 to 90 kg), and phase 4 (90 to 114 kg). Each diet phase reflected the changes in nutrient needs of pigs as they grew. Nutrient levels of the diets met or exceeded NRC (1998) nutrient requirements for growing-finishing pigs gaining 350 g of lean tissue per day. The diet phase changed for each pen when the average BW of pigs in the pen reached 45, 70, and 90 kg, for phases 2, 3, and 4, respectively. Diets within each phase were formulated to contain similar levels of metabolizable energy, amino acids, vitamins, and minerals. The ratios of metabolizable energy to amino acids, amino acids relative to lysine, and total calcium to available phosphorus were also similar across all the dietary treatments within each phase and exceeded NRC (1998) recommendations. Corn and soybean meal (46% CP) nutrient content values were obtained from NRC (1998). The SID amino acid coefficients for DDGS were obtained by averaging the values of all ethanol plants in Minnesota listed by the University of Minnesota (2008). For LS-DDG, the SID amino acid coefficients were obtained from the values for the DDGS from Corn-Plus Cooperative plant in Winnebago, MN (University of Minnesota, 2008). For corn and soybean meal (46% CP), values of SID were as reported by NRC (1998).

Data collection, measurements, and laboratory analyses. Feed samples were collected from each batch of manufactured experimental diets and stored at -20 °C. At the end of the experiment, feed samples were split using a Boerner Divider and reduced by quartering. The subsamples of dietary treatments were sent to the University of Missouri Agricultural

Experiment Station Chemical Laboratories in Columbia, MO for chemical analysis of moisture (Method 934.01; AOAC, 2000), crude protein (Kjeldahl Method 984.13; AOAC, 2000), amino acids (Complete Amino Acid Profile Method 982.30; AOAC, 1995), crude fat (Ether Extraction Method 920.39; AOAC, 2000), crude fiber (Method 978.10; AOAC, 2000), NDF (Hoist, 1973), ADF (Method 973.18; AOAC, 2000), and calcium and phosphorus (inductively coupled plasma atomic emission spectroscopy) content.

Pigs were weighed individually on day zero and biweekly throughout the entire experiment. Weights were recorded weekly when average weight of a pen approached the target weight for a diet phase change. Initial BW was determined on the first day of trial and the final BW was determined at the end of the experiment. Weight of feed and date of feed added to feeders were recorded. Feed added to feeders but not consumed was vacuumed out of the feeders, weighed, and subtracted from the total amount of feed added to each feeder to determine feed disappearance. Average pig weights and feed intake for each pen were used to determine average daily weight gain, average daily feed intake, and gain efficiency. Pigs treated or removed due to injury, illness, and/or death were documented on a treatment sheet. One day before harvest, pigs were weighed individually and tattooed with a unique number to allow carcass identification for data collection. Daily high and low temperatures were observed on a thermometer located in the middle of the room, suspended from the ceiling half way between the ceiling and the floor, and recorded on the temperature sheet. Target room temperature was set at 20 °C.

A total of 194 pigs were harvested at the Hormel Foods Corporation and used for collection of carcass measurements. Hot carcass weight (HCW) and last rib back fat depth were

determined on the plant line immediately after harvest. Dressing percent was calculated as: [(HCW ÷ harvest BW) × 100]. Twenty four hours postmortem, loin (*Longissimus dorsi*) depth and back fat depth were measured after skin removal between the 10^{th} and 11^{th} ribs by Hormel personnel using a Fat-O-Meater. The 10^{th} rib back fat depth was adjusted to a skin-on basis by adding 2.54 mm (NPPC, 2000). Fat-free lean percentage of each carcass was calculated according to the following equation: [(15.31-31.277 × fat depth at the 10^{th} rib (in) + 3.813 × loin depth (in) + 0.51 × hot carcass weight (lb)) ÷ hot carcass weight (lb)] × 100 (NPPC, 2000). Adjusted fat-free lean percentage was obtained by adding 2.54 mm to the 10^{th} rib fat depth term in the above equation (NPPC, 2000).

Within a pen, two pigs (one gilt and one barrow) with body weights closest to the mean pen BW were selected for collection of bellies, back fat samples, and belly fat samples for in-depth evaluation of fat quality. Thickness, length, and flop length (the distance between the two ends of the belly when laying on an elevated bar) of bellies were measured after skin removal by trained Hormel personnel. Temperature in the room was approximately 7 ºC and belly temperatures were between 1.7 and 4.5 ºC at the time of assessment. Degree of belly firmness was calculated as: DEGREES = {ACOS {[(0.5 × L^2) - D^2] ÷ (0.5 × L^2)}}, where L = belly length and D = flop length (Whitney et al., 2006a). From belly and back fat samples, the objective color scores of lightness (L*), redness to greenness change (a*), and yellowness to blueness change (b*) were determined by Hormel personnel using a Minolta Chroma Meter CR 400 spectrophotometer (white calibration plate set as illuminant: D65 Y=93.6, X=0.3158, Y=0.3323, and observer: 2 degrees). In addition, a subjective color score on a scale from 1 (pale) to 4

(yellow) was determined by untrained panelists using the NPPC Japanese color standard as a reference.

The complete fatty acid profile of belly fat samples was determined by the South Dakota State University Analytical Services at Olson Biochemistry Laboratories in Brookings, SD as described by Sukhija and Palmquist (1988). Total amounts of saturated (SFA), monounsaturated (MUFA), and polyunsaturated (PUFA) fatty acids were determined by summing the respective classes of fatty acids. The total amount of unsaturated fatty acids (total UFA) was determined by summing MUFA and PUFA. Iodine values (IV) for belly fat were calculated as: 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) as described by AOCS (1998). Mean melting points of belly fat samples were calculated according to Holman et al. (1989).

Statistical analysis. The MIXED procedure of SAS (SAS Inst. Inc., Cary, NC; version 9.1) was used for all statistical analysis of this randomized complete block design experiment. Pen was the experimental unit for all growth performance analyses. The statistical model for analysis of overall growth performance included dietary treatment as a fixed effect and block as a random effect. The statistical model for analysis of growth performance over time included dietary treatment and phase with their interaction as fixed effects, block as a random effect, and repeated measures in time. The correlation structure over time was modeled to minimize Akaike's Information Criteria.

Carcass characteristics for barrows and gilts were averaged within sex and pen. The within-sex averages for each pen were considered the experimental unit for carcass analyses. The initial statistical model for analysis of carcass characteristics included dietary treatment, sex,

harvest group, and all possible two-way and three-way interactions as fixed effects. However, the three-way interaction of treatment, sex, and harvest group was not significant for any variable. Hence, it was removed from the model. Block was the only random effect in the model. This model employed HCW as a covariate to analyze last rib back fat depth, 10^{th} rib loin and fat depth, and lean percentage of carcasses. The significance of results did not change when HCW was present in the model as a covariate. Therefore, results in tables are being reported from the final model without the use of HCW as a covariate.

Pig was the experimental unit for fat quality analyses. The initial statistical model for analysis of fat quality included dietary treatment, sex, and harvest group with all two-way and three-way interactions as fixed effects, and block as a random effect. The three way interaction was not significant for any variable. Hence, it was removed from the final model.

All reported means are least squares means. Mean separation was accomplished using the probability of difference procedure (PDIFF) in SAS with multiple comparisons by the Tukey-Kramer adjustment. Pooled standard errors were calculated as: $\sqrt{Estimate\ of\ residual\ variance} \div \sqrt{Replications}$. Statistical significance was set at $P < 0.05$ and *P*-values between 0.05 and 0.10 were considered to be trends.

RESULTS AND DISCUSSION

Experiment 1

Throughout both replicated trials, health of barrows remained excellent. Room temperature ranged between 19.0 ± 0.6 and 24.2 ± 1.0 °C during both trials.

Energy content of LS-DDG and DDGS. The GE of LS-DDG and DDGS used in this study was 5,536 and 5,543 kcal/kg DM, respectively. The mean DE determined in LS-DDG among diets containing 30, 40, or 50% LS-DDG was 3,232 ± 75.0 kcal/kg DM (58% of GE); with values from individual pigs ranging from 2,734 to 3,555 kcal/kg DM. The DE in LS-DDG determined in the 30, 40, and 50% LS-DDG dietary treatments were 3,214; 3,169; and 3,312 kcal/kg DM, respectively (Table 7). The mean DE content of DDGS was determined to be 3,351 ± 122.0 kcal/kg DM (60% of GE), among diets containing 30 or 40% DDGS; with values from individual pigs ranging from 2,897 to 3,868 kcal/kg DM. The DE in DDGS determined in the 30 and 40% DDGS dietary treatments were 3,478 and 3,223 kcal/kg DM, respectively. The DE concentrations of LS-DDG and DDGS tended ($P = 0.09$) to differ. The slightly lower DE content of LS-DDG might be due to its slightly lower fat (7.95 vs. 8.87%) and higher fiber (18.4 vs. 16.3% ADF) content compared to DDGS (Spiehs et al., 2002; Stein et al., 2006; Soares et al., 2008).

The ME value of LS-DDGS was not determined in one pig (LS- DDG, n = 24; DDGS, n = 15) due to excessive volume of urine excreted ($\chi^2 = 0.625E\text{-}01$, $P = 0.80$). The mean ME values of LS-DDG and DDGS determined in this study were 2,959 ± 100.2 kcal/kg DM (91.5% of DE) and 2,964 ± 81.3 kcal/kg DM (88.5% of DE), respectively (Table 7). The LS-DDG ME values from individual pigs ranged between 2,594 and 3,416 kcal/kg DM. In the 30, 40, and 50% LS-

DDG dietary treatments, the ME values of LS-DDG were 3,068; 2,895; and 2,912 kcal/kg DM, respectively. The ME values of DDGS from individual pigs ranged from 2,612 to 3,533 kcal/kg DM. In the 30 and 40% DDGS dietary treatments, the ME values of DDGS were 3,049 and 2,880 kcal/kg DM, respectively. While the DE content of LS-DDG and DDGS tended to differ, the ME content of LS-DDG and DDGS was very similar ($P = 0.95$). Note that only 88.5% of the digestible energy present in DDGS was converted to metabolizable energy, while 91.5% of the DE of LS-DDG was converted to ME. A reasonable explanation for this difference is that the protein content of DDGS might be less available than the protein content of LS-DDG and require more energy to eliminate the indigestible portion of crude protein. Increased amounts of solubles in DDGS require greater time and/or higher temperatures during the drying process to attain a dry matter concentration similar to that of LS-DDG. This can increase the Maillard reaction between lysine and unfermented sugars resulting in decreased lysine digestibility (Stein et al. 2006; Pahm et al., 2008). Subsequently, some ME could be diverted for deamination and excretion of this excess nitrogen (Chen et al., 1999).

The DE (3,351 kcal/kg DM) and ME (2,964 kcal/kg DM) content of DDGS determined in this study were slightly higher than the DE and ME values of DDGS (3,200 and 2,820 kcal/kg, respectively) published by NRC (1998). The values determined in this experiment were very similar to those determined in a metabolism study with two different sources of DDGS (DE = 3,347; ME = 3,087 kcal/kg DM for source 1 and DE = 3,459; ME = 3,199 kcal/kg DM for source 2) reported by Soares et al. (2008). However, the DE and ME values determined for DDGS in this study were lower than the values (4,140 and 3,897 kcal/kg DM, respectively) determined among ten different sources of DDGS presented by Pedersen et al. (2007) and the values

between two different sources of DDGS (DE = 3,871; ME = 3,697 kcal/kg for new plant and DE = 3,728; ME = 3,587 kcal/kg for old plant) presented by Hastad et al. (2004). In addition, the DE and ME values determined for DDGS in this study are lower than calculated values (4,077 and 3,818 kcal/kg DM, respectively) presented by the University of Minnesota (2008) using the prediction equations of Noblet and Perez (1993).

An additional comparison was made using the DE [DE = – 12,637 – (128.27 × Ash) + (25.38 × CP) – (115.72 × Fat) – (138.02 × ADF) + (3.569 × GE)] and ME [ME = – 10,267 – (175.78 × Ash) + (23.09 × CP) – (71.22 × Fat) – (137.93 × ADF) + (3.036 × GE)] prediction equations of Pedersen et al. (2007) with the proximate analysis values of LS-DDG and DDGS used in this research. The values calculated in this scenario for DE were 3,844 and 3,897 kcal/kg DM and for ME were 3,455 and 3,528 kcal/kg DM for LS-DDG and DDGS, respectively. The values calculated using these prediction equations are higher than the values determined in the present metabolism trial.

A greater proportion of the reduced DE and ME content found in this study may be due to the lower fat (7.95 and 8.87%), lower ash (2.32 and 2.87%), and higher ADF content (18.4 and 16.3%) of LS-DDG and DDGS compared to other sources of distiller's grains. To quantify the magnitude of difference in energy that ADF content could account for, a calculation was made using the above Pedersen et al. (2007) equation for estimation of DE. In this scenario, the values obtained for gross energy, fat, crude protein, and ash of DDGS used in this study were used. However instead of using the ADF value (18.4%) determined for the DDGS in this study, the ADF value (11.6%) from Pedersen et al. (2007) was used. As expected, the DE calculated

from this equation using the lower ADF value from Pedersen et al. (2007) was 938.5 kcal/kg DM (3,897 vs. 4,836 kcal/kg DM) greater due to the 7% difference in ADF concentration.

Another factor that can explain a proportion of the lower DE and ME values found for LS-DDG and DDGS in this study is the underestimation of the digestibility of diets that can occur when chromic oxide is used as an indigestible marker in the partial collection method (Adeola, 2001). Previous research indicates that the energy content of DDGS can vary depending on the method utilized for its determination (Hastad et al., 2004). In the present experiment an indirect method of determining energy digestibility was performed using chromic oxide as an indigestible marker. Losses of chromic oxide during feed preparation, animal feeding, fecal collection, and feed and fecal laboratory analyses can occur decreasing the dietary coefficients of digestibility and consequently reducing the DE and ME values of diets compared to total collection methods (Jagger et al., 1992; Hill et al., 1996). These losses may explain a portion of the lower DE and ME content found for LS-DDG and DDGS in the present study.

Energy balance of dietary treatments. Initial and final BW, ADFI, and GE intake of pigs did not differ among dietary treatments (Tables 8 and 9). The LS-DDG and DDGS linear contrasts for digestibility were significant ($P < 0.01$) suggesting a reduction in digestibility of diets with increasing concentrations of LS-DDG (0, 30, 40, or 50%) and DDGS (0, 30, or 40%) in the diet. In addition, the quadratic contrasts were also significant ($P < 0.04$) suggesting that the reduction in digestibility with increasing LS-DDG and DDGS inclusion also follows a curvilinear pattern. The control diet was more digestible compared to all diets formulated with either LS-DDG or DDGS. The reduction in digestibility of diets as co-product inclusion level increased is probably related to the subsequent incremental increase in ADF concentration which

can reduce the total energy utilization of the diet (Etienne, 1987; Le Goff et al., 2002). Diets with 30% LS-DDG and 30% DDGS had similar digestibility. In addition, diets with 40% LS-DDG and 40% DDGS were similarly digestible; and the diet with 50% LS-DDG had comparable digestibility to both 40% co-product inclusion diets.

The DE content of diets formulated with 0, 30, 40, or 50% LS-DDG followed decreasing linear and quadratic patterns. When a treatment means separation was performed, all diets including LS-DDG displayed a similar amount of DE. For diets formulated with DDGS, a linear decrease in dietary DE content was observed with increased inclusion levels of DDGS. When comparing means, the diet containing 40% DDGS displayed a lower DE compared to the diet containing 30% DDGS. All dietary treatments containing LS-DDG and the dietary treatment containing 40% DDGS had lower concentrations of DE compared to the control diet, while the dietary treatment containing 30% DDGS had similar concentration of DE compared to the control diet. The diet containing 50% LS-DDG displayed similar DE content compared to diets containing either 40% LS-DDG or 40% DDGS.

As concentrations of either co-product increased in diets, the GE present in urine of pigs fed the respective diets also increased. This was not surprising due to the fact that diets were not formulated to be isonitrogenous and as the co-product inclusion levels increased crude protein concentrations of the diets also increased. Pigs fed diets formulated with 30 or 40% LS-DDG had urinary GE concentrations similar to pigs receiving the control diet. Urine from pigs fed both the 30% LS-DDG and the 30% DDGS diets contained similar concentrations of GE, as did urine from pigs fed both the 40% LS-DDG and the 40% DDGS diets, respectively. However, values for GE of urine from pigs fed either one of the DDGS diets were greater than those

receiving the control diet. These relationships are surprising because they do not follow the relationships among crude protein values present in the dietary treatments. Recall that at each respective inclusion level, crude protein values for diets containing LS-DDG were greater than those for diets containing DDGS. Also, diets formulated with either LS-DDG or DDGS had a greater crude protein compared to the control diet. If protein was utilized in the same way among pigs receiving LS-DDG and DDGS dietary treatments, we would expect the urine from pigs fed LS-DDG to have a greater GE content compared to the control diet and compared to the DDGS diets at same inclusion levels. However, this was not the case and may indicate a difference in protein digestibility between these two co-products. Recall that DDGS, due to its higher amount of solubles compared to the LS-DDG requires longer time and/or higher temperatures to achieve similar moisture levels. This increased drying time and temperature may increase the Maillard reaction between lysine and unfermented sugars (Stein et al. 2006; Pahm et al., 2008) which reduces the overall protein digestibility of DDGS (Stein et al., 2006). The urinary GE values for two pigs (Control = 1; DDGS30% = 7) were not determined due to excessive volume of urine excreted ($\chi^2 = 0.25$, $P = 0.99$). Consequently, these two pigs were also not included in the ME content and ME corrected for nitrogen content calculations.

As dietary levels of LS-DDG and DDGS increased, the ME concentration of diets linearly decreased. Additionally, diets containing LS-DDG or DDGS had similar ME content compared to each other but lower ME content compared to the control diet. When the dietary ME was corrected for the corresponding dietary nitrogen balance (Diggs et al., 1965), the ME content of diets also decreased with increasing levels of co-products. The dietary treatment with

50% LS-DDG had similar ME corrected for dietary nitrogen balance compared to dietary treatments with 40% LS-DDG or DDGS.

Nitrogen balance of dietary treatments. Increasing dietary levels of LS-DDG and DDGS increased nitrogen intake of pigs compared to pigs receiving the control diet (Tables 10 and 11). This was expected due to the fact that the five dietary treatments containing LS-DDG or DDGS were formulated by substituting a constant proportion of corn and soybean meal from the control diet without trying to equalize the level of crude protein among diets. Consequently, the high protein content of LS-DDG and DDGS increased dietary crude protein concentration as LS-DDG and DDGS inclusion rates increased. This increased crude protein concentration of diets increased nitrogen intake of pigs compared with contemporaries consuming the control diet. There were no differences in nitrogen intake between pigs receiving the same level of LS-DDG and DDGS, both for the 30 and 40% diets.

Pigs fed diets containing the same levels of LS-DDG and DDGS exhibited similar amounts of nitrogen in feces. Compared to pigs receiving the control diet, pigs receiving diets with LS-DDG or DDGS had a greater ($P < 0.01$) amount of fecal nitrogen. This is not surprising due to the fact that pigs offered diets with LS-DDG or DDGS had a higher nitrogen intake compared to pigs fed the control diet. Greater concentrations of nitrogen in feces when high levels of LS-DDG or DDGS are fed to pigs may increase ammonia emissions in the barn (Spiehs et al, 2002) and increase the amount of land required for manure application. One way to address this issue would be to replace protein sources in diets with synthetic amino acids which may result in a lower amount of dietary crude protein with an equal amount of available amino acids.

Pigs receiving diets with LS-DDG or DDGS had a greater amount ($P < 0.01$) of nitrogen digested per day compared to pigs receiving the control diet. Pigs fed the same levels of LS-DDG and DDGS displayed similar amounts of nitrogen digested per day. Additionally, pigs fed the diet with 50% LS-DDG digested more nitrogen than pigs from any other treatments. There were no differences in nitrogen digestibility between pigs fed the 30% LS-DDG or 30% DDGS, and the 40% LS-DDG or 40% DDGS. Nitrogen digestibility was similar among dietary treatments; except for pigs receiving the 40% DDGS diet. These pigs displayed reduced ($P < 0.05$) nitrogen digestibility compared to pigs fed the control and the 30% and 50% LS-DDG diets. A potential reason that could explain this lower nitrogen digestibility of pigs receiving the diet with 40% DDGS may, again, be due to a lower protein digestibility in the DDGS caused by excessive heat during the drying process of this co-product (Stein et al., 2006). Nitrogen digestibility did not change with increased levels of LS-DDG but it declined with increased levels of DDGS.

Pigs fed diets containing the same levels of LS-DDG and DDGS exhibited similar amounts of nitrogen in urine. Compared to pigs receiving the control diet, pigs receiving diets with LS-DDG or DDGS had a greater ($P < 0.01$) amount of urinary nitrogen. This is not surprising due to the fact that pigs offered diets with LS-DDG or DDGS had a higher nitrogen intake and a relatively similar nitrogen digestibility compared to pigs fed the control diet. Similarly to fecal nitrogen, greater amounts of nitrogen in urine can have negative effects to the environment. However, producers can replace protein sources in diets with synthetic amino acids to decrease the presence of excess nitrogen without increasing the cost of the diet.

Nitrogen balance quadratically decreased with increasing levels of LS-DDG. However, pigs receiving diets with 30, 40, or 50% LS-DDG displayed similar nitrogen balance compared to pigs receiving the control diet. As dietary levels of DDGS increased, a linear decrease in nitrogen balance was observed. Within pigs receiving diets with DDGS a reduction in nitrogen balance was observed compared to pigs receiving the control diet ($P < 0.02$; contrast DDGS vs. Control). Pigs receiving diets with 30 or 40% DDGS, or 50% LS-DDG exhibited lower percent of nitrogen retained compared to pigs receiving the control diet. The reduction in nitrogen retention by pigs receiving the 50% LS-DDG diet may be due to its higher crude protein concentration compared to the control diet. What is intriguing and very interesting is that pigs receiving diets with 30 or 40% DDGS, which had a lower crude protein and ADF content compared to diets with similar levels of LS-DDG, displayed a reduced percentage of nitrogen retained compared to pigs receiving the control diet. However, pigs receiving diets with 30 or 40% LS-DDG obtained similar levels of nitrogen retained compared to pigs receiving the control diet. This again suggests that the protein present in LS-DDG may be more digestible than the protein present in DDGS, possibility due to less heat damage during LS-DDG production compared to DDGS.

Experiment 2

Growth Performance. Throughout the entire experiment, the health of 212 pigs remained excellent. However, four pigs failed to complete the study due to poor health or injury. In the second week of the study, one pig died due to an undefined cause. Three additional pigs were removed from the study due to injuries. Neither premature death nor injuries were

associated with dietary treatment (χ^2 = 0.833E-01; P = 0.96). Room temperature remained between 16.8 ± 0.19 and 21.6 ± 0.24 °C during the entire experimental period.

There were no significant interactions among dietary treatments and phases. Body weight initially (Table 12), and throughout the experiment (Figure 1) did not differ among dietary treatments. In addition, pigs' overall weight gain and weight gain during each of the four phases (Figure 2) were similar regardless of dietary treatment. Dietary addition of LS-DDG and DDGS did not influence overall feed intake or feed intake in any phase (Figure 3) compared to the control group.

Gain efficiency of pigs fed the DDGS diet was similar to pigs fed the control diet (Table 12). Previous studies also demonstrated no effects on ADG, ADFI, and G:F when the same level of DDGS (20%) was used in growing-finishing swine diets (Whitney et al., 2006b,c,d; Widmer et al., 2008). However, other studies found that pigs fed diets with 20% DDGS displayed lower ADG, ADFI, or G:F (Whitney et al., 2006a; Xu et al., 2007; Linneen et al., 2008). Pigs fed the LS-DDG diet tended (P = 0.07) to display lower overall gain eficiency compared to pigs fed the control diet. This difference was not observed (P = 0.86) when compared to the pigs fed the DDGS diet. This tendency was driven by a numerically (P > 0.38) lower ADG and increased feed intake in pigs fed the LS-DDGS diet compared to pigs receiving the control diet. The slightly lower gain efficiency of pigs receiving the diet with the 20% LS-DDG could be due to an overestimation of the amino acid digestibility of LS-DDG. All diets were formulated on a SID amino acid basis. However, a large database of amino acid SID coefficients is not available for LS-DDG. Therefore, the amino acid SID of DDGS from the Corn-Plus ethanol reported by the University of Minnesota (2008) was used to formulate the LS-DDG diet. The SID amino

acid coefficients for DDGS were estimated by averaging the SID data presented by the University of Minnesota (2008). This conservative approach may have provided excess amino acids available for pig growth in the DDGS diet. The overestimated SID amino acid concentration used to formulate the dietary treatment containing LS-DDG may have resulted in this slightly lower gain efficiency of pigs receiving the LS-DDG diet compared to pigs receiving the control diet, while similar to pigs receiving the DDGS diet. Therefore, the determination of amino acid digestibility in the LS-DDG is crucial to accurate diet formulation (Widmer et al., 2007).

Carcass composition. There were no significant interactions among dietary treatments, sex, and harvest group for any of the response variables. Therefore, only effects of dietary treatment are presented.

Two hundred and twelve pigs remained healthy throughout the entire experiment and were available for harvesting. However, 18 pigs were not harvested because they did not reach the minimum required weight (104 kg) for harvesting without severe financial penalties. These pigs were distributed over all three dietary treatments (Control = 4; LS-DDG = 9; DDGS = 5). There was no significant relationship between number of pigs that did not reach the minimum harvest weight and dietary treatment (χ^2 = 1.73; P = 0.42). In addition, four carcasses from the 194 harvested pigs were lost during processing. These four carcasses were distributed randomly (χ^2 = 0.912E-01; P = 0.96) across dietary treatments (Control = 2; LS-DDG = 1; DDGS = 1).

Harvest weights of pigs, hot carcass weights, and last rib back fat were similar among dietary treatments (Table 13). Widmer et al. (2008) also showed no effect of swine finishing diets containing 20% DDGS on HCW. In contrast, several authors reported a reduction in HCW

when 20% DDGS was included in diets (Whitney et al., 2006a; Linneen et al., 2008). Pigs fed the LS-DDG diet had a similar dressing percent compared to pigs fed the DDGS diet. However, pigs assigned to LS-DDG and DDGS diets had lower ($P < 0.01$) dressing percentage compared to pigs fed the control diet. Dressing percentage is often reduced (Xu et al., 2007; Linneen et al., 2008); but sometimes unaffected (Widmer et al., 2008) by adding 20% DDGS in finishing pig diets. It is very well known that diets with high crude protein (Chen et al., 1999) and fiber (Pond et al., 1988) content may increase weight of visceral organs (especially stomach, liver, and intestines) and weight of digesta, which might explain this decrease in dressing percentage for pigs fed both the LS-DDG and DDGS diets. Pigs fed the LS-DDG diet had a similar 10^{th} rib loin depth compared to pigs fed both the control and DDGS diets. However, the DDGS diet reduced ($P < 0.01$) 10^{th} rib loin depth of pigs compared to the control diet. Many other studies found no effect of 20% dietary DDGS on 10^{th} rib loin depth (Linneen et al., 2008; Widmer et al., 2008). Diets containing 20% LS-DDG reduced 10^{th} rib back fat depth ($P = 0.02$) and increased lean percentage ($P < 0.01$) compared to diets with DDGS. This could be due to the fact that the phase 3 and 4 LS-DDG diets had lower ME to SID lysine ratios compared to the phase 3 and 4 DDGS diets. Thus, less energy relative to amino acids was available for fat deposition at this stage of growth. However, pigs fed the LS-DDG and DDGS diets had similar 10^{th} rib back fat depth and lean percentage compared to pigs fed the control diet. Similar to our results, Widmer et al. (2008) reported no differences in 10^{th} rib back fat depth of pigs fed diets with 20% DDGS. Conversely, Benz et al. (2008) and Weimer et al. (2008) found that pigs fed diets with 20% DDGS had reduced 10^{th} rib back fat depth compared to pigs not fed DDGS.

Fat quality. There were no significant interactions among dietary treatments, sex, and harvest group for any measures of fat quality. Therefore, only main effects of dietary treatment are presented.

Two bellies from the 48 subsampled group of pigs were lost ($\chi^2 = 0.13$; $P = 0.94$) during processing (Control = 1; LS-DDG = 1). Belly thickness did not differ among dietary treatments (Table 14). Previous research clearly showed that inclusion of 20% DDGS in diets for finishing pigs had no impact on belly thickness (Whitney et al., 2006a; Weimer et al., 2008; Widmer et al., 2008; Xu et al., 2008a). Bellies from pigs fed the DDGS diet were softer ($P < 0.01$) than those from pigs fed the control diet. This was due to the high amount of unsaturated fatty acids present in diets with DDGS (Ellis and Isbell, 1926; Apple et al., 2007). Weimer et al. (2008) and Widmer et al. (2008) also demonstrated that pigs fed diets with 20% DDGS had decreased belly firmness compared to pigs fed a control diet. However, Whitney et al. (2006a) demonstrated that 20% dietary DDGS did not affect belly firmness. The values of belly firmness determined in this study are lower than values presented in previous research (Whitney et al., 2006a; Weimer et al., 2008; Widmer et al., 2008) because of the differences in the method used to calculate the flop angle degree. In this study, bellies had the skin removed and were positioned on the elevated bar with the skin area facing up. While in other studies, bellies had the skin present and were positioned on elevated bars with the skin facing down. Only a tendency ($P = 0.07$) for softer bellies was observed when pigs received the LS-DDG diet compared to the control diet. This slight improvement in belly firmness in pigs fed the LS-DDG may result in improved processing of bacon and sausage (NPPC, 2000).

The L*, a*, and b* Minolta color score was unable to be performed on one belly fat sample due to an incompatibility of sample size with the equipment (Control = 16; LS- DDG = 15; DDGS = 16; $\chi^2 = 0.63$, $P = 0.97$). Dietary treatments had minimal effects on color of fat (Table 15). Back fat samples had similar L*, a*, and b* color scores regardless of dietary treatment. Likewise, a* and b* color scores of belly fat did not differ among dietary treatments. However, pigs fed the LS-DDG diet had darker belly fat than pigs fed the control diet; but similar to pigs fed the DDGS diet. A similar result was reported by Widmer et al. (2008) when 20% DDGS was included in diets for finishing pigs. This difference in back fat lightness, determined by the Minola L*, observed in pigs receiving the diet containing LS-DDG could be a problem when exporting pork. Several major export markets (mainly Asian countries such as Japan and China) have fat color parameters established. These countries believe that consumers' acceptance is greater with a bright whiter pork fat color. However, this difference in back fat lightness of pigs receiving the dietary treatment containing LS-DDG was not perceived by panelists according to the subjective Japanese color score.

Fat composition. Three of the belly fat samples were not analyzed for fatty acid composition due to spoilage during storage, without association to dietary treatments (Control = 1; DDGS =2; $\chi^2 = 0.35$, $P = 0.84$). Fatty acid profiles of belly fat were influenced by dietary treatments (Table 16). Belly fat from pigs fed the control diet had a larger amount of SFA ($P < 0.01$) and MUFA ($P < 0.01$) and a lower amount of PUFA ($P < 0.01$) compared to belly fat from pigs fed both the LS-DDG and DDGS diets. Consequently, the control treatment had a lower iodine value and a higher mean melting point compared to both LS-DDG and DDGS treatments. However, pigs fed all three dietary treatments had an IV considered acceptable for good quality

fat (NPPC, 2000). Many other researchers have reported similar results with the addition of DDGS to diets (Benz et al., 2008; Xu et al., 2008a,b).

The differences among dietary treatments in the total amount of SFA were mostly due to the greater amounts of palmitic acid (C16:0) in pigs fed the control diet compared to pigs fed both LS-DDG and DDGS diets ($P < 0.01$). The amount of arachidic acid (C20:0) was also greater ($P = 0.03$) in belly fat from the control group compared to the DDGS group. However, the amount of arachidic acid in the control group only tended to be greater compared to the LS-DDG group ($P = 0.09$). Among the four analyzed MUFA, three of them (palmitoleic – C16:1, oleic – C18:1, and II-eicosanoic – C20:1 acids) were higher in belly fat from the control pigs compared to pigs fed the DDGS diet. However, only two of these MUFA (oleic and II-eicosamoic acids) were higher in the control compared to the LS-DDG. The amount of palmitoleic acid was similar between belly fat of pigs fed the control and the LS-DDG diets. All of the PUFA analyzed were lower in the control group compared to the DDGS group. However, eicosatrienoic (C20:3) and docosatrienoic (C22:4) acids were similar between LS-DDG and control treatments. It is important to notice that the amount of PUFA in belly fat from pigs fed the LS-DDG diet was lower ($P = 0.01$) compared to belly fat from pigs fed the DDGS diet. Consequently, the IV of the LS-DDG treatment tended to be lower ($P = 0.06$) compared to the DDGS treatment. This is mostly due to the lower ($P = 0.02$) amount of linoleic acid (C18:2), the major fatty acid among the PUFA, in the LS-DDG treatment compared to the DDGS treatment. Lower amount of PUFA in the fat can result in firmer pork fat which facilitates the processing of pork products, especially bacon and sausage (NPPC, 2000).

The lower ratio of omega-6 to omega-3 in the LS-DDG treatment compared to the DDGS treatment is also explained by the lower (P = 0.02) amount of linoleic acid, the major omega six fatty acid, in the LS-DDG treatment compared to the DDGS treatment. Greater amount of omega-3 fatty acids compared to omega-6 fatty acids are often correlated to reduced fat oxidation, increased fat firmness, and potential beneficial to human health--decreased risk of cardiovascular diseases (Simopoulos, 2001; Corino et al., 2002).

Dietary treatment and sex interactions. Significant interactions were observed between dietary treatment and sex for various fatty acid concentrations of belly fat (Figures 5 to 7). Gilts fed the LS-DDG diet had a lower (P = 0.02) amount of linoleic acid (C18:2) compared to gilts fed the DDGS diet (Figure 5), while there was no difference among diets for barrows. Linoleic acid is the major fatty acid among the omega six fatty acids and the total amount of PUFA. Consequently, the amount of omega six fatty acids and the total amount of PUFA were lower (P < 0.02) in gilts fed the LS-DDG diet compared to gilts fed the DDGS diet (Figures 6 and 7), while barrows showed no difference between LS-DDG and DDGS diets. These results are a good indicator that pork fat of gilts may be more sensitive to dietary LS-DDG than that of barrows allowing gilts to receive a greater inclusion of LS-DDG in their diets than barrows if an adequate growth performance is achievable. Previous research has demonstrated that gilts have a lower lipid deposition than barrows (Wiseman et al. 2007a,b; Schinckel et al., 2008).

IMPLICATIONS

Results from this experiment demonstrate that the digestible and metabolizable energy values of LS-DDG were 3,232 and 2,959 kcal/kg DM, respectively. Thus, LS-DDG used in this

study can replace typical DDGS in swine diets without compromising the energy content in the diet. Nitrogen balance and retention of pigs fed LS-DDG were greater compared to pigs fed diets with DDGS. This could have important implications for the environment in terms of ammonia emissions and land mass required for manure application resulting from diets containing LS-DDG compared to those containing DDGS.

Low-solubles distiller's dried grains from Corn-Plus can be added as an alternative ingredient in swine growing-finishing diets at an inclusion rate of 20% without compromising growth performance or carcass characteristics of pigs. However, to achieve a more accurate feed formulation the amino acid digestibility of this co-product needs to be determined. The LS-DDG can lessen some of the negative impacts of DDGS on carcass characteristics (loin and back fat depth and lean percentage) and pork fat quality (belly firmness). Also, pork fat of gilts may be more sensitive to dietary LS-DDG than that of barrows.

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Table 1. Nutrient composition of Low-Solubles Distiller's Dried Grains (LS-DDG) and Distiller's Dried Grains with Solubles (DDGS) (as-fed basis)

Component , %	LS-DDG	DDGS
Dry matter	90.33	88.53
Crude protein	31.60	30.10
Lysine	0.94	0.91
Methionine	0.59	0.56
Methionine + cysteine	1.13	1.07
Threonine	1.10	1.06
Tryptophan	0.18	0.18
Crude fat	7.95	8.87
ADF	18.40	16.30
Ash	2.32	2.87
Total calcium	0.03	0.03
Total phosphorus	0.55	0.66
Total sulfur	0.63	0.69

University of Missouri Agricultural Experiment Station Chemical Laboratories in Columbia, MO

Table 2. Composition and nutrient analysis of experimental diets (as-fed basis; Exp. 1)

	Dietary treatments[1]					
Ingredient, %	Control	LS-DDG 30%	LS-DDG 40%	LS-DDG 50%	DDGS 30%	DDGS 40%
Corn	78.95	55.26	47.37	39.47	55.26	47.37
SBM[2], 46% CP	18.90	13.23	11.34	9.45	13.23	11.34
LS-DDG	0.00	29.36	39.14	48.93	0.00	0.00
DDGS	0.00	0.00	0.00	0.00	29.36	39.14
Limestone	0.70	0.70	0.70	0.70	0.70	0.70
Dical. Phosphate[3]	0.60	0.60	0.60	0.60	0.60	0.60
Salt	0.30	0.30	0.30	0.30	0.30	0.30
V-M premix[4]	0.30	0.30	0.30	0.30	0.30	0.30
Chromic oxide	0.25	0.25	0.25	0.25	0.25	0.25
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis:						
ME, kcal/kg[5]	3,339	3,211	3,169	3,126	3,211	3,169
Laboratory analysis, %:						
Dry matter	95.58	96.33	96.11	96.19	95.95	95.54
Crude protein	13.50	19.67	22.07	23.40	18.86	20.59
Lysine	0.74	0.81	0.81	0.83	0.82	0.78
Methionine	0.20	0.32	0.36	0.40	0.31	0.34
Met + Cysteine	0.42	0.64	0.71	0.78	0.61	0.68
Threonine	0.49	0.67	0.75	0.81	0.68	0.72
Tryptophan	0.14	0.16	0.16	0.17	0.15	0.16
Crude fat	3.10	4.50	5.52	6.01	4.93	5.76
Crude fiber	1.64	3.65	4.39	5.20	3.53	3.97
NDF	7.16	16.99	22.70	24.83	16.94	19.88
ADF	2.26	6.42	8.07	9.64	6.16	7.30
Calcium	0.46	0.50	0.53	0.52	0.49	0.50
Phosphorus	0.44	0.49	0.53	0.53	0.52	0.56

[1] Control = typical corn-soybean meal based diet; LS-DDG30% = control containing 30% low-solubles distiller's dried grains; LS-DDG40% = control containing 40% low-solubles distiller's dried grains; LS-DDG50% = control containing 50% low-solubles distiller's dried grains; DDGS30% = control containing 30% distiller's dried grains with solubles; and DDGS40% = control containing 40% distiller's dried grains with solubles.

[2] Soybean meal.

[3] Dicalcium phosphate.

[4] Vitamin and mineral premix that supplemented the following amounts per kg of diet: 5,512.5 IU vitamin A; 1,378.1 IU vitamin D_3; 27.6 IU vitamin E; 2.2 mg vitamin K; 248.1 mg choline; 27.6 mg niacin; 16.5 mg pantothenic acid; 5.0 mg riboflavin; 1.1 mg biotin; 1.1 mg pyridoxine; 0.8 mg folic acid; 0.6 mg thiamine; 27.6 μg vitamin B_{12}; 45.2 mg zinc; 27 mg iron; 9 mg manganese; 2.7 mg copper; 1.1 mg iodine; and 0.2 mg selenium.

[5] ME values for corn and SBM taken from NRC (1998). ME values for LS-DDG and DDGS were 2,977 kcal/kg.

Table 3. Composition and nutrient analysis of phase 1 diets – 20 to 45 kg (as-fed basis; Exp. 2)

	Dietary treatments[1]		
Ingredient, %	Control	LS-DDG	DDGS
Corn	68.92	54.40	53.06
Soybean meal, 46% CP	28.55	22.99	24.33
LS-DDG	0.00	20.00	0.00
DDGS	0.00	0.00	20.00
Limestone	1.03	1.06	1.06
Monocalcium phosphate	0.80	0.85	0.85
Salt	0.30	0.30	0.30
Vitamin-mineral premix[2]	0.25	0.25	0.25
L-Lysine·HCl	0.15	0.15	0.15
TOTAL	100.00	100.00	100.00
Calculated analysis:			
ME, kcal/kg[3]	3,265	3,187	3,184
ME:SID Lysine[4]	334.9	334.9	334.8
Total Ca: Available P[5]	2.55	2.63	2.62
Laboratory analysis, %:			
Dry matter	86.67	87.64	87.48
Crude protein	18.84	21.08	21.02
Lysine	1.15	1.10	1.11
Methionine	0.29	0.34	0.34
Methionine + Cysteine	0.60	0.69	0.70
Threonine	0.76	0.80	0.80
Tryptophan	0.23	0.23	0.23
Crude fat	2.12	3.50	3.47
Crude fiber	1.85	3.37	3.16
NDF	7.44	15.67	15.42
ADF	2.45	5.56	5.29
Total calcium	0.66	0.63	0.64
Total phosphorus	0.50	0.53	0.53

[1]Control = typical corn-soybean meal based diet; LS-DDG = control containing 20% low-solubles distiller's dried grains; and DDGS = control containing 20% distiller's dried grains with solubles.

[2]Supplemented the following amounts per kg of final diet: 8,820 IU vitamin A; 1,653.7 IU vitamin D_3; 33.1 IU vitamin E; 4.4 mg vitamin K; 38.6 mg niacin; 22 mg pantothenic acid; 6.6 mg riboflavin; 44.1 µg vitamin B_{12}; 60.6 mg zinc; 36.4 mg iron; 12.1 mg manganese; 3.6 mg copper; 1.1 mg iodine; and 0.3 mg selenium.

[3]ME values for corn and SBM from NRC (1998) and for LS-DDG and DDGS of 2,977 kcal/kg.

[4]Standardized Ileal Digestible (SID) lysine values for corn and SBM from NRC (1998), for LS-DDG = 0.57, and for DDGS = 0.73.

[5]Bioavailability of phosphorus for corn and SBM from NRC (1998) and for LS-DDG = 0.49, and for DDGS = 0.59.

Table 4. Composition and nutrient analysis of phase 2 diets – 45 to 70 kg (as-fed basis; Exp. 2)

	Dietary treatments[1]		
Ingredient, %	Control	LS-DDG	DDGS
Corn	76.49	61.85	60.49
Soybean meal, 46% CP	21.21	15.84	17.20
LS-DDG	0.00	20.00	0.00
DDGS	0.00	0.00	20.00
Limestone	0.95	0.95	0.95
Monocalcium phosphate	0.65	0.66	0.66
Salt	0.30	0.30	0.30
Vitamin-mineral premix[2]	0.25	0.25	0.25
L-Lysine·HCl	0.15	0.15	0.15
TOTAL	100.00	100.00	100.00
Calculated analysis:			
ME, kcal/kg[3]	3,290	3,214	3,211
ME:SID Lysine[4]	408.7	408.7	408.5
Total Ca: Available P[5]	2.70	2.83	2.82
Laboratory analysis, %:			
Dry matter	86.27	86.65	87.72
Crude protein	15.77	18.13	18.68
Lysine	0.94	0.89	0.93
Methionine	0.26	0.32	0.32
Methionine + Cysteine	0.53	0.64	0.65
Threonine	0.59	0.71	0.76
Tryptophan	0.19	0.19	0.20
Crude fat	2.39	3.43	3.92
Crude fiber	1.80	3.35	2.94
NDF	8.10	15.64	16.08
ADF	2.30	5.28	5.30
Total calcium	0.48	0.57	0.78
Total phosphorus	0.41	0.45	0.57

[1]Control = typical corn-soybean meal based diet; LS-DDG = control containing 20% low-solubles distiller's dried grains; and DDGS = control containing 20% distiller's dried grains with solubles.

[2]Supplemented the following amounts per kg of final diet: 8,820 IU vitamin A; 1,653.7 IU vitamin D_3; 33.1 IU vitamin E; 4.4 mg vitamin K; 38.6 mg niacin; 22 mg pantothenic acid; 6.6 mg riboflavin; 44.1 µg vitamin B_{12}; 60.6 mg zinc; 36.4 mg iron; 12.1 mg manganese; 3.6 mg copper; 1.1 mg iodine; and 0.3 mg selenium.

[3]ME values for corn and SBM from NRC (1998) and for LS-DDG and DDGS of 2,977 kcal/kg.

[4]Standardized Ileal Digestible (SID) lysine values for corn and SBM from NRC (1998), for LS-DDG = 0.57, and for DDGS = 0.73.

[5]Bioavailability of phosphorus for corn and SBM from NRC (1998) and for LS-DDG = 0.49, and for DDGS = 0.59.

Table 5. Composition and nutrient analysis of phase 3 diets – 70 to 90 kg (as-fed basis; Exp. 2)

	Dietary treatments[1]		
Ingredient, %	Control	LS-DDG	DDGS
Corn	81.52	66.29	65.39
Soybean meal, 46% CP	16.29	11.49	12.39
LS-DDG	0.00	20.00	0.00
DDGS	0.00	0.00	20.00
Limestone	0.92	0.92	0.92
Monocalcium phosphate	0.57	0.60	0.60
Salt	0.30	0.30	0.30
Vitamin-mineral premix[2]	0.25	0.25	0.25
L-Lysine·HCl	0.15	0.15	0.15
TOTAL	100.00	100.00	100.00
Calculated analysis:			
ME, kcal/kg[3]	3,306	3,228	3,226
ME:SID Lysine[4]	478.3	470.7	478.2
Total Ca: Available P[5]	2.85	2.95	2.94
Laboratory analysis, %:			
Dry matter	85.36	87.55	88.75
Crude protein	14.36	15.25	16.62
Lysine	0.85	0.69	0.79
Methionine	0.23	0.28	0.30
Methionine + Cysteine	0.48	0.56	0.61
Threonine	0.58	0.61	0.68
Tryptophan	0.17	0.15	0.18
Crude fat	2.19	4.09	4.67
Crude fiber	2.03	3.31	3.04
NDF	8.43	15.87	17.57
ADF	2.22	5.47	5.58
Total calcium	0.53	0.40	0.45
Total phosphorus	0.39	0.42	0.48

[1]Control = typical corn-soybean meal based diet; LS-DDG = control containing 20% low-solubles distiller's dried grains; and DDGS = control containing 20% distiller's dried grains with solubles.

[2]Supplemented the following amounts per kg of final diet: 8,820 IU vitamin A; 1,653.7 IU vitamin D_3; 33.1 IU vitamin E; 4.4 mg vitamin K; 38.6 mg niacin; 22 mg pantothenic acid; 6.6 mg riboflavin; 44.1 µg vitamin B_{12}; 60.6 mg zinc; 36.4 mg iron; 12.1 mg manganese; 3.6 mg copper; 1.1 mg iodine; and 0.3 mg selenium.

[3]ME values for corn and SBM from NRC (1998) and for LS-DDG and DDGS of 2,977 kcal/kg.

[4]Standardized Ileal Digestible (SID) lysine values for corn and SBM from NRC (1998), for LS-DDG = 0.57, and for DDGS = 0.73.

[5]Bioavailability of phosphorus for corn and SBM from NRC (1998) and for LS-DDG = 0.49, and for DDGS = 0.59.

Table 6. Composition and nutrient analysis of phase 4 diets – 90 to 114 kg (as-fed basis; Exp. 2)

	Dietary treatments[1]		
Ingredient, %	Control	LS-DDG	DDGS
Corn	86.18	70.60	70.00
Soybean meal, 46% CP	11.69	7.31	7.91
LS-DDG	0.00	20.00	0.00
DDGS	0.00	0.00	20.00
Limestone	0.91	0.85	0.85
Monocalcium phosphate	0.52	0.54	0.54
Salt	0.30	0.30	0.30
Vitamin-mineral premix[2]	0.25	0.25	0.25
L-Lysine·HCl	0.15	0.15	0.15
TOTAL	100.00	100.00	100.00
Calculated analysis:			
ME, kcal/kg[3]	3,319	3,242	3,241
ME:SID Lysine[4]	567.8	550.5	567.7
Total Ca: Available P[5]	3.00	3.00	2.99
Laboratory analysis, %:			
Dry matter	85.59	86.53	86.67
Crude protein	12.12	14.72	14.88
Lysine	0.69	0.67	0.67
Methionine	0.21	0.28	0.27
Methionine + Cysteine	0.44	0.56	0.55
Threonine	0.50	0.58	0.61
Tryptophan	0.14	0.14	0.15
Crude fat	2.35	3.71	3.85
Crude fiber	1.83	3.34	2.73
NDF	7.08	16.64	15.67
ADF	2.03	5.04	4.97
Total calcium	0.46	0.38	0.44
Total phosphorus	0.36	0.41	0.43

[1]Control = typical corn-soybean meal based diet; LS-DDG = control containing 20% low-solubles distiller's dried grains; and DDGS = control containing 20% distiller's dried grains with solubles.

[2]Supplemented the following amounts per kg of final diet: 8,820 IU vitamin A; 1,653.7 IU vitamin D_3; 33.1 IU vitamin E; 4.4 mg vitamin K; 38.6 mg niacin; 22 mg pantothenic acid; 6.6 mg riboflavin; 44.1 µg vitamin B_{12}; 60.6 mg zinc; 36.4 mg iron; 12.1 mg manganese; 3.6 mg copper; 1.1 mg iodine; and 0.3 mg selenium.

[3]ME values for corn and SBM from NRC (1998) and for LS-DDG and DDGS of 2,977 kcal/kg.

[4]Standardized Ileal Digestible (SID) lysine values for corn and SBM from NRC (1998), for LS-DDG = 0.57, and for DDGS = 0.73.

[5]Bioavailability of phosphorus for corn and SBM from NRC (1998) and for LS-DDG = 0.49, and for DDGS = 0.59.

Table 7. Digestible and metabolizable energy content of LS-DDG[1] and DDGS[2] (DM basis; Exp. 1)

Item	No. of pigs	DE, kcal/kg	SEM	ME, kcal/kg	SEM
LS-DDG at 30% of diet	8	3,213.7	74.99	3,068.4	100.18
LS-DDG at 40% of diet	8	3,169.2	74.99	2,895.2	100.18
LS-DDG at 50% of diet	8	3,312.2	74.99	2,911.9	100.18
Average LS-DDG	24	3,231.7[x]	74.99	2,958.5	100.18
DDGS at 30% of diet[3]	8	3,478.4	122.04	3,048.6	81.27
DDGS at 40% of diet	8	3,223.2	122.04	2,879.9	86.83
Average DDGS[3]	16	3,350.8[y]	122.04	2,964.3	81.27

[1]Low-solubles distiller's dried grains.
[2]Distiller's dried grains with solubles.
[3]ME value for one pig (DDGS30%) was not determined due to excessive volume of urine excreted.
[x,y] Within a column means with a different superscript tend to differ ($P < 0.10$).

Table 8. Effects of LS-DDG and DDGS levels on energy balance (DM basis; Exp. 1)

Item	Dietary treatments[1]						PSE	*P*-value[2]
	Control	LS-DDG 30%	LS-DDG 40%	LS-DDG 50%	DDGS 30%	DDGS 40%		
Number of pigs	8	8	8	8	8	8	---	---
Initial BW, kg	52.1	51.7	51.8	51.8	52.1	51.9	1.92	1.00
Final BW, kg	59.4	58.3	59.6	58.7	60.0	58.9	2.28	1.00
ADFI, kg	1.39	1.41	1.41	1.42	1.40	1.41	0.049	1.00
GE of diet, kcal/kg	4,418	4,650	4,827	4,890	4,711	4,797	---	---
GE intake, kcal/d	6,125	6,558	6,809	6,933	6,607	6,764	230.5	0.21
GE of feces, kcal/kg	4,793^{a}	5,007^{b}	5,102^{cd,y}	5,113^{d}	5,039^{bcd}	5,023^{bc,x}	20.60	< 0.01
Digestibility, %	84.9^{a}	77.3^{b}	73.0^{c}	72.3^{c}	78.0^{b}	73.9^{c}	0.58	< 0.01
DE of diet , kcal/kg	3,753^{a}	3,595^{bc}	3,525^{c}	3,537^{c}	3,672^{ab}	3,546^{c}	27.4	< 0.01
GE in urine, kcal/d[3]	171.7^{a,x}	199.9^{ab,wx}	273.2^{abc,xy}	377.4^{c}	300.7^{bc,yz}	308.1^{c}	24.93	< 0.01
ME of diet, kcal/kg[3]	3,615^{a}	3,455^{b,x}	3,333^{bc,y}	3,271^{c}	3,449^{b}	3,327^{bc,y}	31.3	< 0.01
N Balance, g/d	13.6^{ab}	15.9^{a}	13.5^{ab}	5.5^{b}	8.3^{ab}	5.2^{b}	2.25	< 0.01
Caloric correction, kcal/kg[4]	66.5^{ab,x}	77.7^{a}	66.0^{ab,x}	25.9^{b,y}	40.7^{ab}	26.0^{b,y}	10.32	< 0.01
ME_N of diet, kcal/kg[3]	3,548^{a}	3,376^{bc,xy}	3,267^{cd,z}	3,234^{d}	3,408^{b,x}	3,290^{bcd,yz}	20.28	< 0.01

[1]Control = typical corn-soybean meal based diet; LS-DDG30% = control containing 30% low-solubles distiller's dried grains; LS-DDG40% = control containing 40% low-solubles distiller's dried grains; LS-DDG50% = control containing 50% low-solubles distiller's dried grains; DDGS30% = control containing 30% distiller's dried grains with solubles; and DDGS40% = control containing 40% distiller's dried grains with solubles.

[2]Overall effect of dietary treatments.

[3]ME values for two pigs (Control = 1; DDGS30% = 1) were not determined due to excessive volume of urine excreted.

[4]Caloric correction = [N Balance, g/d × 6.77, kcal] ÷ ADFI, kg (Diggs et al., 1965).

[a,b,c,d] Within a row, means without a common superscript differ ($P < 0.05$).

[w,x,y,z] Within a row, means without a common superscript differ ($P < 0.10$).

Table 9. P-value of contrasts for energy balance of dietary treatments (DM basis; Exp. 1)

	LS-DDG[1]			DDGS[2]			LS-DDG 30%	LS-DDG 40%
Item	Linear	Quadratic	vs. Control	Linear	Quadratic	vs. Control	vs. DDGS 30%	vs. DDGS 40%
GE intake, kcal/d	0.01	0.50	0.02	0.06	0.57	0.05	0.88	0.89
GE of feces, kcal/kg	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.28	< 0.01
Digestibility, %	< 0.01	< 0.01	< 0.01	< 0.01	0.04	< 0.01	0.43	0.28
DE of diet , kcal/kg	< 0.01	< 0.01	< 0.01	< 0.01	0.50	< 0.01	0.05	0.59
GE in urine, kcal/d[3]	< 0.01	0.14	< 0.01	< 0.01	0.07	< 0.01	< 0.01	0.33
ME of diet, kcal/kg[3]	< 0.01	0.13	< 0.01	< 0.01	0.58	< 0.01	0.90	0.89
N Balance, g/d	0.01	0.03	0.45	0.01	0.69	0.02	0.02	0.01
Caloric correction, kcal/kg[4]	< 0.01	0.02	0.41	< 0.01	0.66	0.01	0.02	< 0.01
ME_N of diet, kcal/kg[3]	< 0.01	0.02	< 0.01	< 0.01	0.74	< 0.01	0.43	0.55

[1]Low-solubles distiller's dried grains.

[2]Distiller's dried grains with soluble.

Table 10. Effects of LS-DDG and DDGS levels on nitrogen balance (DM basis; Exp. 1)

Item	Dietary treatments[1]						PSE	*P*-value
	Control	LS-DDG 30%	LS-DDG 40%	LS-DDG 50%	DDGS 30%	DDGS 40%		
Number of pigs	8	8	8	8	8	8	---	---
ADFI, kg of DM	1.39	1.41	1.41	1.42	1.40	1.41	0.049	1.00
N Intake, g/d	31.3^{a}	46.1^{bc}	51.8^{cd}	55.2^{d}	44.1^{b}	48.0^{bc}	1.59	< 0.01
N Feces, g/d	7.0^{a}	$10.3^{b,x}$	$12.6^{c,z}$	$12.5^{bc,yz}$	$10.5^{bc,xy}$	$12.6^{bc,yz}$	0.55	< 0.01
N Digested, g/d	24.4^{a}	35.8^{bc}	39.2^{cd}	42.6^{d}	33.6^{b}	35.5^{bc}	1.23	< 0.01
N Digestibility, %	77.7^{a}	77.7^{a}	75.5^{ab}	$77.3^{ab,x}$	76.1^{ab}	$73.9^{b,y}$	0.80	0.01
N Urine, g/d	10.7^{a}	19.9^{b}	25.7^{bc}	37.2^{d}	25.3^{bc}	30.3^{cd}	2.10	< 0.01
N Balance, g/d	13.6^{ab}	15.9^{a}	13.5^{ab}	5.5^{b}	8.3^{ab}	5.2^{b}	2.25	< 0.01
N Retained, %	43.4^{a}	35.1^{ab}	26.5^{abc}	9.8^{c}	19.1^{bc}	11.3^{c}	4.59	< 0.01

[1]Control = typical corn-soybean meal based diet; LS-DDG30% = control containing 30% low-solubles distiller's dried grains; LS-DDG40% = control containing 40% low-solubles distiller's dried grains; LS-DDG50% = control containing 50% low-solubles distiller's dried grains; DDGS30% = control containing 30% distiller's dried grains with solubles; and DDGS40% = control containing 40% distiller's dried grains with solubles.

[2]Overall effect of dietary treatments.

[a,b,c,d] Within a row, means without a common superscript differ ($P < 0.05$).

[x,y,z] Within a row, means without a common superscript differ ($P < 0.10$).

Table 11. P-value of contrasts for nitrogen balance of dietary treatments (Exp. 1)

	LS-DDG[1]			DDGS[2]			LS-DDG 30%	LS-DDG 40%
Item	Linear	Quadratic	vs. Control	Linear	Quadratic	vs. Control	vs. DDGS 30%	vs. DDGS 40%
N Intake, g/d	< 0.01	< 0.01	< 0.01	< 0.01	0.03	< 0.01	0.38	0.10
N Feces, g/d	< 0.01	< 0.01	< 0.01	< 0.01	0.26	< 0.01	0.75	0.94
N Digested, g/d	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01	0.20	0.04
N Digestibility, %	0.32	0.27	0.34	< 0.01	0.75	< 0.01	0.17	0.18
N Urine, g/d	< 0.01	0.58	< 0.01	< 0.01	0.07	< 0.01	0.08	0.13
N Balance, g/d	0.01	0.03	0.45	0.01	0.69	0.02	0.02	0.01
N Retained, %	< 0.01	0.37	< 0.01	< 0.01	0.15	< 0.01	0.02	0.02

[1]Low-solubles distiller's dried grains.

[2]Distiller's dried grains with solubles.

Table 12. Effect of dietary treatment on overall growth performance (Exp. 2)

Item	Dietary treatments[1]			PSE	*P*-value
	Control	LS-DDG	DDGS		
No. of pens	8	8	8	---	---
No. of pigs[2]	71	70	71	---	---
Initial BW, kg	18.8	18.8	18.8	0.01	0.72
Final BW, kg	113.8	112.1	114.0	0.89	0.27
ADG, kg	0.88	0.86	0.88	0.011	0.38
ADFI, kg	2.32	2.35	2.39	0.039	0.41
G:F	0.380^{x}	0.367^{y}	0.370^{xy}	0.0041	0.08

[1]Control = typical corn-soybean meal based diet; LS-DDG = control containing 20% low-solubles distiller's dried grains; and DDGS = control containing 20% distiller's dried grains with solubles.

[2]Four pigs failed to complete the research due to premature death or injuries not associated with dietary treatments (χ^2 = 0.833E-01; P = 0.96).

[x,y]Within a row, means without a common superscript tend to differ ($P < 0.10$).

Table 13. Effect of dietary treatment on carcass characteristics (Exp. 2)

Item	Dietary treatments[1]			SEM	*P*-value
	Control	LS-DDG	DDGS		
No. of within-sex pen	16	16	16	---	---
No. of pigs[2]	67	61	66	---	---
Harvest wt, kg	114.4	113.8	115.2	0.83	0.48
Hot carcass wt, kg	84.5	82.9	83.8	0.68	0.26
Dressing, %	73.85^{a}	72.80^{b}	72.77^{b}	0.220	<0.01
Last rib back fat[3], cm	2.4	2.4	2.4	0.04	0.40
10^{th} rib loin depth[3], mm	62.5^{a}	60.5^{ab}	58.6^{b}	0.72	<0.01
10^{th} rib back fat depth[3], mm	12.9^{ab}	11.7^{a}	13.5^{b}	0.47	0.02
Adj. 10^{th} rib back fat depth[3,4], mm	15.5^{ab}	14.2^{a}	16.0^{b}	0.47	0.02
Lean[3], %	58.49^{ab}	58.97^{a}	57.65^{b}	0.295	0.01
Adj. lean[3,4], %	54.12^{ab}	54.83^{a}	53.43^{b}	0.328	0.02

[1]Control = typical corn-soybean meal based diet; LS-DDG = control containing 20% low-solubles distiller's dried grains; and DDGS = control containing 20% distiller's dried grains with solubles.

[2]Eighteen pigs, without association with dietary treatments (χ^2 = 1.73; P = 0.42), were not harvested because they did not reach the minimum required weight (104 kg) for harvesting without severe financial penalties.

[3]Means represent 65, 60, and 65 observations for Control, LS-DDG, and DDGS treatments, respectively.

[4]Measured fat depth increased by 2.54 mm to account for skin removal.

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

Table 14. Effect of dietary treatment on belly firmness (Exp. 2)

Item	Dietary treatments[1]			SEM	*P* - value
	Control	LS-DDG	DDGS		
No. of bellies[2]	15	15	16	---	---
Belly thickness, cm	1.6	1.6	1.5	0.12	0.61
Belly firmness score, degrees	$17.7^{a,x}$	$14.1^{ab,y}$	12.9^{b}	1.07	0.01

[1]Control = typical corn-soybean meal based diet; LS-DDG = control containing 20% low-solubles distiller's dried grains; and DDGS = control containing 20% distiller's dried grains with solubles.

[2]Two bellies were lost during processing with no association to dietary treatments ($\chi^2 = 0.13$; $P = 0.94$).

[a,b]Within a row, means without a common superscript differ ($P < 0.05$).

[x,y]Within a row, means without a common superscript differ ($P < 0.10$).

Table 15. Effect of dietary treatment on fat color scores (Exp. 2)

Item	Dietary treatments[1]			SEM	*P* – value
	Control	LS-DDG	DDGS		
No. of pigs	16	16	16	---	---
Back fat					
Minolta L*[2]	76.4	76.2	76.5	0.68	0.95
Minolta a*[3]	5.0	4.4	5.2	0.50	0.48
Minolta b*[4]	6.2	5.9	5.9	0.34	0.71
Japanese[5]	2.6	2.7	2.7	0.10	0.87
Belly fat[6]					
Minolta L*	78.4^{a}	76.8^{b}	77.9^{ab}	0.41	0.04
Minolta a*	3.2	2.9	3.4	0.33	0.56
Minolta b*	5.1	4.6	5.3	0.24	0.13
Japanese	2.0	2.1	1.9	0.12	0.40

[1]Control = typical corn-soybean meal based diet; LS-DDG = control containing 20% low-solubles distiller's dried grains; and DDGS = control containing 20% distiller's dried grains with solubles.

[2]Lightness scale: 0 = black to 100 = white.

[3]Redness scale: smaller number = green to greater number = red.

[4]Yellowness scale: smaller number = blue to greater number = yellow.

[5]Scale: 1 = pale to 4 = yellow.

[6]L*, a*, and b* Minolta color score could not be performed in one belly fat sample for LS-DDG.

[a,b]Within a row, means without a common superscript differ ($P < 0.05$)

Table 16. Effect of dietary treatment on fatty acid profile of belly fat (Exp. 2)

Item	Dietary treatments[1]			SEM	*P* – value
	Control	LS-DDG	DDGS		
No. of pigs[2]	15	16	14	---	---
Calculated:					
Iodine Value	57.82^{a}	63.12^{b,x}	64.95^{b,y}	0.525	<0.01
Mean melting point, ºC	33.14^{a}	31.25^{b}	30.68^{b}	0.220	<0.01
SFA[3], wt %	36.18^{a}	34.88^{b}	34.43^{b}	0.362	<0.01
MUFA[4], wt %	49.12^{a}	46.63^{b}	46.07^{b}	0.500	<0.01
PUFA[5], wt %	9.39^{a}	13.98^{b}	15.42^{c}	0.341	<0.01
Total UFA[6], wt %	58.54^{a}	60.62^{b}	61.48^{b}	0.470	<0.01
Omega-6:omega-3	19.51^{a}	25.03^{b}	25.97^{c}	0.224	<0.01
Fatty Acids, wt %					
C 10:0	0.03	0.04	0.05	0.008	0.27
C 12:0	0.02	0.02	0.03	0.006	0.48
C 14:0	1.28	1.24	1.24	0.026	0.49
C 16:0	23.24^{a}	22.39^{b}	22.01^{b}	0.186	<0.01
C 17:0	0.29	0.30	0.29	0.013	0.61
C 18:0	10.99	10.61	10.57	0.266	0.51
C 20:0	0.22^{a,x}	0.20^{ab,y}	0.19^{b}	0.006	0.02
C 16:1	2.95^{a}	2.69^{ab}	2.51^{b}	0.105	0.03
C 17:1	0.31	0.30	0.28	0.012	0.21
C 18:1	44.96^{a}	42.81^{b}	42.49^{b}	0.474	<0.01
C 20:1	0.90^{a}	0.83^{b}	0.79^{b}	0.023	<0.01
C 18:2	8.36^{a}	12.56^{b}	13.85^{c}	0.302	<0.01
C 20:2	0.40^{a}	0.59^{b}	0.63^{b}	0.018	<0.01
C 18:3	0.44^{a}	0.51^{b}	0.55^{b}	0.013	<0.01
C 20:3 omega-6	0.02^{a}	0.06^{b}	0.06^{b}	0.012	0.02
C 20:3 omega-9	0.02^{a}	0.03^{ab}	0.05^{b}	0.009	0.09
C 20:4	0.14^{a}	0.20^{b}	0.22^{b}	0.011	<0.01
C 22:4	0.02^{a}	0.04^{ab}	0.06^{b}	0.011	0.03
Omega-3	0.44^{a}	0.51^{b}	0.55^{b}	0.013	<0.01
Omega-6	8.53^{a}	12.84^{b}	14.18^{c}	0.310	<0.01

[1]Control = typical corn-soybean meal based diet; LS-DDG = control containing 20% low-solubles distiller's dried grains; and DDGS = control containing 20% distiller's dried grains with solubles.

[2]Three belly fat samples were not analyzed due to spoilage during storage, without association with dietary treatments ($\chi^2 = 0.35$, $P = 0.84$).

[3]Saturated fatty acids.

[4]Monounsaturated fatty acids.

[5]Polyunsaturated fatty acids.

[6]Unsaturated fatty acids.

[a,b,c]Within a row, means without a common superscript differ ($P < 0.05$).

[x,y]Within a row, means without a common superscript tend to differ ($P < 0.10$).

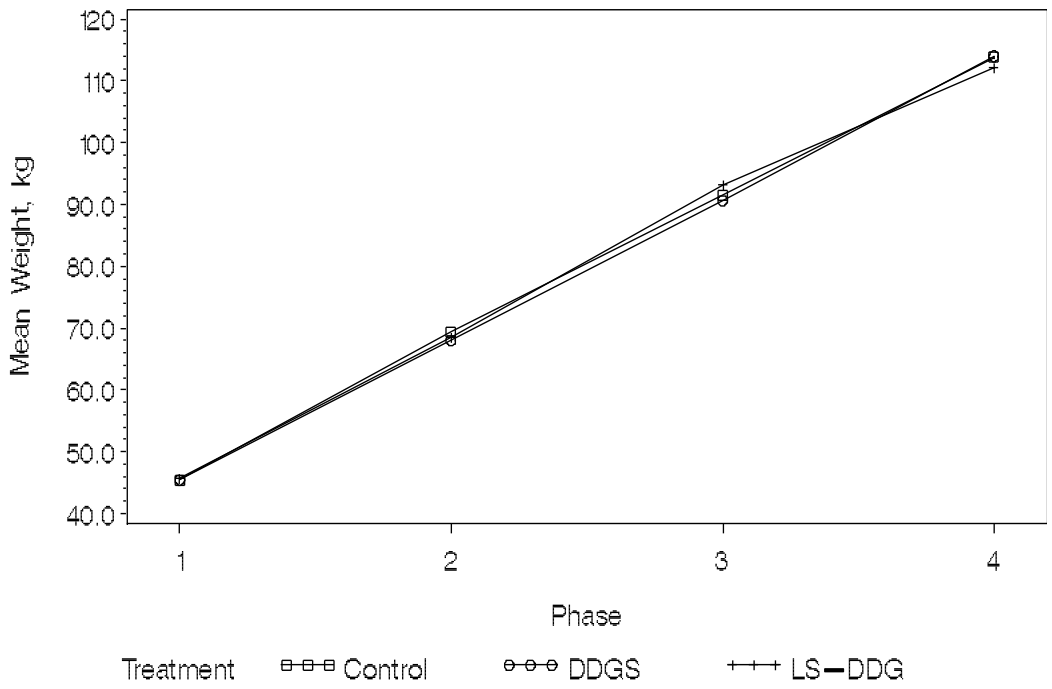

Figure 1. Effect of dietary treatment on BW at the end of each phase of the growing-finishing period (PSE = 0.750; *P* = 0.68; Exp. 2)

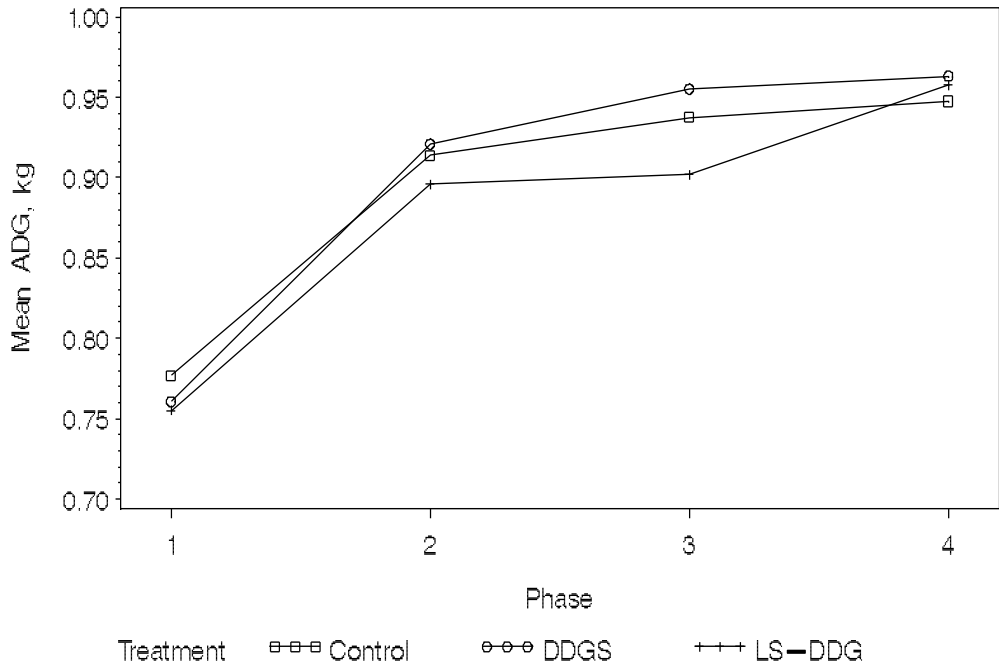

Figure 2. Effect of dietary treatment on ADG at each phase of the growing-finishing period (PSE = 0.024; *P* = 0.36; Exp. 2)

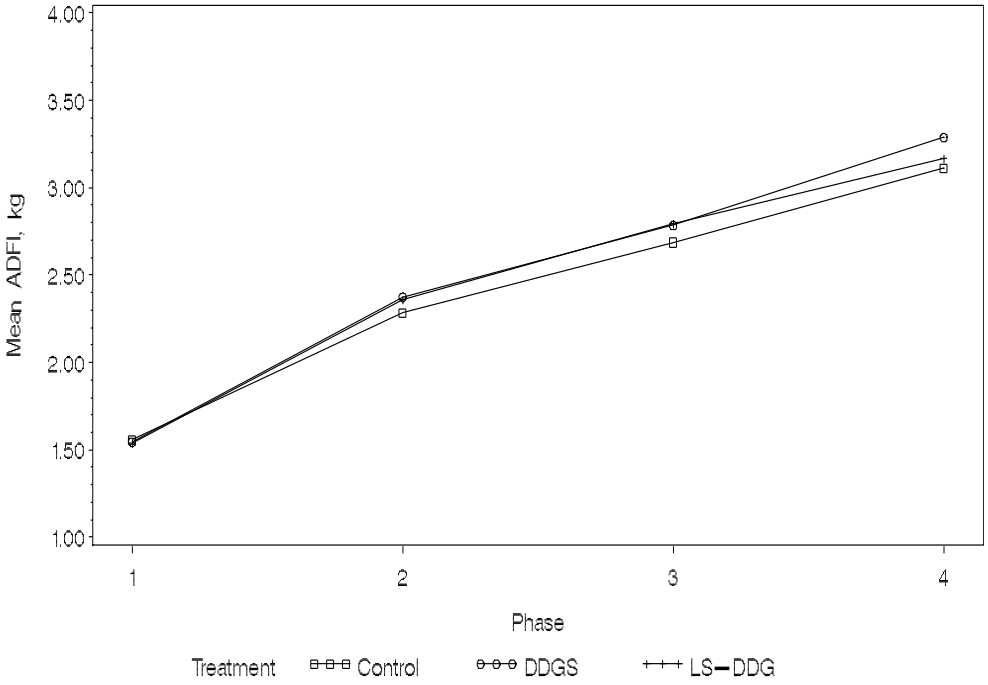

Figure 3. Effect of dietary treatment on ADFI at each phase of the growing-finishing period (PSE = 0.048; *P* = 0.28; Exp. 2)

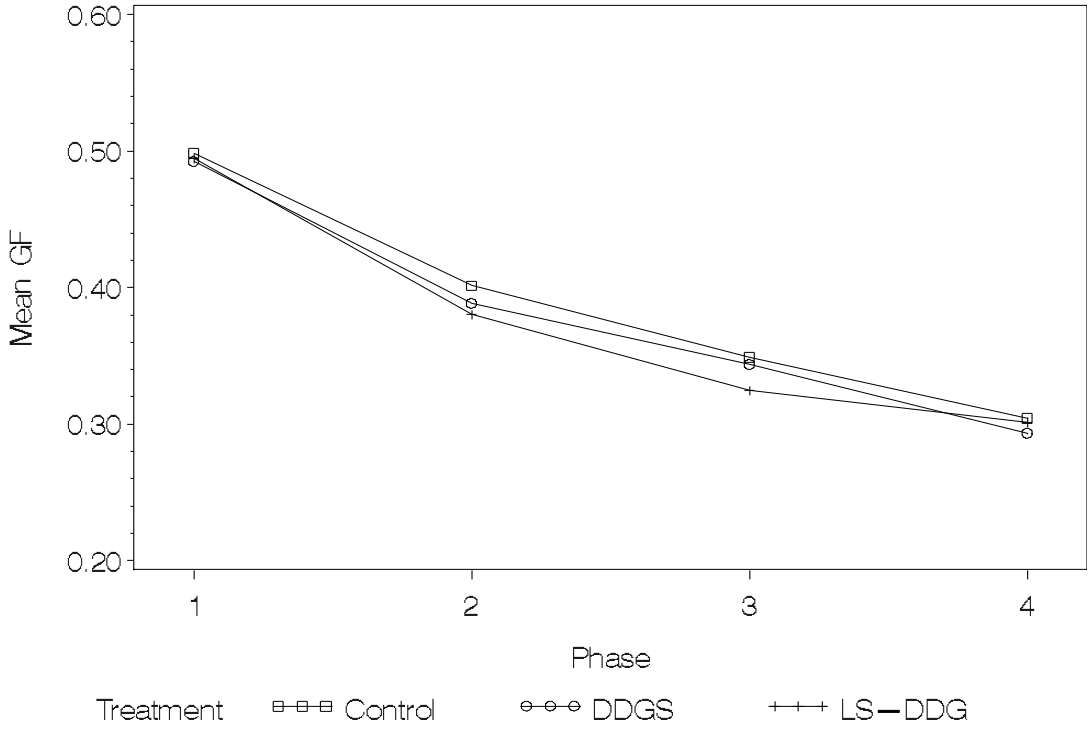

Figure 4. Effect of dietary treatment on G:F at each phase of the growing-finishing period (PSE = 0.008; *P* = 0.09; Exp. 2)

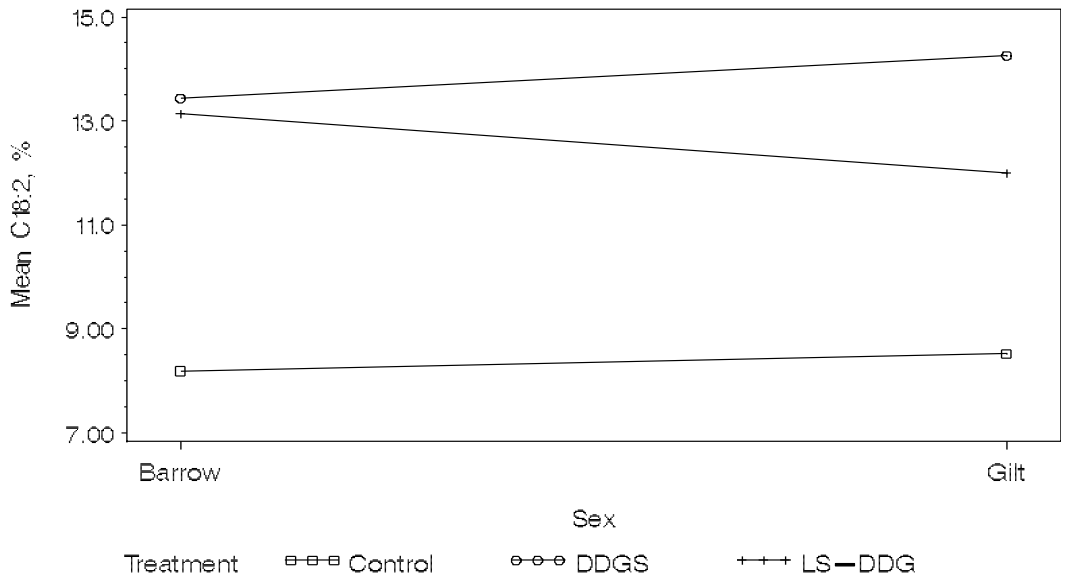

Figure 5. Interactive effect of dietary treatment and sex on linoleic acid (C18:2) content of belly fat (PSE = 0.288; *P* = 0.07; Exp. 2)

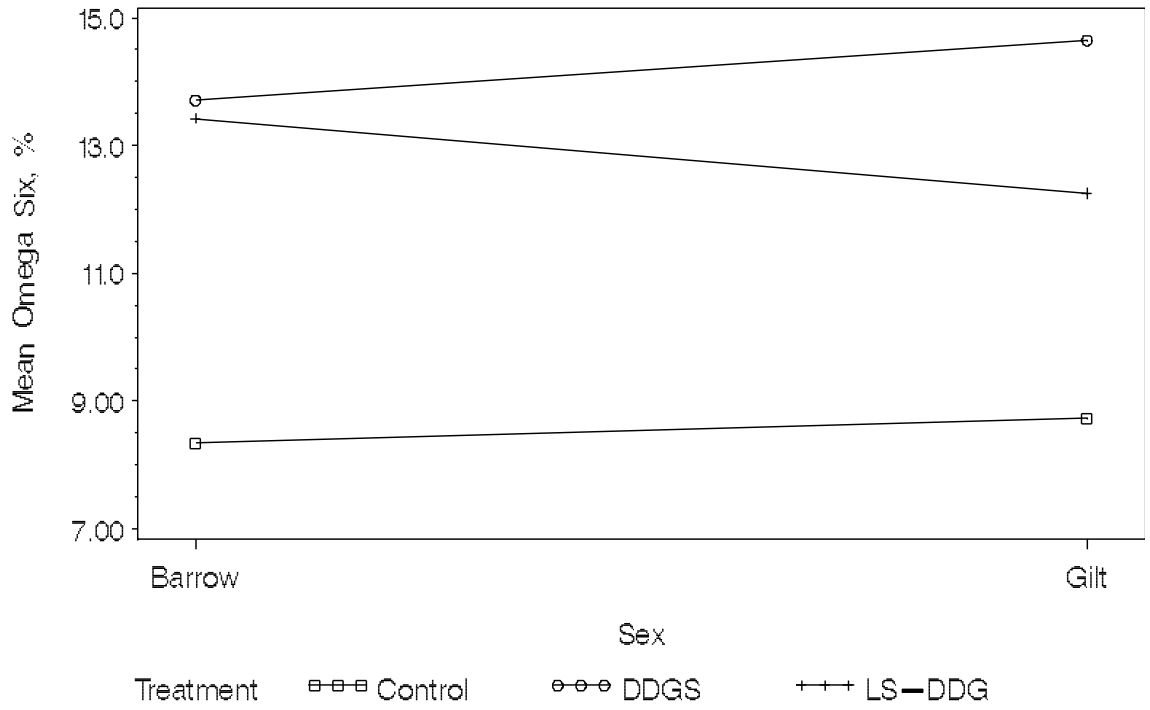

Figure 6. Interactive effect of dietary treatment and sex in the total amount of omega six fatty acids content of belly fat (PSE = 0.289; *P* = 0.05; Exp. 2)

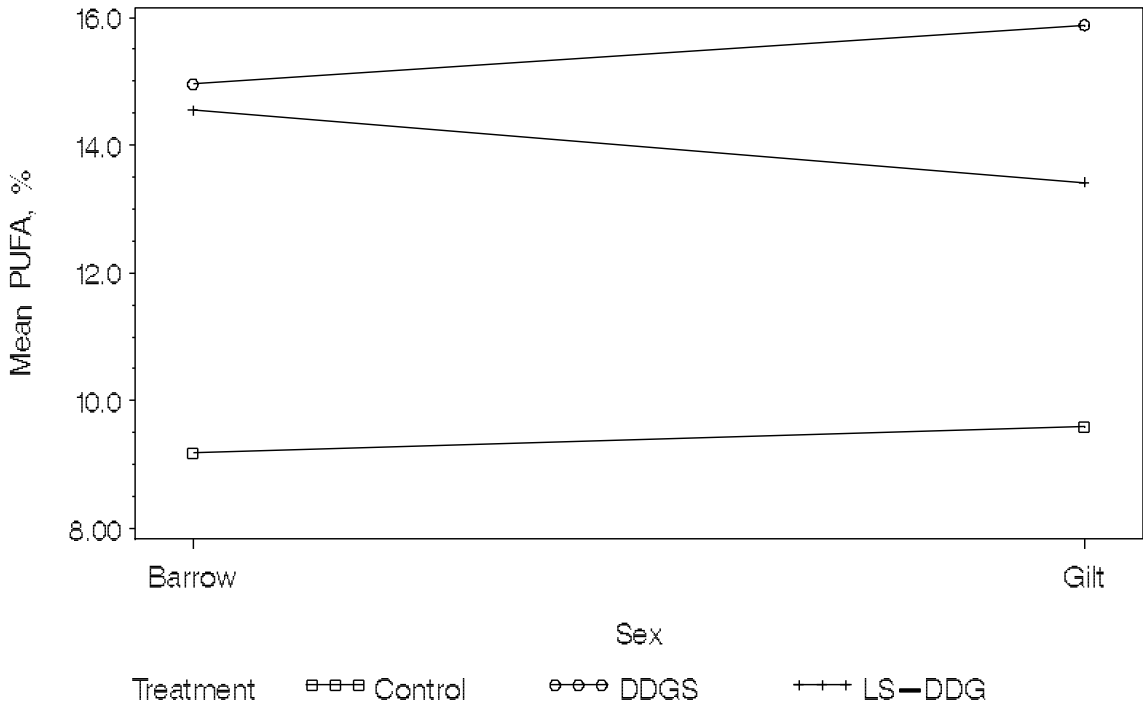

Figure 7. Interactive effect of dietary treatment and sex in the total amount of polyunsaturated fatty acids content of belly fat (PSE = 0.312; *P* = 0.08; Exp. 2)