FACTORS ASSOCIATED WITH VARIATION IN THE FATTY ACID COMPOSITION AND IODINE VALUE OF CARCASS FAT IN PIGS FED INCREASING LEVELS OF DRIED DISTILLERS GRAINS WITH SOLUBLES

BY

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THESIS

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ABSTRACT

The effect of fat sampling location, pig removal program (pigs taken off test at one time [Single-group] vs. pigs taken off test in 6 groups over time [Multiple-groups]), and experimental subsample size (number of pigs/pen selected for IV measurement [2, 4, 6, 8, 10, or 12 pigs]) on fat quality composition was evaluated in a study involving 1,632 pigs. The pigs were reared under commercial conditions from 23.4 ± 1.14 kg to 128.3 ± 2.15 kg BW in groups of 34 animals and were fed diets with a range of DDGS inclusion levels (0, 20, 40, 60%). At the end of the growth period, pigs were harvested at a commercial plant and fat samples were collected from the belly (anterior end), jowl (anterior end), backfat 1 (3^{rd} thoracic vertebra), and backfat 2 (clear plate). Fat composition was measured on subsamples of pigs from each pen. Fatty acid profile was measured using gas chromatography (GC). Iodine value (IV) was either predicted with an equation from AOCS (1998) based on unsaturated fatty acid profile from the GC analysis or measured using near infrared spectroscopy (NIR). Increasing DDGS level increased fat IV linearly for all sampling locations. Removal program had limited to no effect on fat composition and IV. IV measured using either GC or NIR were similar ($P > 0.05$) for all locations (Pearson correlation = 0.96). Jowl fat IV was higher ($P < 0.05$) compared to belly, backfat 1 and backfat 2 (5, 2, and 3 g/100g, respectively). The correlations between IV at the 4 sampling locations were relatively high (from 0.86 to 0.92). The development of equations using other sampling locations to predict belly fat IV indicated that using the IV of the fat from jowl, backfat 1, or backfat 2 would give similar precision of prediction of belly fat IV (R^2 = 0.78, 0.75, and 0.73, respectively). The DDGS inclusion level and dietary iodine value product (IVP) were highly correlated (i.e., 0.86 to 0.90) with fat IV for all sampling locations. For equations to predict the IV of fat at the sampling locations, DDGS inclusion level was the first variable

selected (e.g., jowl fat IV = DDGS level × 0.24 + 72.99; R^2 = 0.81). The inclusion of other variables resulted in little or no improvement in R^2. DDGS inclusion level was highly correlated with dietary IVP (0.99), so using DDGS inclusion level or dietary IVP to predict pork fat IV resulted in similar R^2 values. For Single- and Multiple-groups removal programs, a minimum subsample size of 2 and 4 pigs (closest to the mean pen BW) were needed to represent the mean and standard deviation, respectively, of fat IV. Results of this study can be used to appropriately design studies to evaluate fat composition under commercial conditions.

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CHAPTER 1: LITERATURE REVIEW

Introduction

The inclusion of dried distillers grains with solubles (DDGS) in swine diets is widely practiced in the U.S., as a consequence of the increased availability of this co-product of ethanol production from corn (Shurson et al., 2008). With the high costs of corn, DDGS have become an acceptable alternative to partially replace corn in swine diets. The impact of including DDGS in diets for growing-finishing pigs on carcass characteristics and fat quality traits has been investigated in a number of studies (Whitney et al., 2006; Shurson et al., 2008; Widmer et al., 2008; Stein and Shurson, 2009; Benz et al., 2010; Xu et al., 2010a and 2010b). In general, these studies have shown negative effects of feeding DDGS on fat quality (e.g., softer fat and change in color), even with inclusion levels as low as 10% (Benz et al., 2010). Recently, research has been focused on approaches to ameliorate these negative effects of DDGS inclusion, and, also, on developing reliable and economic methods to measure fat quality. This literature review will focus on fat quality measurements in pigs fed DDGS, including effects of sampling site and measurement methods.

DDGS Production and Composition

The production of DDGS has generally been increasing over recent years as ethanol production from corn has increased. In the U.S. in 2012, over 34 million tonnes of DDGS were produced from more than 200 ethanol plants (RFA, 2013) and a significant proportion of this is used in livestock feeds. The ethanol process involves the fermentation of corn starch into ethanol leaving the co-product of DDGS. Thus, DDGS contains all of the nutritional components of corn, other than starch, at higher concentrations than in the original corn (Bothast and Schlicher, 2005). For example, NRC (2012) reported concentration of crude protein, crude

fat and fiber were 8.2%, 3.7%, and 2.0%, respectively, for corn compared to 27.4%, 8.7%, and 8.9%, respectively, for DDGS.

One of the greatest challenges when using DDGS in animal nutrition is the variation in nutrient content between samples from different sources. This variation is the result of variation in the initial composition of corn used in the process together with variation in processing methodology and conditions (Shurson et al., 2008). For example, Stein and Shurson (2009) in a review of published studies suggested that the coefficient of variation of starch content of 46 samples of DDGS from different sources was 19%, and Mendoza (2013) analyzed the 17 sources of DDGS and showed that the range in crude protein and crude fat was from 27.8 to 32.2%, and from 8.2 to 11.5%, respectively. Similarly Martinez-Amezcua et al. (2007) compared 4 DDGS production methods that involved varying degrees of oil extraction from the DDGS and found that the crude fat content ranged between 5.4 to 15%. However, in this study there was no effect of production method on the fatty acid profile of the fat in the DDGS samples, indicating that the production process influenced the amount, but not the fatty acid profile, of the DDGS. This is an important finding when considering the impact of including DDGS in the diet on carcass fat composition and quality.

DDGS and Pork Fat Quality

Pork fat quality is defined according to physical and nutritive characteristics (Ellis and McKeith, 1999), which are mainly driven by the tissue fatty acid composition. Important quality characteristics of the fat, as consistency (firmness/softness), susceptibility to oxidation, and color are related to the proportion of poly-unsaturated fatty acids in the fat (especially linoleic acid). In contrast, firmer pork fat is related with the high content of palmitic and oleic acids, which traditionally can add up to 60% of the pork fat profile (Wood et al., 2004; 2008). In this

manner, the saturated, mono-unsaturated, and poly-unsaturated fatty acid balance will greatly determine important fat quality characteristics.

The importance of using DDGS in swine diets for fat quality relates to the high concentration of linoleic acid in this ingredient (approximately 55%). Major DDGS fatty acid concentrations are presented in Table 1.

Dietary fatty acids consumed by the pig will be absorbed in the gut and eventually will be bound to hepatocytes, adipocytes, or muscle fibers, where they will be either stored (deposited) or oxidized as an energy source (Bauer et al., 2005). This is particularly important since the poly-unsaturated fatty acids (mainly linoleic and α-Linoleic acids) present in the diet will be deposited into the adipose tissue of pigs (Ellis and McKeith, 1999; Rosenvold and Andersen, 2003; Wood et al., 2008). Therefore, pigs fed DDGS will have a high level of PUFA (Benz et al., 2010, 2011a, 2011b; Leick et al., 2010; Xu et al., 2010b; Duttlinger et al., 2012; McClelland et al., 2012). In addition, pigs are also capable of synthesizing some fatty acids (mostly saturated and mono-unsaturated; e.g., C16:0 and C18:1) from dietary carbohydrates and protein. This process is known as *de novo* fat synthesis (Kloareg et al., 2007); consequently, the higher the level of *de novo* synthesis and/or the lower the levels of PUFA in the diet, the lower the degree of unsaturation of the fat deposited in the carcass (Rosenvold and Andersen, 2003; Wood et al., 2004; 2008).

In addition, the rate of deposition of body fat in the pig is closely related with the fat quality of the carcass. As the rate of deposition of carcass fat decreases, less of the fat is derived from *de novo* synthesis and more is derived from the diet. Thus, leaner animals (e.g., gilts rather than barrows, and lean compared to fat genetic lines) will tend to have more unsaturated adipose

tissue (Madsen et al., 1992). The fat deposition rate of the carcass changes with age and differs between carcass locations. McMeekan (1940) described the relative rates of fat deposition at different carcass locations over the life of pigs, and found that during the late finishing period, pelvic fat had the greatest deposition rate compared to neck, thoracic and back fat (over the loin). However, this study was carried out many years ago and these findings may not apply to modern genotypes.

In summary, the fatty acid composition, and therefore the quality, of carcass fat in the pig is influenced by a number of factors, including the age and weight of the pigs, the rate of fat deposition, and, particularly, the diet fed.

Iodine Value and Methods of Measurement and Prediction

It has been proposed by some that iodine value (IV) could be used as an index of fat quality for use under commercial conditions because it measures the degree of unsaturation of fat. The IV is measured as the amount of iodine (grams) bound to 100 g of fat. When added to fat, halogens, including iodine, bind to the double bonds in unsaturated fatty acids; thus, the higher the IV, the higher unsaturated fatty acid content of the fat (Madsen et al., 1992).

Two methods have been traditionally used to determine IV, namely, direct measurement that is a chemical test that measures the amount of iodine that binds to 100 g of fat tissue, or indirect prediction using equations based on the unsaturated fatty acid profile of the fat. For the indirect method, the fatty acid profile is measured using gas chromatography (GC).

A commonly used equation to predict IV based on fatty acid profile is that of AOCS (1998) which is as follows:

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)

Both approaches to measuring or predicting IV have substantial disadvantages. Both are laboratory based and, in addition, the disadvantages of the direct method for measuring IV is that it involves the use of hazardous reagents and can produce considerable variability in results (Guillen and Cobo, 1997). The indirect method is based on GC which is expensive and labor intensive. Consequently, there has been interest in developing less expensive approaches to measuring IV, particularly of use under practical conditions. One technique that appears to offer considerable potential is the use of near-infrared spectroscopy (NIR) to measure IV (Gjerlaug-Enger et al., 2011). The major potential advantages of NIR as a potential tool to measure the IV (and potentially individual fatty acids) are that it is a rapid measurement, doesn't require the use of reagents, does not need highly trained personnel, and is relatively low cost.

There is limited published information on the use of NIR technology in comparison with other methods of measurement of IV. Ripoche and Guillard (2001) compared the Fourier transform infrared spectroscopy (FTIR) to GC for measuring individual fatty acids and found a strong relationship between NIR and GC IV values for total saturated fatty acids, total poly-unsaturated fatty acids, and oleic and linoleic acid concentrations ($R^2 > 0.94$); however, the relationship was weaker for total monounsaturated fatty acids, and palmitoleic acid concentration ($R^2 < 0.85$). More recently, Gjerlaug-Enger et al. (2011) did a calibration study with backfat samples from 112 pigs fed diets based on barley, oats, and soybean meal, and found an R^2 of 0.98 when predicting the fat IV with NIR compared to GC. In addition, Salyer et al. (2012) used NIR to measure jowl fat IV from pigs fed diets with 0 or 30% DDGS but did not compare the NIR with GC values.

Iodine Value Product

One of the problems with using IV as an index of the fatty acid composition of a diet is that it is a measure of the concentration of unsaturated fatty acids in dietary fat and not of the amount of unsaturated fatty acid in the diet. The impact of a diet on carcass fat composition will depend not only on the IV of the dietary fat but also on the amount of fat in the diet. An index that combines both, the amount of dietary fat and the IV of that fat, is the Iodine Value Product (IVP) which is calculated as follows:

IVP = % of ingredient lipids × iodine value of the lipids × 0.1 (Madsen et al., 1992).

The IVP is an index of the total unsaturated fatty acid content of ingredients and/or diets and is likely to be a better predictor of the impact of a particular diet on carcass fat quality than IV per se.

Factors Influencing the Iodine Value of Pork Fat

A number of factors associated with the animal (e.g., genotype, gender, live weight, feed intake, growth rate, fat deposition rate, etc.) could potentially influence the fatty acid composition of carcass fat in the pigs, and therefore, its IV. However, by far, the biggest influence on pork fat composition in most situations is likely to be the quantity and composition (i.e., fatty acid profile) of the dietary fat.

Relationship between dietary fat and pork fat composition. Several papers have evaluated the use of the dietary iodine value product (IVP) to predict the IV of pork fat. Dietary IVP combines both the IV and, also, the amount of the dietary fat; consequently, it should be a reasonable predictor of the likely effect of feeding the diet on carcass fat composition.

Madsen et al., (1992) developed a single-variable regression equation based on IVP per day (calculated by combining dietary IVP with daily feed intake) to predict the IV of backfat. The equation was as follows:

Backfat IV = 47.1 + 0.14 × IVP/day; R^2 = 0.86.

Bergstrom et al. (2010) carried out a meta-analysis involving 21 studies in which they developed an equation to predict the IV of carcass fat using the IVP as the only predictor variable. This equation had much lower precision of prediction than the equation of Madsen et al. (1992). The equation was as follows:

Backfat IV = 57.89 + 0.18 × IVP; R^2 = 0.58.

In addition, Benz et al. (2011a) compared diets formulated to have either high or low IVP and reported that the dietary linoleic acid concentration was a better predictor of the IV of backfat than dietary IVP. These results are similar to those of Gatlin et al., (2002) who showed that linoleic acid intake was a relatively accurate predictor of the linoleic content of backfat. In summary, there are inconsistencies in the published literature regarding the best index of dietary fat composition to use to predict the likely impact of feeding that diet on carcass fat composition and further research in this area is warranted.

Relationships between growth performance and carcass characteristics and pork fat composition. There has been relatively limited research that has evaluated the relationship between the growth performance and carcass characteristics and pork fat quality. Correa et al. (2008) compared pigs with low and high growth rates and found that faster growing pigs had higher belly fat IV, however, the difference was small. The equation to predict backfat IV selected by Bergstrom et al. (2010) included the average daily gain as one of the variables

because this helped explain some of the variation in carcass fat IV. Some other authors have used the average daily feed intake to estimate the daily intake of individual fatty acids or of IVP and have included these as predictor variables in equations (Madsen et al., 1992; Bergstrom et al., 2010; Benz et al., 2011b). The most common carcass measurement that has been related with pork fat quality is carcass leanness, normally measured as backfat thickness. Several studies have shown a negative relation between backfat thickness and carcass fat IV, with pigs with lower backfat thickness having higher carcass fat IV (Rosenvold and Andersen, 2003; Wood et al., 2004, 2008; Correa et al., 2008; Bergstrom et al., 2010). Although the backfat thickness is positively related to the live weight of the pig, with heavier pigs generally having greater backfat, the published relationships between live weight and carcass fat IV is inconsistent. For example (Fiego et al., 2005) reported strong correlations between live weight and carcass fat IV for relatively heavy pigs (i.e., harvested between 151.4 to 175.6 kg). However, Correa et al. (2008) did not find any difference in carcass fat IV for pigs of between 107 to 125 kg live harvest weight. Further research is required to clarify the relationship between carcass fat IV and growth performance and carcass characteristics.

Effect fat depot and pork fat composition. A number of studies have shown that fat IV varies between fat depots within the carcass. This is important when selecting the appropriate sampling location to use in a study or when comparing the results of different studies. Most studies have reported a higher IV for jowl fat compared to belly or backfat (Xu et al., 2010; Benz et al., 2011a, 2011b; Duttlinger et al., 2012). However, the differences between fat depots in these studies were relatively small and not always statistically significant. In addition, the reported relationships between the fatty acid composition of the various fat depots are not consistent. For example, Leick et al. (2010) reported a correlation between belly and jowl fat IV

of 0.39, while (Wiegand et al., 2011) reported *r* values from -0.62 to 0.50 for the correlations between 4 fat depots (including belly and jowl).

In conclusion, the relationships between animal and dietary factors and pork fat quality are complex because of the many variables potentially involved. Further research is needed to provide a clearer understanding of the dynamics of the fat quality development within a population of pigs.

Effect of Study Methodology on Fat Quality Measurements

One significant challenge when designing and carrying out swine studies related to pork fat quality is the applicability of the results to commercial situations. Many published studies on pork fat quality have been carried out at university research facilities with a limited number of animals, smaller group sizes, and much more controlled conditions compared to a commercial environment.

In addition, in many studies, pigs are commonly taken off test as an entire group either after a fixed time on test or at a fixed mean pen weight. However, under commercial conditions many producers send pigs for harvest in several groups from each pen starting with the heaviest pigs with the objective of minimizing variation in live weight at harvest weight. There are no studies in the literature that have compared the impact of removing pigs from test in multiple groups from each pen rather than as a single group.

Because of the relatively high cost of GC analysis of fatty acid profile, many studies carry out this analysis on a relatively small subsample of pigs from each pen. For example, many studies have used a subsample of the 2 pigs in the pen that are nearest to the pen mean body weight to measure fat quality, which in some cases represents a very small proportion of

the total pigs used in the study (often less than 10% of the pigs) (e.g., Correa et al., 2008; Widmer et al., 2008; Benz et al., 2010; Xu et al., 2010a; Benz et al., 2011a, 2011b; Dahlen et al., 2011; Duttlinger et al., 2012). Obviously, such an approach minimizes the variation in weight in the subsample of pigs used for fat quality evaluation compared to that in the entire population. The minimum size of a subsample of pigs from a pen to accurately represent the pen has not been evaluated.

The rearing conditions (e.g., commercial) and sampling procedures could influence the results on pork fat quality measured through IV. The variation of the IV within a pen could also be impacted by the approach used to finish a study. These aspects require further research.

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TABLES

Table 1. Fatty acid composition of dried distillers grains with solubles.

Fatty acid	Martinez-Amezcua et al. (2007)	Widmer et al. (2008)	Benz et al. (2010)
Palmitic acid (16:0), %	12.77	13.40	14.53
Stearic acid (18:0), %	2.03	2.37	2.12
Oleic acid (18:1 cis-9), %	23.17	27.00	26.53
Linoleic acid (18:2n-6), %	56.26	52.80	52.53
α-Linolenic acid (18:3n-3), %	1.48	1.38	1.50
Arachidic acid (20:0), %	0.39	0.45	0.46
Other fatty acids, %	3.90	2.60	2.33

CHAPTER 2: FACTORS ASSOCIATED WITH VARIATION IN THE FATTY ACID COMPOSITION AND IODINE VALUE OF CARCASS FAT IN PIGS FED INCREASING LEVELS OF DRIED DISTILLERS GRAINS WITH SOLUBLES

INTRODUCTION

The fatty acid composition of the pork fat is highly influenced by the composition of the diet fed to pigs. Some of the fatty acids present in the diet, particularly the polyunsaturated fatty acids, are directly deposited in the pig adipose tissue and this can have a substantial effect on the degree of unsaturation and quality of the carcass fat (Ellis and McKeith, 1999). The use of DDGS (a co-product from the ethanol industry with high oil content; from 5 to 12% crude fat; NRC, 2012) in swine diets in the U.S. has brought some challenges to packers related to fat quality because the fat in DDGS has a high content of unsaturated fatty acids (especially linoleic acid), which will increase the unsaturation level of pork fat. High concentration of unsaturated fatty acids in adipose tissue has been related with softer fat, which can cause processing problems and reduced product yields and, also, is more susceptible to oxidation which can reduce the keeping quality and shelf life of products.

There has been a considerable amount of research carried out to date that has focused on evaluating the fat quality of pigs fed increasing levels of DDGS (Stein & Shurson, 2009; Leick et al., 2010; Xu et al., 2010a; Benz et al., 2011; Duttlinger et al., 2012; McClelland et al., 2012); however, there is limited published information available that has evaluated potential relationships between fat quality and carcass characteristics, across different locations within the carcass of the pig. In addition, fat tissue characteristics vary across the carcass (Rosenvold and Andersen, 2003; Wood et al., 2008; Benz et al., 2010), however, this area has not been widely studied in contemporary genotypes reared under typical commercial conditions in the US.

Other potential limitations of the published research in this area include the small number of animals (i.e., fat samples) that are normally used to measure fat quality within any study (often less than 10% of the pigs used in the study). In addition, it is common practice in research studies to take all of the pigs within a pen off test at the same time, when the target mean pen weight has been reached. However, in practice pens of pigs are often sent for harvest in multiple groups. The impact of sample size used for fat quality evaluation and of the approach used to take pens of pigs off test has not been evaluated. Such information is important when designing studies to measure fat composition and quality.

Thus, the objectives of this study were to determine the relationships between diet characteristics, carcass characteristics and fat composition at 4 sampling locations in the carcass, to develop equations to predict the IV of pork fat at each sampling location, and to evaluate the impact of sample size used to measure IV and end of study procedures (i.e., pig removal program) on the IV of pork fat. The fat samples used in this study were taken from the experiment reported by Hardman (2013) where pigs had been fed increasing levels of DDGS, reared under commercial conditions, and taken off test using two pig removal programs.

MATERIALS AND METHODS

The fat samples used in this study came from animals that were part of a larger study previously reported by Hardman (2013). The animals used in the study were raised at the Georgia Technology Center of The Maschhoffs, LLC located near Carlyle, IL, which is a standard commercial wean-to-finish facility that is equipped to collect data on growth performance and feed intake under typical commercial conditions. The protocol for this experiment was approved by the University of Illinois Institutional Animal Care and Use Committee prior to the start of the study.

Experimental Design and Treatments

This study was conducted as a randomized complete block design and evaluated 6 treatments that involved a combination of 4 DDGS dietary inclusion levels and 2 pig removal programs as follows:

1) 0% DDGS, all pigs within a pen were taken off-test at the same time [Single-group]
2) 0% DDGS, pigs within a pen were taken off-test in 6 groups over time [Multiple-groups]
3) 20% DDGS, Single-group
4) 40% DDGS, Single-group
5) 40% DDGS, Multiple-groups
6) 60% DDGS, Single-group

Diets

Diets were fed in pellet form and contained either 0, 20, 40 or 60% DDGS according to treatment, and a 5-phase dietary program was used according to a feed budget as follows:

Phase 1, feed budget 45.4 kg/pig (approximate BW range fed 22.7 – 45.4 kg)

Phase 2, feed budget 52.2 kg/pig (approximate BW range fed 45.4 – 68.0 kg)

Phase 3, feed budget 63.5 kg/pig (approximate BW range fed 68.0 – 90.7 kg)

Phase 4, feed budget 56.7 kg/pig (approximate BW range fed 90.7 – 108.9 kg)

Phase 5, feed budget 63.5 kg/pig (approximate BW range fed 108.9 – 129.3 kg)

Prior to diet manufacture, proximate and amino acid analyses were carried out on the DGGS, corn, and soybean meal that were used to make the diets (Table 2). Within each dietary phase, diets were formulated to be iso-caloric and to the same standardized ileal digestible (SID) Lysine:Calorie ratio. The inclusion level of yellow grease was varied across diets to maintain the same ME level at the different DDGS inclusion levels. The composition and fatty acid profile of diets are presented in Tables 3 to 6.

Allotment

The study involved a total of 1,632 crossbred pigs (progeny of PIC 359 sires mated to PIC C22 or C29 dams). Allotment was carried out at a live weight of 23.4 ± 1.14 kg. A replicate consisted of 6 pens (1 pen/treatment). A total of 48 mixed-gender pens of 34 pigs (17 barrows and 17 gilts) were weighed and formed into outcome groups of 6 pens of similar weight. Pens were randomly allotted to treatment from within each outcome group.

Housing

Pigs were housed in 3 rooms of a tunnel ventilated barn which had fully slatted concrete flooring. Pen divisions consisted of gates with horizontal steel rods, and adjustment gates were located in the back of each pen; in the event of pig death or removal, pen dimensions were adjusted to maintain the same floor space/pig. Each pen was equipped with either one 5-hole wet/dry box feeder or one 4-hole dry tube feeder. Pigs had *ad libitum* access to feed and water throughout the study period.

Growth Measurements

Pen weights were taken at the start of the study and every 2 weeks during the study period. All feed additions and the feed remaining in the feeder were recorded at the time of pig weighing to calculate ADG, ADFI, and G:F. At the end of test (day prior to shipment for harvest), pigs were individually weighed and a transverse ultrasound scan was taken at the 10th rib; backfat depth (over the middle of the *Longissimus* muscle) and *Longissimus* muscle depth were measured on the scan.

End of Test and Harvest

Pens of pigs on the Single-group removal program were taken off-test when the average live weight of the pen reached 128.7 ± 1.96 kg. The first (heaviest) pigs from pens on the Multiple-groups removal program were taken off-test when the average live weight of the pen reached 113.4 ± 2.27 kg, and subsequently, the next heaviest pigs were taken off-test every 7 days according to the following schedule:

Week 1 = heaviest 10% of pigs taken off-test and sent for harvest

Week 2 = heaviest 20%

Week 3 = heaviest 20%

Week 4 = heaviest 20%

Week 5 = heaviest 10%

Week 6 = lightest 20%

After pigs were taken off-test they were held overnight in their original pens with access to feed and water, and on the following day were transported for harvest on a standard trailer (with loads of 165 pigs/each) to Hormel Foods Corporation in Austin, MN.

Fat Samples

Fat samples were collected at the plant on the slaughter line from 4 carcass locations: belly (at the anterior end of the belly), jowl (at the anterior end of the jowl at the site of head removal), and two backfat locations designated as backfat 1 (at the adjacent area of the 3rd thoracic vertebra) and backfat 2 (from the clear plate). Fat samples were kept frozen (-20°C) until analyzed.

Subsamples of Pigs Selected and Carcass Characteristics

Three subsamples of pigs were selected and used for fat quality measurements as follows:

a) Subsample 1: This subsample was used for near-infrared spectroscopy (NIR) analysis of fat iodine value (IV) on each of 4 sampling locations and comprised of 862 pigs (approximately equal numbers of barrows and gilts) representing approximately half of the pigs in the pen (15 to 18 pigs/pen) selected to have the same mean and variation in live weight as the entire pen.
b) Subsamples 2 and 3: These subsamples were used for gas chromatography (GC) analysis of the fatty acid profile and IV determination of fat samples.
    i. <u>Subsample 2:</u> Consisted of fat samples (from the jowl, backfat 1 and backfat 2) from the 2 pigs/pen (1 barrow and 1 gilt) that were closest to the pen mean live weight.

ii. Subsample 3: Fat samples from the belly were not collected for Subsample 2 and, therefore, another subsample was selected that consisted of fat samples (from the belly, jowl and backfat 1) from the 2 pigs/pen (1 barrow and 1 gilt) that were closest to the pen mean live weight (excluding those pigs used in Subsample 2).

Hot carcass weight and midline backfat thickness at the last rib were taken on the slaughter line.

Fatty Acid Analysis and Iodine Value Determination

GC analysis: The fatty acid profile of the fat samples was determined using GC HP 5890 Series II with HP Chemstation (column: DB-WAX 30 m × 0.25 mm × 0.25 μm capillary; Agilent Technologies, Santa Clara, CA). Iodine value was predicted based on the unsaturated fatty acid content using the AOCS (1998) equation: IV = C16:1(0.95) + C18:1(0.86) + C18:2(1.732) + C18:3(2.616) + C20:1(0.785) + C22:1(0.723).

NIR measurement: Iodine value was measured through near-infrared spectroscopy (Model Bruker MPA; Bruker Optics, Billerica, MA). Each fat sample was prepared by removing the skin and lean tissue (if any). Subsequently, a portion of the subsample (dimensions of 2 cm × 2 cm) was cut and homogenized using a kitchen chopper (Rival® 1.5 cup), and the homogenized tissue was transferred to a glass petri dish and left at room temperature until it reached 4 to 6°C. Once the desired temperature was reached, the sample was placed on the NIR machine for IV measurement.

Statistical Analysis

All data were tested for normality using the PROC UNIVARIATE procedure of SAS (SAS Institute Inc., Cary, NC). The individual pig was used as the experimental unit for carcass and fat quality measurements. The model included the fixed effects of DDGS inclusion level, pig removal program, sex, sampling location, and the two-way, three-way, and four-way interactions, and the random effects of block (room) and replicate nested within block. Data meeting the criteria for analysis of variance were analyzed using the PROC MIXED procedure of SAS. Least-squares means were compared using the PDIFF option of SAS. Contrast statements were used to test the difference between pig removal programs (Single-group vs. Multiple-groups). Correlation analysis between sampling location, dietary IVP, carcass characteristics, and fatty acid profile (including IV), was carried out using the PROC CORR procedure of SAS. Regression analysis was carried out using the PROC REG procedure of SAS, and the stepwise selection option was used to select prediction equations. Models were developed for fat IV as the dependent variable. The equations were chosen based on the adjusted R^2 and residual RMSE, selecting the equation with the highest adjusted R^2 and lowest RMSE involving the fewest number of variables.

RESULTS AND DISCUSSION

Growth performance, carcass characteristics, and fat composition

The pigs used in this study came from an experiment that had the primary objective of evaluating the effects of dietary DDGS inclusion level, and pig removal program on growth performance, carcass characteristics, and fat quality of finishing pigs. The results of this experiment were presented and discussed by Hardman (2013). The current study uses material

from the experiment of Hardman (2013) to further evaluate fat quality characteristics. In this section, a summary of the results from this experiment for growth performance, carcass characteristics, and fat quality, are presented here for information purposes and to provide a background for the further analyses carried out as part of the current study.

A summary of the overall effects of DDGS inclusion level and pig removal program on the growth performance and carcass characteristics, and on fat composition are presented in Table 7 and 8, respectively.

Increasing the dietary inclusion level of DDGS from 0 to 40% was associated with reductions in average daily gain, carcass yield, and backfat depth, with no effect on feed efficiency (Table 7). In addition, the proportion of saturated and monounsaturated fatty acids of belly fat generally decreased and the proportion of polyunsaturated fatty acids generally decreased with increasing levels of DDGS (Table 8). Generally speaking, taking pigs off test in one compared to six groups had limited effects on growth, carcass, and fat composition measures (Tables 7 and 8). Specific components of these data will be subjected to further analysis in this thesis and will be discussed more fully at that stage.

Descriptive statistics

Descriptive statistics for carcass measures (live animal ultrasound and post mortem carcass) for all pigs sent for harvest and for Subsamples 1, 2 and 3 are presented in Table 9 with those for fatty acid profile and IV being presented in Table 10.

The average harvest live weight for all pigs sent for harvest was 128.3 ± 9.72 kg, with a range from 92.1 to 156.9 kg. Subsamples 1, 2 and 3 were selected from this population of pigs as follows:

Subsample 1. NIR IV was measured on 3,123 fat samples (from 862 pigs; approximately half of the pigs in each pen). The average harvest live weight of these pigs was 128.0 ± 9.05 kg, which was similar to that for all of the pigs sent for harvest. The average NIR IV was 74.2, 79.4, 77.7, and 75.5 g/100 g for belly, jowl, backfat 1, and backfat 2, respectively (IV SD was 6.71, 6.04, 7.11, and 7.25 g/100 g, respectively). These pigs also showed considerable variation in carcass fat levels; for example, mean backfat thickness at the last rib was 1.1 ± 0.18 cm with a range from 0.5 to 1.7 cm.

Subsample 2. Fat samples (jowl, backfat 1, and backfat 2) from 91, 85, and 74 pigs, respectively, were used for GC analysis. The average harvest live weight for these pigs was 128.2 ± 2.72 kg. The 2 pigs in each pen closest in weight to the pen mean were selected for this subsample and, therefore, it was expected that the average weight would be close to the population mean and that the SD in weight would be substantially lower than for all pigs sent for harvest. The mean NIR IV for jowl, backfat 1 and backfat 2 were 78.7, 78.1 and 75.7 g/100 g, respectively (IV SD was 5.99, 7.26, and 7.49 g/100 g, respectively), which were similar to the values found for Subsample 1 at these locations. Even though these pigs were closer in BW, the variation in backfat thickness (mean = 2.8 ± 0.46 cm) was still relatively high compared to Subsample 1, which ranged between 1.8 to 4.3.

Subsample 3. Fat samples (belly, jowl and backfat 1) from 85, 86 and 80 pigs, respectively, were analyzed for fatty acid profile using GC. The mean harvest live weight was 128.3 ± 4.49 kg, similar to that for Subsamples 1 and 2, however, the standard deviation was greater than for Subsample 2. The intention was to select 2 pigs from each pen for this subsample that were close to the population mean. However, not all pigs had fat samples from all 3 locations available for analysis and the greater variation in harvest weight in Subsample 3

compared to Subsample 2 reflects that pigs with a wider variation in weight had to be used. The NIR IV values were also similar to those found for Subsample 1 on belly, jowl and backfat 1 samples, which were 74.2, 79.7, and 78.0 g/100 g, respectively (IV SD was 6.72, 5.71, and 6.72 g/100 g, respectively). The backfat thickness for this group of pigs was similar to that for Subsample 2, with a mean of 2.8 ± 0.43 and range between 1.8 to 3.8.

The objective of the sampling procedures used in this study was to select pigs that would exhibit a wide range of carcass fat levels and fat fatty acid profiles that would be appropriate to evaluate the relationships between the fatty acid profile of the various pork fat depots and in between carcass measurements and FA profile. On the basis of the descriptive statistics discussed above it would appear that the sampling procedures achieved this objective.

Effects of the pig removal program on fat quality

Least squares means for the effects of DDGS inclusion level, pig removal program, sex, and sampling location on fat composition for Subsample 1, which involved approximately half of the pigs on the study and Subsamples 2 and 3, which involved 2 pigs per pen each, are presented in Tables 11 and 12, with the *P*-values for all main effects and interactions being presented in Tables 13 and 14. Generally speaking, there were relatively few treatment interactions and those that were statistically significant were of limited, if any, practical significance. Therefore, the presentation and discussion of the results will focus on the effects of the treatments.

Effect of DDGS Inclusion Level. The effect of DDGS inclusion level on fat quality and composition (Tables 11 and 12) was similar for all three subsamples. The fat IV was approximately 11 points higher for pigs fed diets containing 40% DDGS compared to those fed diets with 0% DDGS. This increase in IV was largely due to increases in PUFA, particularly,

linoleic acid. These results are similar from those found in previous research (Whitney et al., 2006; Benz et al., 2010; Leick et al., 2010; Xu et al., 2010 and Benz, et al., 2011), confirming the potential impact of feeding DDGS on pork fat composition.

Effect of Pig Removal Program. Subsamples 1 and 2 showed no effect ($P > 0.05$) of the pig removal program on the IV of pork fat. However, for Subsample 3, the pigs taken off test in one group had higher fat IV (approximately 2 g/100g) than those taken off test in 6 groups (Table 11). This difference between removal strategies in IV in Subsample 3 (Table12) is most likely the result of sampling error, particularly as there was no difference ($P > 0.05$) between removal programs for Subsample 1 which was based on a much larger subsample of the pigs used in this study. This difference between the subsamples in the effect of a treatment highlights the importance of using a representative subsample of pigs for all measurements; this will be discussed further in a subsequent section of this thesis.

Effect of Sex. Overall there was no difference on the fat IV between sexes for Subsamples 2 and 3 (Tables 11 and 12). In contrast, in Subsample 1, gilts had a higher ($P < 0.05$) IV (approximately 1.5 g/100g) compared to barrows. Correa et al. (2008) and Benz et al. (2010) also found that the IV of belly fat was greater for gilts than barrows, however, in those studies there was no difference between barrows and gilts for the IV of jowl or backfat. Nevertheless, the results from the present study did not show any interaction between sex and fat sampling location (Tables 13 and 14).

Effect of Sampling Location. For all three subsamples, the jowl fat had the greatest ($P < 0.05$) IV compared to the other 3 fat locations with the differences relative to the jowl fat resulting in approximately 6, 3, and 4 g/100g IV for belly, backfat 1, and backfat 2, respectively.

Backfat sample1, which was taken at the 3rd thoracic area, had higher IV values that backfat sample 2, which was taken at the clear plate area. This result is somewhat surprising given that the two sampling locations for the backfat samples were relatively close together and highlights the importance of accurately defining the location from which fat samples are obtained in any study.

The total PUFA content was relatively similar for jowl and backfat samples, with the major difference between these sampling locations being due to an increase in total MUFA and a reduction in total SFA for the jowl. For belly fat, total PUFA concentration was lower compared to the other sampling locations, largely because of lower linoleic acid content, indicating that the jowl and backfat sampling locations were more unsaturated, general speaking, compared to belly fat. It is important to consider these differences in the fatty acid composition of the various sampling locations when designing studies and, also, when interpreting the results from other studies.

In summary, this study showed a major effect of dietary DDGS inclusion level and important effects of sampling location on fatty acid profile and iodine value. However, removal program and sex had limited effects on fat composition.

Relationships between IV and other measurements

Correlations Between IV at the 4 Sampling Locations: Pearson correlations between NIR IV values at the 4 sampling locations used in this study are presented in Table 15. The data used in this analysis was from Subsample 1 which consisted of fat samples taken from approximately half of the pigs in each pen (15 to 18 pigs per pen with approximately equal numbers of barrows and gilts from each pen). The comparison of IV at various locations in the carcass is practically

important because it could influence the choice of sampling sites to use. Ideally, samples to measure fat composition should be taken from the area of the carcass of interest, which, under U.S. conditions, is the belly. However, obtaining samples from the belly on the slaughter line is relatively difficult and could devalue the carcass. In contrast, the jowl is more accessible than the belly, and obtaining a sample from that area of the carcass is relatively simple and is unlikely to result in any carcass devaluation.

In general, correlation coefficients for IV between fat sampling locations for the present study were relatively high with correlations ranging between 0.86 to 0.92 (Table 15). The correlations between IV of jowl and backfat (0.92 and 0.90 for Backfat 1 and 2, respectively) were stronger than those between jowl and backfat on the one hand and belly fat on the other (0.88, 0.86, and 0.86 for jowl, and Backfat 1 and 2, respectively). However, the differences between correlation coefficients were relatively small and of limited practical significance. These results, therefore, suggest that the fatty acid composition of any 1 of the 4 sites used in this study is strongly related to that of the other sites. This is important when choosing sampling sites for future studies because it suggests that using an accessible and low value site such as the jowl will give results that will be applicable to other potential sampling sites in the carcass.

These results are in contrast to those of Leick et al. (2010) and Wiegand et al. (2011) that showed relatively weak correlations between the IV of jowl and belly fat (0.39 and -0.67 to 0.50 and 0.50, respectively).

However, Bergstrom et al. (2010) conducted a meta-analysis involving 6 studies and found that the correlation between the IV of belly and jowl fat was 0.88, which is in agreement with the results of the current study. One potential reason for this difference between studies in

the strength of correlations between IV of fat from different locations in the carcass is the material that is used to generate the correlations. In the current study, the range in IV values of the samples evaluated was large (which for belly fat ranged from 59.3 to 91.2, Table 10, Subsample 1), largely because of the wide range of DDGS levels fed to the pigs. Further research is needed to clarify the relationship between fatty acid composition and IV from various locations within the carcass.

Correlations between NIR and GC IV: The correlations between IV measured using NIR and predicted from GC fatty acid profile (using the equation of AOCS, 1998) for Subsamples 2 and 3 are presented in Tables 16 and 17, respectively. These 2 subsamples had 2 pigs (1 barrow and 1 gilt) from every pen on the study. In general, correlations were similar for both subsamples and were strong. This suggests that NIR is an appropriate technique for measuring IV of homogenized fat samples which is important given that NIR is a relatively rapid and inexpensive measurement method compared to GC analysis. There have been no previous published studies that have compared these two methods under U.S. conditions. However, Gjerlaug-Enger et al. (2011) and González-Martín et al. (2003) also reported high correlations between IV determined using NIR and GC analysis on fat samples of pigs reared under commercial conditions in Spain and Norway, respectively. Thus, NIR could be a useful technique to rapidly measure IV that could be used in packing plants.

Correlations between Dietary and Animal Measures and NIR IV: Correlations between a number of dietary and animal measures and NIR IV are presented in Table 18. These correlations were developed from the data in Subsample 1 which included approximately half of the pigs on the study. In general, correlations were similar for the 4 sampling locations and, therefore, only those for the pooled fat sample locations will be discussed. Correlations between

the dietary measures [DDGS inclusion level (i.e., dietary treatment); Mean dietary IVP (i.e., mean of all 5 dietary phases); Phase 5 dietary IVP (i.e., the final dietary phase)] and NIR IV were high and similar (0.82 to 0.85). This is not surprising given the very strong correlations between DDGS level and Phase 5 and Mean dietary IVP (0.98 and 0.99, respectively). This suggests that when feeding diets with a relatively wide range of DDGS levels, the actual level of DDGS in the diet is a good predictor of fat IV values.

There was no relationship between harvest live weight and NIR IV (r = -0.03; Table 18), which is not surprising given that pigs were sent for harvest over a relatively narrow range of weights. Correlations between NIR IV and carcass yield and last rib backfat were also relatively weak (-0.19 and -0.19, respectively) but were negative, suggesting that increases in carcass yield and subcutaneous fat levels would be associated with decreases in IV. A number of studies have shown a negative association between DDGS inclusion level and IV of carcass fat (Wood et al., 2008; Stein and Shurson, 2009; Leick et al., 2010; Xu et al., 2010; Benz et al., 2011).

Equations to predict pork fat iodine value

Prediction of IV using diet composition and animal variables. Regression equations to predict the IV of fat at the 4 sampling locations were developed using the PROC REG procedure of SAS and the stepwise selection model, and these are presented, along with statistics relating to model fitness in Table 19. Six independent variables were used that related to dietary composition and carcass characteristics: 1) DDGS inclusion level, 2) dietary iodine value product (IVP) of the feed fed during the last study phase, 3) the mean IVP of diets used during the entire study period, 4) harvest live weight, 5) carcass yield, and 6) backfat thickness (measured at the last rib on the slaughter line). The stepwise selection model option of SAS was

used to determine which of the variables were to be included in the IV prediction equation, from 4 different fat sampling locations. The data used in this analysis was from Subsample 1 which consisted of NIR IV from the fat samples taken from approximately half of the pigs in each pen (15 to 18 pigs per pen with approximately equal numbers of barrows and gilts from each pen) and IV was measured using near-infrared spectroscopy (NIR).

The R^2 values for the selected models to predict IV for all 4 fat sampling locations were relatively similar with a range from 0.75 to 0.84 suggesting that these equations explained between approximately 56% and 70% of the variation in IV at each site. The first variable that was selected for the model for all 4 fat depots was DDGS inclusion level, with equations based on this variable having R^2 values of between 0.75 and 0.81, depending on fat sample location (Table 19). The second variable selected for the model for all fat sampling locations was last rib backfat depth (Table 19), however, adding this variable increased R^2 values by only a small amount (between 0.01 and 0.02). Adding further variables to the models had little, if any, effect on R^2 values.

In contrast to these results, Madsen et al. (1992) and Bergstom et al. (2010) reported that the best single variable to predict the IV of backfat was dietary IVP. In the current study, diets with a wide range of DDGS inclusion levels were used and this may explain why DDGS inclusion level was a better predictor of pork fat IV than was dietary IVP. In fact, in the current study, including dietary IVP in a single variable equation to predict fat IV at any of the sampling locations explained almost as much variation (R^2 of between 0.74 to 0.81; Table 20), suggesting that equations based on dietary IVP could be used.

In conclusion, the results of this analysis suggest that in situations where relatively high levels of DDGS are being fed, DDGS inclusion level is the best predictor of pork fat IV.

Prediction of IV using dietary IVP. Dietary IVP has frequently been used to predict the IV of pork fat and, therefore, single variable equations were developed using the dietary IVP (mean of all dietary phases fed to pigs) as the independent variable to predict pork fat IV on all 4 locations. This analysis was again carried out using data from Subsample 1, where the fat IV was measured with NIR, and results are presented in Table 20.

The R^2 for these equations were 0.74, 0.81, 0.81, and 0.77 for belly, jowl, backfat 1 and backfat 2, respectively (Table 20), which, as previously discussed, are similar to those obtained when using the DDGS inclusion level in the stepwise regression analysis discussed above (Table 19). This result was as expected given the very strong correlation between DDGS inclusion level and dietary IVP previously described (Table 18). Previous studies have shown wide variation in R^2 values when using IVP to predict pork fat IV and less model fitting statistics values. For example, Benz et al. (2011) obtained R^2 lower R^2 values, when using the IVP as the only independent variable as follows:

Jowl fat IV = 0.247 × Diet IVP + 56.479; R^2 = 0.32.

Backfat IV = 0.272 × Diet IVP + 51.946; R^2 = 0.16.

Bergstrom et al. (2010) carried out a meta-analysis involving 6 studies, and also determined the IV of jowl and backfat when using IVP as a single variable with the equations as follows:

Jowl fat IV = 0.15 × Diet IVP + 61.95; R^2 = 0.45.

Backfat IV = 0.18 × Diet IVP + 57.89; R^2 = 0.58.

The results of this study suggest that using either DDGS inclusion level or dietary IVP will predict pork fat IV with similar precision. However, these equations need to be validated using fat samples from other pigs which have been fed diets with a lower, more practically applicable, range of DDGS inclusion levels before their widespread use could be advocated.

Prediction of belly fat IV using the IV of fat from the other sampling locations. In the U.S., the belly is the most valuable cut in the carcass and is also the cut of most concern from a fat quality standpoint. It is widely claimed that soft belly fat resulting from feeding diets with relatively high levels of PUFA causes reduced slicing yields and, therefore, significant economic loss to the processor. In some studies, fat sampling locations other than the belly have been used, including the jowl and backfat. Consequently, a precise equation to predict the IV of belly fat based on the IV at other locations in the carcass would be useful. Such equations were developed from the data for NIR IV collected in this study and these are presented in Table 21.

In agreement with the results obtained from the correlation analysis (Table 15), the equation based on the IV of the jowl fat IV resulted in higher R^2 values compared to Backfat 1 and 2 (Table 21). However, differences between the 3 sampling locations in R^2 were small (R^2 = 0.78, 0.75, and 0.73, respectively), indicating that using the IV of the fat from any of the locations would give similar precision of prediction of belly fat IV.

Effect of subsample size on iodine value measurements.

Due to the relatively high cost of GC analysis of the fatty acid profile and IV of carcass fat, research studies that use relatively large groups of pigs generally take a subsample of the a relatively small number of pigs in the pen which can be less than 10% of the pigs (e.g., Benz et

al., 2010; Xu et al., 2010; Duttlinger et al., 2012). A key question when using subsamples is whether they accurately represent the entire pen for the traits of interest. To address this, an analysis was carried out to evaluate the effect of the size of the subsample (number of pigs) on the mean and variation of pork fat IV. The pigs in Subsample 1 were used for this analysis, which consisted of from 15 to 18 pigs/pen (approximately equal number of barrows and gilts), representing about half of the pigs in the pen (pigs/pen at start = 34) that were selected to have the same mean and variation in live weight as the entire pen. Iodine value was measured using near-infrared spectroscopy on fat samples from jowl, backfat 1 (sample taken at 3rd thoracic vertebra) and backfat 2 (sample taken at clear plate).

The first subsample evaluated was the 2 pigs (one barrow and one gilt) in each pen that were closest in live weight to the pen mean live weight (i.e., the same 2 pigs that were used for Subsample 2). Subsequently, the next 2 pigs that were closest to the pen mean live weight at time of harvest were selected, and so on (forming subsample sizes of 2, 4, 6, 8, 10 or 12 pigs/pen). The means and standard deviations for each subsample size were compared for the two pig removal program separately and the results of this analysis are presented in Table 22.

There was no effect ($P > 0.05$) of subsample size on the mean of the IV for either pig removal program for any of the sampling locations (Table 22). This is an important finding in that it suggest that a subsample as limited as 2 pigs with the same mean live weight as the pen taken from a group of 15 to 18 (11 to 13% of the group) will give an accurate estimate of the mean.

For the multiple group pig removal program, there was no effect of subsample size on the variation in IV within each subsample (measured as the standard deviation) for any of the fat

sampling locations (Table 22). This is perhaps not surprising given that the range in weights within the pens of pigs taken off test in multiple groups was, by design, relatively limited (the SD of live weight for the multiple and single removal programs was 6.0 vs. 10.6 kg, respectively). However, for the pens that were taken off test in a single-group, the standard deviation of IV for jowl and backfat 1 sample locations was lower ($P < 0.05$) for subsamples of 2 pigs/pen compared with the other subsample sizes which had similar ($P > 0.05$) standard deviations (Table 22). This suggests that with pens taken off test as a single group, subsamples of 11 to 13% of the pen could underestimate the within-pen variation. On the basis of these results, it would appear that subsample sizes of approximately 22 to 26% of the animals in the pen are required to give an accurate estimate of both the pen mean and the standard deviation. Further research would be required to more accurately determine the minimum subsample size to use in studies of fat composition.

CONCLUSIONS

The results of this, which involved fat samples from 4 sampling locations of pigs fed increasing levels of DDGS, reared under commercial conditions, and taken off test using two pig removal programs, suggest that DDGS and fat sampling location had major effect on pork fat iodine value (IV). Increasing DDGS level in the diet resulted in an increase of IV, and jowl fat had greater IV compared to the other 3 locations. The pig removal program had limited to no effect on pork fat composition. The correlations between IV values at the various fat sampling locations (belly, jowl, backfat samples 1 and 2) were relatively high (between 0.86 to 0.96), and so using jowl, backfat 1 or backfat 2 in equations to predict belly fat IV gave similar precision ($R^2 = 0.78$, 0.75, and 0.73, respectively). The dietary characteristics iodine value product (IVP) and DDGS inclusion level were highly correlated with the fat IV, and using either of these

characteristics in equations to predict belly fat IV gave similar levels of precision (R^2 = 0.75 and 0.74, respectively). Measuring fat IV using near-infrared spectroscopy, which is a rapid and relatively inexpensive technique, gave very similar results to estimating fat IV using the fatty acid profile of the fat determined using gas chromatography. Finally, using relatively small subsamples from pens (11 to 13%) gives an accurate estimate of the pen mean IV but a larger subsample (22 to 26% of the pigs in the pen) is needed to estimate the standard deviation of IV.

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TABLES

Table 2. Analyzed composition of the distillers dried drains with solubles (DDGS), corn and soybean meal (SBM) used to manufacture experimental diets.

Item	DDGS[1]	Corn	SBM[2]
Proximate analysis, % as-fed basis[3]			
Dry matter	90.17	88.59	88.85
Crude protein	27.77	8.01	48.19
Crude fat	8.78	3.32	1.33
Crude fiber	6.11	2.06	3.65
Acid detergent fiber	12.3	3.25	5.43
Neutral detergent fiber	27.14	8.2	8.33
Phosphorus	0.88	0.31	0.71
Calcium	0.02	-	0.48
Sodium	0.21	-	-
Ash	4.16	1.28	6.1
Chloride	0.16	-	-
Amino acid analysis (total), % as-fed basis[4,5]			
Lysine	0.85	-	2.85
Threonine	0.99	-	1.81
Methionine	0.55	-	0.63
Cystine	0.5	-	0.68
Methionine + Cystine	1.05	-	-
Arginine	1.26	-	3.25
Isoleucine	1.01	-	2.18
Leucine	2.94	-	3.48
Valine	1.3	-	2.18
Histidine	0.7	-	1.2
Alanine	1.88	-	1.98
Glutamic acid	4.41	-	8.08
Glycine	1.06	-	1.91
Aspartic acid	1.73	-	5.13
Phenylalanine	1.29	-	2.35
Proline	2.12	-	2.32
Serine	1.29	-	2.33
Tyrosine	0.82	-	1.24
Tryptophan	0.23	-	0.62

[1]DDGS origin: Big River Resources, LLC, Burlington, IA.

[2]SBM origin: ADM, Quincy, IL.

[3]Proximate analysis was performed at Midwest Laboratories, Omaha, NE.

[4]Amino acid analysis was performed using High-Performance Liquid Chromatography (HPLC).

[5]Amino acid analysis for Corn was not recorded.

Table 3. Calculated and analyzed composition of diets for phases 1 and 2 (fed 45.4 and 52.2 kg per pig, respectively; as-fed basis).

	Diets for phase 1				Diets for phase 2			
Item	0%	20%	40%	60%	0%	20%	40%	60%
Ingredient, %								
Corn	60.15	47.32	34.11	21.28	69.76	55.85	41.53	27.62
Soybean meal	37.26	29.22	20.93	12.88	27.85	20.79	13.51	6.45
DDGS	0.00	19.80	40.20	60.00	0.00	19.80	40.20	60.00
Limestone	0.99	1.15	1.31	1.47	0.94	1.11	1.30	1.48
Salt	0.51	0.40	0.30	0.20	0.51	0.40	0.30	0.20
Surface	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mono-cal 21% P	0.40	0.27	0.13	0.00	0.27	0.18	0.09	0.00
DL-Methionine OH analogue	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00
Fat (Yellow grease)	0.00	0.98	1.99	2.98	0.00	1.03	2.10	3.13
L-Lysine HCl	0.00	0.18	0.37	0.56	0.04	0.20	0.35	0.51
Trace minerals premix	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09
Vitamins premix	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Optiphos PF 1000[1]	0.03	0.02	0.01	0.00	0.03	0.02	0.01	0.00
Calculated composition								
ME, Kcal/kg	3246.52	3246.52	3246.52	3246.52	3254.10	3254.06	3254.03	3253.99
Crude Protein, %	22.09	22.68	23.28	23.87	18.29	19.24	20.23	21.18
Crude Fat, %	2.29	4.31	6.38	8.40	2.52	4.56	6.66	8.70
Calcium, %	0.65	0.65	0.65	0.66	0.56	0.58	0.61	0.63
Phosphorus, %	0.50	0.55	0.60	0.66	0.43	0.50	0.56	0.63
Total lysine, %	1.23	1.27	1.31	1.35	1.01	1.05	1.10	1.14
Total Methionine + Cysteine, %	0.71	0.74	0.78	0.82	0.58	0.64	0.70	0.75
Total Threonine, %	0.84	0.85	0.86	0.87	0.69	0.72	0.74	0.77
Total Tryptophan, %	0.28	0.26	0.24	0.22	0.23	0.21	0.20	0.19
Analyzed composition[2]								
Crude Protein, %	23.40	24.10	24.20	24.80	19.00	20.40	21.30	23.10
Crude Fat, %	2.90	6.11	7.70	8.83	3.28	6.14	6.98	8.87
Calcium, %	0.70	0.74	0.84	0.75	0.65	0.66	0.72	0.82
Phosphorus, %	0.59	0.66	0.69	0.69	0.47	0.60	0.66	0.73
Total lysine, %	1.42	1.44	1.47	1.48	1.21	1.30	1.28	1.36
Total Methionine + Cysteine, %	0.52	0.59	0.69	0.78	0.46	0.57	0.63	0.73
Total Threonine, %	0.91	0.94	0.96	0.96	0.79	0.84	0.83	0.86
Total Tryptophan, %	0.23	0.25	0.25	0.24	0.19	0.21	0.20	0.21
Total iodine value, g/100g[3]	121.78	112.82	112.20	110.47	121.91	113.48	111.41	110.01
Iodine value product[4]	35.32	68.93	86.40	97.55	39.99	69.68	77.76	97.58

[1]Phytase enzyme

[2]Values for amino acids were obtained using near infrared spectroscopy at DFS labs; values for proximate components were obtained using wet chemistry at Midwest Labs.

[3]Total iodine value = C16:1(0.95) + C18:1(0.86) + C18:2(1.732) + C18:3(2.616) + C20:1(0.785) + C22:1(0.723) + C14:1(1.062) + C17:1(n7)(0.903) + C20:2(n6)(1.581) + C20:3(n6)(2.386) + C20:3(n3)(2.386) + C20:4(n6)(3.201) + C22:4(n6)(2.941).

[4]Iodine value product = % of diet lipids × iodine value of the dietary lipids × 0.1.

Table 4. Calculated and analyzed composition of diets for phases 3 and 4 (fed 63.5 and 56.7 kg per pig, respectively; as-fed basis).

	Phase 3				Phase 4			
Item	0%	20%	40%	60%	0%	20%	40%	60%
Ingredient, %								
Corn	77.75	61.69	45.14	29.08	81.23	64.95	48.19	31.92
Soybean meal	20.02	15.04	9.91	4.94	16.62	11.82	6.87	2.07
DDGS	0.00	19.80	40.20	60.00	0.00	19.80	40.20	60.00
Limestone	0.88	1.08	1.28	1.48	0.86	1.06	1.27	1.48
Salt	0.51	0.40	0.30	0.20	0.51	0.40	0.30	0.20
Surface	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Mono-cal 21% P	0.12	0.08	0.04	0.00	0.07	0.04	0.02	0.00
DL-Methionine OH analogue	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fat (Yellow grease)	0.00	1.10	2.23	3.33	0.00	1.12	2.27	3.39
L-Lysine HCl	0.10	0.19	0.28	0.37	0.10	0.18	0.27	0.35
Trace minerals premix	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Vitamins premix	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Optiphos PF 1000[1]	0.03	0.02	0.01	0.00	0.02	0.02	0.01	0.00
Calculated composition								
ME, Kcal/kg	3262.57	3262.57	3262.57	3262.57	3265.23	3265.23	3265.23	3265.23
Crude Protein, %	15.16	16.90	18.70	20.44	13.77	15.58	17.43	19.24
Crude Fat, %	2.72	4.77	6.88	8.93	2.80	4.87	6.99	9.06
Calcium, %	0.48	0.53	0.58	0.62	0.45	0.50	0.56	0.61
Phosphorus, %	0.37	0.45	0.54	0.62	0.35	0.43	0.52	0.61
Total lysine, %	0.85	0.89	0.94	0.99	0.75	0.80	0.85	0.90
Total Methionine + Cysteine, %	0.51	0.58	0.66	0.74	0.47	0.55	0.63	0.71
Total Threonine, %	0.57	0.62	0.68	0.74	0.51	0.57	0.63	0.69
Total Tryptophan, %	0.18	0.18	0.18	0.18	0.16	0.16	0.16	0.16
Analyzed composition[2]								
Crude Protein, %	16.78	17.78	19.60	20.17	15.50	16.40	18.50	20.90
Crude Fat, %	2.73	5.08	6.61	9.41	3.07	5.17	6.92	9.46
Calcium, %	-	-	-	-	0.55	0.55	0.65	0.65
Phosphorus, %	-	-	-	-	0.39	0.48	0.58	0.70
Total lysine, %	1.04	1.09	1.17	1.19	0.97	0.98	1.10	1.20
Total Methionine + Cysteine, %	0.41	0.49	0.59	0.68	0.38	0.46	0.54	0.68
Total Threonine, %	0.68	0.71	0.76	0.77	0.63	0.63	0.70	0.78
Total Tryptophan, %	0.16	0.17	0.19	0.19	0.14	0.15	0.17	0.19
Total iodine value, g/100g[3]	122.08	108.32	110.12	107.06	122.54	106.22	108.59	106.28
Iodine value product[4]	33.33	55.03	72.79	100.75	37.62	54.92	75.15	100.54

[1]Phytase enzyme

[2]Phase 3: values for amino acids and proximate components were obtained using near infrared spectroscopy at DFS labs; phase 4: values for amino acids were obtained using near infrared spectroscopy at DFS labs; values for proximate components were obtained using wet chemistry at Midwest Labs

[3]Total iodine value = C16:1(0.95) + C18:1(0.86) + C18:2(1.732) + C18:3(2.616) + C20:1(0.785) + C22:1(0.723) + C14:1(1.062) + C17:1(n7)(0.903) + C20:2(n6)(1.581) + C20:3(n6)(2.386) + C20:3(n3)(2.386) + C20:4(n6)(3.201) + C22:4(n6)(2.941).

[4]Iodine value product = % of diet lipids × iodine value of the dietary lipids × 0.1.

Table 5. Calculated and analyzed composition of diets for phase 5 (fed 63.5 kg per pig; as-fed basis).

	Phase 5			
Item	0% DDGS	20%	40% DDGS	60% DDGS
Ingredient, %				
Corn	82.65	66.27	49.39	33.01
Soybean meal	15.16	10.49	5.67	1.00
DDGS	0.00	19.80	40.20	60.00
Limestone	0.86	1.06	1.27	1.48
Salt	0.51	0.40	0.30	0.20
Surface	0.50	0.50	0.50	0.50
Mono-cal 21% P	0.09	0.06	0.03	0.00
DL-Methionine hidroxy analogue	0.00	0.00	0.00	0.00
Fat (Yellow grease)	0.00	1.11	2.26	3.38
L-Lysine HCl	0.10	0.18	0.26	0.34
Trace minerals premix	0.08	0.08	0.08	0.08
Vitamins premix	0.03	0.03	0.03	0.03
Optiphos PF 1000[1]	0.02	0.02	0.01	0.00
Calculated composition				
ME, Kcal/kg	3264.37	3264.37	3264.37	3264.37
Crude Protein, %	13.18	15.03	16.95	18.80
Crude Fat, %	2.84	4.90	7.01	9.07
Calcium, %	0.45	0.50	0.55	0.61
Phosphorus, %	0.35	0.43	0.52	0.61
Total lysine, %	0.72	0.76	0.81	0.86
Total Methionine + Cysteine, %	0.46	0.54	0.62	0.70
Total Threonine, %	0.49	0.55	0.61	0.68
Total Tryptophan, %	0.15	0.15	0.15	0.15
Analyzed composition[2]				
Crude Protein, %	14.00	15.60	18.00	20.70
Crude Fat, %	2.97	3.87	6.64	9.58
Calcium, %	0.51	0.49	0.60	0.73
Phosphorus, %	0.39	0.41	0.54	0.69
Total lysine, %	0.95	0.91	1.06	1.14
Total Methionine + Cysteine, %	0.35	0.38	0.54	0.70
Total Threonine, %	0.60	0.59	0.69	0.75
Total Tryptophan, %	0.13	0.14	0.17	0.19
Total iodine value, g/100g[3]	122.60	119.82	112.24	110.35
Iodine value product[4]	36.41	46.37	74.53	105.72

[1]Phytase enzyme

[2]Values for amino acids were obtained using near infrared spectroscopy at DFS labs; values for

[3]Total iodine value = C16:1(0.95) + C18:1(0.86) + C18:2(1.732) + C18:3(2.616) + C20:1(0.785) + C22:1(0.723) + C14:1(1.062) + C17:1(n7)(0.903) + C20:2(n6)(1.581) + C20:3(n6)(2.386) +

[4]Iodine value product = % of diet lipids × iodine value of the dietary lipids × 0.1

Table 6. Fatty acid profile of dietary fat from diets fed for phases 1 to 5.

	Diets for phase 1[1]				Diets for phase 2[1]				Diets for phase 3[1]				Diets for phase 4[1]				Diets for phase 5[1]			
	DDGS inclusion level,				DDGS inclusion level, %				DDGS inclusion level, %				DDGS inclusion level, %				DDGS inclusion level, %			
Item	0	20	40	60	0	20	40	60	0	20	40	60	0	20	40	60	0	20	40	60
Fatty acid, %																				
Lauric [C12:0]	0.06	0.36	0.40	0.42	0.00	0.07	0.09	0.10	0.00	0.04	0.04	0.05	0.00	0.32	0.34	0.37	0.00	0.04	0.13	0.11
Myristic [C14:0]	0.13	0.45	0.48	0.53	0.09	0.36	0.43	0.48	0.08	0.54	0.47	0.60	0.06	0.71	0.65	0.73	0.07	0.15	0.43	0.47
Palmitic [C16:0]	13.98	15.67	15.72	16.06	13.85	15.62	16.10	16.34	13.05	16.12	15.94	16.37	13.31	16.96	16.39	16.81	13.53	14.03	15.6	16.09
Palmitoleic [C16:1]	0.25	0.55	0.56	0.62	0.23	0.58	0.65	0.72	0.26	0.84	0.77	0.96	0.20	0.71	0.70	0.78	0.23	0.32	0.59	0.65
Stearic [C18:0]	3.01	4.08	4.16	4.41	2.57	3.90	4.25	4.39	2.63	4.95	4.38	4.82	2.29	5.08	4.39	4.79	2.28	2.70	3.98	4.32
Oleic [C18:1]	24.26	27.11	27.40	28.04	25.16	27.39	27.98	28.49	25.83	29.42	28.98	30.10	25.88	28.73	28.75	29.49	25.21	25.99	28.32	28.79
Linoleic [C18:2(n6)]	53.32	48.10	47.63	46.48	53.77	48.33	46.99	46.18	53.94	44.57	46.03	43.81	54.34	43.94	45.51	43.91	54.76	53.04	47.65	46.29
α-Linoleic [C18:3(n3)]	3.03	1.90	1.86	1.72	2.54	1.88	1.74	1.56	2.19	1.60	1.51	1.33	2.14	1.52	1.40	1.27	2.07	1.85	1.56	1.56
Arachidic [C20:0]	0.39	0.35	0.35	0.31	0.41	0.32	0.31	0.30	0.43	0.31	0.34	0.31	0.39	0.34	0.37	0.31	0.38	0.40	0.37	0.31
Gondoic [C20:1]	0.31	0.36	0.36	0.38	0.28	0.39	0.38	0.37	0.39	0.36	0.39	0.42	0.34	0.37	0.37	0.41	0.38	0.37	0.34	0.37
Other fatty acids[2]	1.03	1.06	1.06	1.04	1.10	1.13	1.09	1.07	1.20	1.25	1.16	1.23	1.04	1.33	1.12	1.14	1.09	1.11	1.00	1.04
Total MUFA[3]	24.89	28.15	28.46	29.18	25.72	28.51	29.18	29.76	26.55	30.85	30.37	31.73	26.47	29.99	30.00	30.87	25.87	26.75	29.4	29.97
Total PUFA[4]	56.41	50.14	49.64	48.36	56.32	50.35	48.88	47.88	56.19	46.32	47.66	45.29	56.52	45.60	47.03	45.32	56.89	54.96	49.34	47.98
MUFA:PUFA ratio	0.44	0.56	0.57	0.60	0.46	0.57	0.60	0.62	0.47	0.67	0.64	0.70	0.47	0.66	0.64	0.68	0.45	0.49	0.60	0.62
SFA[5]	18.30	21.71	21.90	22.46	17.96	21.15	21.94	22.36	17.26	22.83	21.97	22.98	17.01	24.41	22.97	23.81	17.25	18.29	21.25	22.04
Iodine value, g/100 g																				
AOCS equation[6]	121.62	112.40	111.75	110.00	121.86	113.04	110.93	109.55	121.93	107.76	109.64	106.47	122.43	105.75	108.17	105.78	122.47	119.65	111.8	109.92
Total UFA equation[7]	121.78	112.82	112.20	110.47	121.91	113.48	111.41	110.01	122.08	108.32	110.12	107.06	122.54	106.22	108.59	106.28	122.60	119.82	112.24	110.35

[1]Amount of feed fed: phase 1 = 45.4 kg/pig; phase 2 = 52.2 kg/pig; phase 3 = 63.5 kg/pig; phase 4 = 56.7 kg/pig; phase 5 = 63.5 kg/pig.

[2]Other fatty acids = Capric acid [C10:0] + Myristoleic acid [C14:1] + Pentadecanoic acid [C15:0] + Margaric acid [C17:0] + Heptadecenoic acid [C17:1(n7)] + Eicosadienoic acid [C20:2(n6)] + Arachidonic acid [C20:4(n6)] + Behenic acid [C22:0] + Lignoceric acid [C24:0]

[3]MUFA= mono-unsaturated fatty acid = 14:1 + 16:1 + 17:1 + 18:1 + 20:1 + 22:1(n9).

[4]PUFA = poly-unsaturated fatty acid = 18:2(n6) + 18:3(n3) + 20:2(n6) + 20:3(n6) + 20:4(n6) + 20:3(n3) + 22:4(n6).

[5]SFA = saturated fatty acid = 10:0 + 12:0 + 14:0 + 15:0 + 16:0 + 17:0 + 18:0 + 20:0 + 22:0 + 24:0.

[6]AOCS equation (1998): IV = 16:1(0.95) + 18:1(0.86) + 18:2(1.732) + 18:3(2.616) + 20:1(0.785) + 22:1(0.723).

[7]Total unsaturated (UFA) fatty acid equation = AOCS (1998) equation + 14:1(1.062) + 17:1(n7)(0.903) + 20:2(n6)(1.581) + 20:3(n6)(2.386) + 20:3(n3)(2.386) + 20:4(n6)(3.201) + 22:4(n6)(2.941).

Table 7. Least squares means for the effects of DDGS inclusion level and pig removal program on the growth performance, carcass characteristics and, iodine value (IV) of growing-finishing pigs.

	Treatment[1] (Trt)							*P*-value		
	1	2	3	4	5	6				
Item[2]	Single-group, 0% DDGS	Multiple-groups, 0% DDGS	Single-group, 20% DDGS	Single-group, 40% DDGS	Multiple-groups, 40% DDGS	Single-group, 60% DDGS	SEM	Trt	DDGS[3,4]	[1 & 4] vs. [2 & 5][5]
Growth performance										
Number of pens	8	8	8	8	8	8	-	-	-	-
Number of pigs	272	272	272	272	272	272	-	-	-	-
Body weight, kg										
Start of test (week 6 post-weaning)	23.4	23.4	23.4	23.4	23.3	23.2	0.43	0.89	0.72	0.74
End of test	129.0^{ab}	127.2^{bc}	129.5^{a}	127.6^{bc}	126.4^{c}	129.7^{a}	0.68	0.01	0.01^{z}	0.04
Overall ADG, kg	0.88^{bc}	0.91^{a}	0.88^{bc}	0.86^{c}	0.90^{ab}	0.83^{d}	0.012	<0.001	0.001^{x}	0.001
Overall ADFI, kg	2.30^{ab}	2.33^{a}	2.28^{ab}	2.26^{b}	2.28^{ab}	2.19^{c}	0.024	0.001	<0.001^{x}	0.28
Overall G:F, kg:kg	0.381	0.389	0.385	0.381	0.395	0.378	0.0047	0.08	0.56	0.01
Live ultrasound measures[6]										
10th rib backfat depth, cm	2.04^{bc}	2.31^{a}	1.99^{c}	1.90^{c}	2.24^{ab}	1.85^{c}	0.107	0.004	0.13	0.001
10th rib *Longissimus* muscle depth, cm	5.37^{ab}	5.47^{a}	5.41^{ab}	5.33^{bc}	5.31^{bc}	5.26^{c}	0.041	0.004	0.004^{z}	0.29
Carcass characteristics[7]										
Number of pens	8	7	8	8	6	8	-	-	-	-
Number of pigs	236	191	225	233	194	238	-	-	-	-
Harvest live weight, kg	129.1^{ab}	127.4^{bc}	128.8^{ab}	127.4^{bc}	126.6^{c}	129.7^{a}	0.71	0.03	0.02^{z}	0.09
Hot carcass weight, kg	96.8^{a}	95.2^{bc}	95.9^{b}	95.0^{c}	94.1^{d}	95.1^{c}	0.27	<0.001	0.001^{z}	<0.001
Carcass yield, %	75.5^{a}	74.3^{bc}	74.8^{b}	74.1^{c}	73.4^{d}	74.2^{c}	0.21	<0.001	<0.001^{z}	<0.001
Last rib backfat depth, cm	2.82^{a}	2.78^{ab}	2.71^{bc}	2.71^{abc}	2.76^{abc}	2.64^{c}	0.043	0.05	0.02	0.93

^{a,b,c,d}Means within a row with different superscripts are different ($P \leq 0.05$).

[1]Pigs were sent for harvest using two removal programs: Single-group = all pigs were sent to harvest at the same time; Multiple-groups = [Week 1 = Heaviest 10% of pigs removed from group and sent for harvest; Week 2 = Heaviest 20%, Week 3 = Heaviest 20%, Week 4 = Heaviest 20%, Week 5 = Heaviest 10%, Week 6 = Lightest 20% of pigs].

[2]All data (except for body and harvest live weights) were corrected to a common harvest live weight of 128.2 kg.

[3]Effect of DDGS level [(Treatments 1 and 2) vs. 20% DDGS (Treatment 3) vs. 40% DDGS (Treatments 4 and 5) vs. 60% DDGS (Treatment 6)] was compared using orthogonal contrasts,

[4]x = linear response, y = quadratic response, z = cubic response.

[5]Pig removal programs means were compared using orthogonal contrasts.

[6]Live ultrasound measurements: taken on live animal at the farm on the day prior to shipment for harvest.

[7]Carcass characteristics were measured on slaughter line.

Table 8. Least squares means for the effects of DDGS inclusion level, sex, and pig removal program on the fatty acid profile of belly fat from Subsample 3[1].

	Treatment[2] (Trt)							Sex			*P*-values				
	1	2	3	4	5	6									
Item	Single-group, 0% DDGS	Multiple-groups, 0% DDGS	Single-group, 20% DDGS	Single-group, 40% DDGS	Multiple-groups, 40% DDGS	Single-group, 60%	SEM	Gilt	Barrow	SEM	Trt	Sex	Trt× Sex	DDGS level[3,4]	Trt's [1 & 4] vs. [2 &5][5]
Number of pigs	14	14	11	19	13	14	-	45	40	-	-	-	-	-	-
Harvest live weight, kg	129.8	127.1	128.7	128.1	126.6	129.7	1.28	127.6	129	0.82	0.34	0.14	0.77	0.55	0.07
Fatty acid, %															
Myritic acid [C14:0]	1.31^{b}	1.43^{a}	1.31^{b}	1.19^{c}	1.24^{bc}	1.05^{d}	0.035	1.26	1.25	0.02	<0.01	0.56	0.03	<0.01^{x}	0.02
Sex															
Gilt	1.33^{b}	1.49^{a}	1.26^{bcd}	1.13^{de}	1.31^{b}	1.06^{e}	0.049	-	-	-	-	-	-	-	-
Barrow	1.30^{bc}	1.36^{ab}	1.36^{ab}	1.26^{bc}	1.17^{cde}	1.04^{e}	-	-	-	-	-	-	-	-	-
Palmitic acid [C16:0]	23.58^{a}	24.63^{a}	22.21^{b}	20.74^{c}	21.08^{bc}	19.42^{d}	0.396	22.06	21.83	0.23	<0.01	0.49	0.33	<0.01^{x}	0.08
Palmitoleic acid [C16:1(n7)]	2.45^{a}	2.57^{a}	2.35^{ab}	2.10^{c}	2.15^{bc}	1.84^{d}	0.091	2.22	2.26	0.053	<0.001	0.63	0.03	<0.01^{x}	0.32
Sex															
Gilt	2.51^{ab}	2.68^{a}	2.13^{cdef}	1.90^{f}	2.23^{bcde}	1.90^{ef}	0.129	-	-	-	-	-	-	-	-
Barrow	2.39^{abcd}	2.46^{abc}	2.56^{ab}	2.29^{bcd}	2.08^{def}	1.77^{f}	-	-	-	-	-	-	-	-	-
Margaric acid [C17:0]	0.29^{b}	0.29^{b}	0.34^{ab}	0.38^{a}	0.31^{b}	0.37^{a}	0.02	0.32	0.34	0.011	0.01	0.42	0.45	<0.01^{x}	0.07
Heptadecenoic acid [C17:1(n7)]	0.29	0.29	0.31	0.29	0.28	0.26	0.014	0.27^{b}	0.30^{a}	0.009	0.12	0.02	0.29	0.05^{x}	0.39
Stearic acid [C18:0]	10.98^{a}	11.74^{a}	9.80^{b}	9.16^{bc}	9.05^{bc}	8.83^{c}	0.313	9.83	10.02	0.187	<0.01	0.44	0.38	<0.01^{y}	0.28
Oleic acid [C18:1(n9)]	42.01^{a}	41.17^{ab}	39.68^{bc}	38.23^{cd}	39.69^{bc}	37.42^{d}	0.693	39.2	40.2	0.401	<0.01	0.08	0.42	<0.01^{x}	0.65
Linoleic acid [C18:2(n6)]	16.03^{d}	15.03^{d}	20.69^{c}	24.44^{b}	22.66^{bc}	27.09^{a}	0.892	21.43	20.54	0.516	<0.01	0.23	0.40	<0.01^{x}	0.11
α-Linoleic acid [C18:3(n3)]	0.54^{c}	0.51^{c}	0.66^{b}	0.72^{ab}	0.69^{ab}	0.76^{a}	0.026	0.66	0.63	0.015	<0.01	0.25	0.37	<0.01^{x}	0.21
Gondoic acid [C20:1(n9)]	0.86^{a}	0.76^{b}	0.77^{b}	0.74^{b}	0.75^{b}	0.79^{ab}	0.029	0.77	0.79	0.017	0.05	0.47	0.42	0.20	0.13
Eicosadienoic acid [C20:2(n6)]	0.69^{c}	0.61^{c}	0.82^{b}	0.89^{b}	0.87^{b}	1.02^{a}	0.032	0.81	0.82	0.018	<0.01	0.98	0.14	<0.01^{x}	0.09
Arachinodic acid [C20:4(n6)]	0.22^{c}	0.24^{c}	0.25^{bc}	0.29^{a}	0.27^{ab}	0.29^{a}	0.013	0.28^{a}	0.24^{b}	0.009	<0.01	0.001	0.6	<0.01^{x}	0.98
Other fatty acids[6]	0.74^{b}	0.74^{b}	0.79^{ab}	0.82^{a}	0.76^{b}	0.79^{ab}	0.017	0.77	0.78	0.012	<0.01	0.68	0.73	0.01^{x}	0.06
MUFA[7]	45.63^{a}	44.81^{ab}	43.12^{bc}	41.38^{cd}	42.96^{bc}	40.39^{d}	0.777	42.53	43.57	0.45	<0.01	0.11	0.35	<0.01^{x}	0.62
PUFA[8]	17.77^{d}	16.64^{d}	22.75^{e}	26.68^{b}	24.95^{bc}	29.53^{a}	0.954	23.56	22.55	0.553	<0.01	0.20	0.44	<0.01^{x}	0.13
SFA[9]	36.61^{b}	38.55^{a}	34.10^{c}	31.93^{d}	32.09^{d}	30.08^{e}	0.644	33.9	33.89	0.383	<0.01	0.98	0.43	<0.01^{x}	0.09
MUFA:PUFA ratio	2.71^{a}	2.74^{a}	1.92^{b}	1.60^{bc}	1.76^{b}	1.42^{c}	0.121	1.99	2.05	0.07	<0.01	0.55	0.57	<0.01^{y}	0.42
UFA[10]:SFA	1.74^{d}	1.60^{d}	1.94^{c}	2.15^{b}	2.13^{b}	2.34^{a}	0.061	1.99	1.98	0.036	<0.01	0.93	0.44	<0.01^{x}	0.16
Iodine value, g/kg															
AOCS equation[11]	68.31^{d}	65.81^{d}	74.51^{c}	79.67^{b}	77.88^{bc}	83.52^{a}	1.185	75.32	74.58	0.686	<0.01	0.45	0.41	<0.01^{x}	0.07
NIR[12]	68.50^{d}	65.95^{d}	73.24^{c}	78.77^{ab}	76.18^{bc}	81.37^{a}	1.15	73.94	73.84	0.723	<0.01	0.86	0.30	<0.01^{x}	0.01

[a,b,c,d,e,f]Means within a row with different superscripts are different ($P \leq 0.05$).

[1]Subsample 3 = 2 pigs (one barrow and one gilt) with harvest live weight closest to the mean pen live weight from each pen, were selected for fatty acid analysis using gas chromatography.

[2]Removal programs: Single-group = all pigs were sent to harvest at the same time; Multiple-groups = [Week 1 = Heaviest 10% of pigs removed from group and sent for harvest; Week 2 = Heaviest 20%, Week 3 = Heaviest 20%, Week 4 = Heaviest 20%, Week 5 = Heaviest 10%, Week 6 = Lightest 20% of pigs].

[3]Effect of DDGS level [(Treatments 1 and 2) vs. 20% DDGS (Treatment 3) vs. 40% DDGS (Treatments 4 and 5) vs. 60% DDGS (Treatment 6)] was compared using orthogonal contrasts,

[4]x = linear response, y = quadratic response, z = cubic response.

[5]Means were compared using orthogonal contrasts.

[6]Other fatty acids = C10:0 + C12:0 + C14:1 + C15:0 + C20:0 + C20:3(n3) + C20:3(n6) + C22:4(n6)

[7]MUFA: total mono-unsaturated fatty acid = C14:1 + C16:1(n7) + C17:1(n7) + C18:1(n9) + C20:1(n9) + C22:1(n9).

[8]PUFA: total poly-unsaturated fatty acid = C18:2(n6) + C18:3(n3) + C20:2(n6) + C20:3(n6) + C20:4(n6) + C20:3(n3) + C22:4(n6).

[9]SFA: total saturated fatty acid = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

[10]UFA: total unsaturated fatty acid = MUFA + PUFA

[11]AOCS equation (1998): 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).

[12]Iodine value measured using NIR (near-infrared spectroscopy).

Table 9. Descriptive statistics of carcass traits.

	Mean	Standard deviation	Minimum	Maximum
All pigs sent for harvest[1]				
Number of pigs	1317	-	-	-
Live ultrasound measurements[2]				
10th rib backfat depth, cm	2.01	0.607	0.70	4.00
10th rib *Longissimus* muscle depth, cm	5.36	0.489	3.92	7.05
Carcass characteristics[3]				
Harvest live weight, kg	128.3	9.71	92.1	156.9
Hot carcass weight, kg	95.4	7.65	64.4	117.9
Carcass yield, %	74.3	1.78	67.8	79.5
Last rib backfat depth, cm	2.73	0.466	1.27	4.32
Subsample 1[4]				
Number of pigs	862			
Live ultrasound measurements[2]				
10th rib backfat depth, cm	2.05	0.626	0.70	4.00
10th rib *Longissimus* muscle depth, cm	5.37	0.481	3.92	6.85
Carcass characteristics[3]				
Harvest live weight, kg	128.0	9.05	100.2	156.0
Hot carcass weight, kg	95.1	7.16	73.5	117.5
Carcass yield, %	74.2	1.94	66.2	81.5
Last rib backfat depth, cm	2.76	0.464	1.27	4.32
Subsample 2[5]				
Number of pigs	90	-	-	-
Live ultrasound measurements[2]				
10th rib backfat depth, cm	2.03	0.648	0.77	3.79
10th rib *Longissimus* muscle depth, cm	5.45	0.477	4.38	6.85
Carcass characteristics[3]				
Harvest live weight, kg	128.2	2.72	121.1	135.2
Hot carcass weight, kg	95.3	3.04	85.7	103.9
Carcass yield, %	74.3	1.90	69.3	78.9
Last rib backfat depth, cm	2.80	0.463	1.78	4.32
Subsample 3[6]				
Number of pigs				
Live ultrasound measurements[2]				
10th rib backfat depth, cm	2.04	0.651	0.90	3.80
10th rib *Longissimus* muscle depth, cm	5.38	0.471	4.25	6.42
Carcass characteristics[3]				
Harvest live weight, kg	128.3	4.49	117.9	142.4
Hot carcass weight, kg	95.4	4.34	81.6	107.5
Carcass yield, %	74.3	2.11	66.2	81.5
Last rib backfat depth, cm	2.79	0.430	1.78	3.81

[1]Measurements taken on all pigs sent for harvest.
[2]Live ultrasound measurements: measured on live animal at the farm on the day prior to shipment for harvest.
[3]Carcass characteristics were measured on slaughter line.
[4]Subsample 1 = approximately 15 to 18 pigs (gilts and barrows) per pen were randomly selected to determine iodine value (with near-infrared spectroscopy) from 4 fat sampling locations (belly, jowl, 3rd thoracic vertebra backfat, clear plate backfat) post-mortem.
[5]Subsample 2 = 2 pigs (one barrow and one gilt) with harvest live weight closest to the mean pen live weight from each pen, were selected for fatty acid analysis using gas chromatography. Fat sampling locations: jowl, 3rd thoracic vertebra backfat, and clear plate backfat.
[6]Subsample 3 = 2 pigs (one barrow and one gilt) with harvest live weight closest to the mean pen live weight from each pen, were selected for fatty acid analysis using gas chromatography. Fat sampling locations: belly, jowl and 3rd thoracic vertebra backfat.

Table 10. Descriptive statistics of fatty acid profile and iodine value from 4 pork fat sampling locations.

	Sampling location															
	Belly				Jowl				Backfat[1] 1				Backfat[1] 2			
Item	Mean	SD[2]	Min[2]	Max[2]	Mean	SD[2]	Min[2]	Max[2]	Mean	SD[2]	Min[2]	Max[2]	Mean	SD[2]	Min[2]	Max[2]
Subsample 1[3]																
Number of fat samples[4]	727	-	-	-	791	-	-	-	828	-	-	-	777	-	-	-
NIR[5] iodine value, g/100 g	74.18	6.712	59.30	91.20	79.39	6.044	65.90	93.20	77.67	7.105	62.40	92.60	75.51	7.249	56.90	90.60
Subsample 2[6]																
Number of fat samples[4]	-	-	-	-	91	-	-	-	85	-	-	-	74	-	-	-
Fatty acid, %																
Capric [C10:0]	-	-	-	-	0.07	0.015	0.04	0.11	0.06	0.018	0.03	0.12	0.06	0.014	0.03	0.09
Lauric [C12:0]	-	-	-	-	0.07	0.010	0.03	0.09	0.07	0.008	0.05	0.09	0.07	0.008	0.05	0.09
Myritic [C14:0]	-	-	-	-	1.18	0.150	0.77	1.63	1.14	0.163	0.78	1.53	1.12	0.155	0.77	1.45
Myristoleic [C14:1]	-	-	-	-	0.02	0.011	0.00	0.04	0.01	0.010	0.00	0.03	0.01	0.010	0.00	0.03
Pentadecylic [C15:0]	-	-	-	-	0.07	0.016	0.02	0.12	0.07	0.016	0.04	0.11	0.06	0.016	0.03	0.10
Palmitic [C16:0]	-	-	-	-	19.90	1.843	15.68	23.88	20.68	2.309	16.01	24.88	21.05	2.482	16.57	26.66
Palmitoleic [C16:1(n7)]	-	-	-	-	2.39	0.395	1.76	3.80	1.92	0.354	0.09	2.92	1.90	0.266	1.36	2.89
Margaric [C17:0]	-	-	-	-	0.38	0.067	0.20	0.58	0.38	0.069	0.23	0.60	0.35	0.073	0.20	0.55
Heptadecenoic [C17:1(n7)]	-	-	-	-	0.36	0.072	0.24	0.58	0.31	0.057	0.20	0.53	0.27	0.053	0.17	0.44
Stearic [C18:0]	-	-	-	-	8.28	1.447	5.12	11.73	9.81	2.008	5.94	14.76	10.48	2.084	6.37	15.04
Oleic [C18:1(n9)]	-	-	-	-	40.77	2.315	35.86	46.88	38.23	1.931	33.79	42.32	38.53	1.902	34.01	42.00
Linoleic [C18:2(n6)]	-	-	-	-	22.99	4.829	13.57	31.81	23.97	5.399	14.45	34.76	22.94	5.808	11.90	36.10
α-Linoleic [C18:3(n3)]	-	-	-	-	0.74	0.103	0.49	0.98	0.72	0.115	0.49	0.94	0.66	0.132	0.36	0.92
Arachidic [C20:0]	-	-	-	-	0.15	0.028	0.10	0.27	0.19	0.040	0.11	0.35	0.21	0.046	0.11	0.36
Gondoic [C20:1(n9)]	-	-	-	-	0.88	0.091	0.71	1.14	0.84	0.093	0.63	1.07	0.82	0.116	0.60	1.17
Eicosadienoic [C20:2(n6)]	-	-	-	-	1.05	0.194	0.63	1.54	1.00	0.199	0.62	1.43	0.92	0.195	0.55	1.35
Eicosatrienoic [C20:3(n3)]	-	-	-	-	0.12	0.015	0.08	0.16	0.11	0.016	0.08	0.15	0.10	0.017	0.07	0.14
Dihomo-γ-linoleic[C20:3(n6)]	-	-	-	-	0.13	0.022	0.09	0.18	0.11	0.021	0.06	0.18	0.10	0.022	0.06	0.17
Arachinodic acid [C20:4(n6)]	-	-	-	-	0.29	0.042	0.22	0.41	0.25	0.040	0.16	0.34	0.23	0.047	0.14	0.34
Homo-γ-linolenic [C22:4(n6)]	-	-	-	-	0.14	0.025	0.09	0.21	0.12	0.025	0.07	0.18	0.11	0.023	0.07	0.17
MUFA[7]	-	-	-	-	44.45	2.677	39.01	51.87	41.31	2.197	36.40	46.37	41.55	2.127	36.58	45.80
PUFA[8]	-	-	-	-	25.47	5.158	15.36	34.87	26.28	5.750	16.11	37.74	25.06	6.181	13.33	38.95
MUFA:PUFA ratio	-	-	-	-	1.82	0.455	1.14	2.84	1.67	0.452	0.96	2.67	1.79	0.551	0.94	3.26
Total SFA[9]	-	-	-	-	30.08	3.244	23.44	37.30	32.40	4.340	24.97	40.95	33.38	4.554	24.46	43.21
Unsaturated:Saturated ratio	-	-	-	-	2.36	0.366	1.68	3.27	2.14	0.426	1.44	3.01	2.05	0.427	1.31	3.09
Iodine value, g/100 g																
AOCS equation[10]	-	-	-	-	79.78	6.805	66.36	91.48	78.77	8.311	62.79	93.77	77.04	8.936	58.89	96.27
Modified AOCS equation[11]	-	-	-	-	83.78	7.216	69.00	96.18	82.32	8.767	65.83	98.09	80.31	9.383	61.00	100.38
NIR[5]	-	-	-	-	78.70	5.990	67.20	88.60	78.05	7.266	64.00	91.00	75.67	7.493	60.10	89.50
Subsample 3[12]																
Number of fat samples[4]	85	-	-	-	86	-	-	-	80	-	-	-	-	-	-	-
Fatty acid, %																
Capric [C10:0]	0.14	0.039	0.07	0.29	0.12	0.034	0.05	0.24	0.11	0.031	0.05	0.20	-	-	-	-

Table 10 (Cont.)

Lauric [C12:0]	0.08	0.009	0.05	0.10	0.07	0.008	0.05	0.08	0.07	0.008	0.05	0.09	-	-	-	-
Myritic [C14:0]	1.25	0.175	0.85	1.69	1.13	0.137	0.83	1.49	1.11	0.142	0.76	1.59	-	-	-	-
Myristoleic [C14:1]	0.02	0.009	0.00	0.04	0.02	0.008	0.00	0.04	0.02	0.008	0.00	0.03	-	-	-	-
Pentadecylic [C15:0]	0.06	0.016	0.03	0.10	0.07	0.016	0.04	0.12	0.07	0.018	0.03	0.12	-	-	-	-
Palmitic [C16:0]	21.90	2.273	17.11	26.83	19.85	1.746	16.36	23.28	21.01	2.157	16.96	26.99	-	-	-	-
Palmitoleic [C16:1(n7)]	2.26	0.440	1.36	3.43	2.29	0.349	1.51	3.47	1.85	0.285	1.28	2.74	-	-	-	-
Margaric [C17:0]	0.34	0.080	0.19	0.57	0.38	0.080	0.25	0.60	0.39	0.078	0.26	0.57	-	-	-	-
Heptadecenoic [C17:1(n7)]	0.29	0.052	0.19	0.47	0.35	0.070	0.22	0.52	0.29	0.054	0.20	0.45	-	-	-	-
Stearic [C18:0]	9.90	1.574	6.82	14.66	8.29	1.223	6.08	11.55	10.13	1.962	7.08	16.07	-	-	-	-
Oleic [C18:1(n9)]	39.56	2.972	31.53	46.24	40.63	2.687	31.91	46.36	37.86	2.345	31.18	43.14	-	-	-	-
Linoleic [C18:2(n6)]	21.19	5.443	10.61	34.06	23.27	4.659	14.58	34.12	23.79	5.338	13.40	35.49	-	-	-	-
α-Linoleic [C18:3(n3)]	0.65	0.131	0.34	0.97	0.74	0.103	0.50	1.00	0.71	0.118	0.43	0.97	-	-	-	-
Arachidic [C20:0]	0.16	0.030	0.11	0.26	0.15	0.026	0.10	0.22	0.19	0.042	0.11	0.34	-	-	-	-
Gondoic [C20:1(n9)]	0.77	0.110	0.51	1.08	0.89	0.107	0.71	1.15	0.84	0.108	0.62	1.11	-	-	-	-
Eicosadienoic [C20:2(n6)]	0.82	0.177	0.46	1.23	1.06	0.192	0.67	1.53	0.98	0.191	0.51	1.36	-	-	-	-
Eicosatrienoic [C20:3(n3)]	0.09	0.017	0.06	0.13	0.12	0.018	0.08	0.16	0.11	0.017	0.07	0.15	-	-	-	-
Dihomo-γ-linoleic [C20:3(n6)]	0.11	0.024	0.04	0.18	0.13	0.022	0.09	0.19	0.11	0.019	0.06	0.15	-	-	-	-
Arachinodic [C20:4(n6)]	0.26	0.049	0.17	0.40	0.29	0.040	0.20	0.40	0.24	0.040	0.15	0.32	-	-	-	-
Homo-γ-linolenic [C22:4(n6)]	0.12	0.028	0.07	0.20	0.14	0.023	0.09	0.19	0.11	0.025	0.05	0.17	-	-	-	-
MUFA[7]	42.91	3.356	34.10	50.60	44.18	2.943	34.93	50.42	40.89	2.597	33.53	46.58	-	-	-	-
PUFA[8]	23.26	5.814	11.95	36.76	25.75	4.979	16.36	37.39	26.05	5.673	15.04	38.27	-	-	-	-
MUFA:PUFA ratio	2.00	0.676	0.96	3.96	1.79	0.472	1.00	3.07	1.67	0.487	0.92	2.78	-	-	-	-
SFA[9]	33.83	3.734	26.75	42.29	30.07	2.880	24.34	35.98	33.06	4.007	26.68	43.35	-	-	-	-
Unsaturated:Saturated ratio	1.99	0.330	1.36	2.74	2.36	0.319	1.78	3.11	2.07	0.359	1.31	2.75	-	-	-	-
Iodine value, g/100 g																
AOCS equation[10]	75.18	7.623	60.00	91.78	80.05	6.273	67.67	93.72	78.06	7.913	60.21	94.03	-	-	-	-
Modified AOCS equation[11]	78.50	8.144	62.39	95.71	84.00	6.694	70.78	98.71	81.51	8.352	62.80	97.93	-	-	-	-
NIR[5]	74.16	6.719	58.90	87.20	79.68	5.714	68.80	91.70	77.96	6.723	62.60	89.70	-	-	-	-

[1]Backfat samples were taken from 2 different locations: backfat 1 = 3rd thoracic vertebra, and backfat 2 = clear plate.

[2]SD= Standard Deviation; Min= Minimum; Max= Maximum.

[3]Subsample 1 = approximately 15 to 18 pigs (gilts and barrows) per pen were randomly selected to determine iodine value (with near-infrared spectroscopy) from 4 fat sampling locations (belly, jowl, 3rd thoracic vertebra backfat, clear plate backfat) post-mortem.

[4]Number of fat samples refers to the total fat samples analyzed within a subsample.

[5]Iodine value measured using near-infrared spectroscopy (NIR).

[6]Subsample 2 = 2 pigs (one barrow and one gilt) with harvest live weight closest to the mean pen live weight from each pen, were selected for fatty acid analysis using gas chromatography. Fat sampling locations: jowl, 3rd thoracic vertebra backfat, and clear plate backfat.

[7]MUFA: total mono-unsaturated fatty acid = C14:1 + C16:1(n7) + C17:1(n7) + C18:1(n9) + C20:1(n9) + C22:1(n9).

[8]PUFA: total poly-unsaturated fatty acid = C18:2(n6) + C18:3(n3) + C20:2(n6) + C20:3(n6) + C20:4(n6) + C20:3(n3) + C22:4(n6).

[9]SFA: total saturated fatty acid = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0..

[10]AOCS equation (1998): 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).

[11]Modified AOCS equation = AOCS (1998) equation + C14:1(1.062) + C17:1(n7)(0.903) + C20:2(n6)(1.581) + C20:3(n6)(2.386) + C20:3(n3)(2.386) + C20:4(n6)(3.201) + C22:4(n6)(2.941).

[12]Subsample 3 = 2 pigs (one barrow and one gilt) with harvest live weight closest to the mean pen live weight from each pen, were selected for fatty acid analysis using gas chromatography. Fat sampling locations: belly, jowl and 3rd thoracic vertebra backfat.

Table 11. Least square means for the effect of DDGS inclusion level, pig removal program, sex, and fat sampling location on the fatty acid profile and iodine value of pork fat for Subsamples 1 and 2.

	DDGS inclusion level			Removal program[2] (RP)			Sex (S)			Sampling location (SL)			
Item[1]	0%	40%	SEM	Single-group	Multiple-groups	SEM	Gilt	Barrow	SEM	Jowl	BF 1[3]	BF 2[3]	SEM
Subsample 1[4]													
Number of fat samples	843	845	-	706	982	-	864	824	-	555	589	544	-
Harvest live weight, kg	128.0^{a}	127.2^{b}	0.44	128.6^{a}	126.6^{b}	0.44	126.6^{b}	128.5^{a}	0.44	127.6	127.6	127.6	0.48
NIR iodine value, g/100 g[5]	69.92^{b}	81.61^{a}	0.249	75.74	75.79	0.249	76.48^{a}	75.04^{b}	0.249	77.86^{a}	75.92^{b}	73.51^{c}	0.259
Subsample 2[6]													
Number of fat samples	81	83	-	77	87	-	83	81	-	55	59	50	-
Harvest live weight, kg	127.5	127.8	0.39	128.1^{a}	127.2^{b}	0.40	127.4	127.9	0.39	127.8	127.7	127.5	0.45
Fatty acid, %													
Myritic acid [C14:0]	1.28^{a}	1.08^{b}	0.016	1.19	1.18	0.016	1.16^{b}	1.21^{a}	0.016	1.22^{a}	1.18^{ab}	1.16^{b}	0.017
Palmitic acid [C16:0]	22.86^{a}	19.30^{b}	0.160	20.99	21.17	0.160	20.91	21.25	0.159	20.30^{b}	21.29^{a}	21.66^{a}	0.182
Palmitoleic acid [C16:1(n7)]	2.30^{a}	1.99^{b}	0.036	2.12	2.17	0.036	2.10	2.19	0.036	2.47^{a}	2.01^{b}	1.95^{b}	0.043
Margaric acid [C17:0]	0.37	0.37	0.014	0.37	0.37	0.014	0.37	0.38	0.014	0.38^{a}	0.38^{a}	0.35^{b}	0.015
Heptadecenoic acid [C17:1(n7)]	0.35^{a}	0.30^{b}	0.009	0.33	0.32	0.009	0.32^{b}	0.34^{a}	0.009	0.38^{a}	0.32^{b}	0.28^{c}	0.010
Stearic acid [C18:0]	11.26^{a}	8.49^{b}	0.187	9.93	9.82	0.188	10.05	9.71	0.186	8.42^{c}	10.19^{b}	11.00^{a}	0.207
Oleic acid [C18:1(n9)]	40.77^{a}	38.41^{b}	0.286	39.34^{b}	39.85^{a}	0.288	39.52	39.67	0.286	41.23^{a}	38.66^{b}	38.39^{b}	0.307
Linoleic acid [C18:2(n6)]	17.54^{b}	26.32^{a}	0.499	22.22	21.63	0.502	22.15	21.71	0.499	21.91	22.46	21.41	0.532
α-Linoleic acid [C18:3(n3)]	0.59^{b}	0.77^{a}	0.014	0.69	0.67	0.014	0.67	0.69	0.014	0.72^{a}	0.70^{a}	0.62^{b}	0.015
Gondoic acid [C20:1(n9)]	0.87^{a}	0.84^{b}	0.013	0.86	0.85	0.013	0.83^{b}	0.89^{a}	0.013	0.88^{a}	0.85^{ab}	0.83^{b}	0.015
Eicosadienoic acid [C20:2(n6)]	079^{b}	1.09^{a}	0.021	0.95	0.93	0.021	0.93	0.95	0.021	1.00^{a}	0.94^{b}	0.88^{c}	0.023
Arachinodic acid [C20:4(n6)]	0.23^{b}	0.27^{a}	0.008	0.25	0.26	0.008	0.26^{a}	0.24^{b}	0.008	0.29^{a}	0.24^{b}	0.22^{c}	0.008
Other fatty acids[7]	0.75	0.75	0.012	0.76	0.75	0.012	0.75	0.76	0.012	0.78^{a}	0.75^{b}	0.73^{c}	0.013
MUFA[8]	44.34^{a}	41.55^{b}	0.297	42.67^{b}	43.23^{a}	0.300	42.78	43.12	0.298	44.99^{a}	41.86^{b}	41.99^{b}	0.324
PUFA[9]	19.47^{b}	28.83^{a}	0.541	24.45	23.85	0.544	24.38	23.92	0.541	24.33^{ab}	24.68^{a}	23.44^{b}	0.577
SFA[10]	36.19^{a}	29.61^{b}	0.319	32.88	32.81	0.321	32.85	32.95	0.319	30.68^{c}	33.45^{b}	34.56^{a}	0.361
MUFA:PUFA ratio	2.31^{a}	1.46^{b}	0.045	1.84^{b}	1.93^{a}	0.045	1.88	1.90	0.045	1.94^{a}	1.80^{b}	1.92^{a}	0.049
UFA:SFA ratio[11]	1.78^{b}	2.40^{a}	0.031	2.09	2.09	0.031	2.10	2.08	0.031	2.30^{a}	2.04^{b}	1.94^{c}	0.035
Iodine value, g/100 g													
AOCS equation[12]	69.86^{b}	83.17^{a}	0.692	76.81	76.22	0.695	76.77	76.26	0.692	78.33^{a}	76.55^{b}	74.67^{c}	0.750
NIR[5]	69.71^{b}	81.61^{a}	0.565	75.82	75.49	0.568	75.80	75.52	0.564	77.37^{a}	76.20^{b}	73.41^{c}	0.616

^{a,b,c}Means within a row with different superscripts are different ($P \leq 0.05$).

[1]All data (except for harvest live weights) were corrected to a common harvest live weight of 128.2 kg.

[2]Pigs were sent for harvest using two removal programs: Single-group = pigs were sent to harvest at the same time; Multiple-groups = [Week 1 = Heaviest 10% of pigs removed from group and sent for harvest; Week 2 = Heaviest 20%, Week 3 = Heaviest 20%, Week 4 = Heaviest 20%, Week 5 = Heaviest 10%, Week 6 = Lightest 20% of pigs].

[3]BF 1= backfat from 3rd thoracic vertebra; BF 2 = backfat from clear plate.

[4]Subsample 1 = 15 to 18 pigs (gilts and barrows) per pen were randomly selected to determine iodine value (with near-infrared spectroscopy) from 4 fat sampling locations (belly, jowl, 3rd thoracic vertebra backfat, clear plate backfat) post-mortem.

[5]Iodine value measured using NIR (Near Infrared spectroscopy).

[6]Subsample 2 = 2 pigs (one barrow and one gilt) with harvest live weight closest to the mean pen live weight from each pen, were selected for fatty acid analysis using gas chromatography.

[7]Other fatty acids = C10:0 + C12:0 + C14:1 + C15:0 + C20:0 + C20:3(n3) + C20:3(n6) + C22:4(n6)

[8]MUFA: total mono-unsaturated fatty acid = C14:1 + C16:1(n7) + C17:1(n7) + C18:1(n9) + C20:1(n9) + C22:1(n9).

[9]PUFA: total poly-unsaturated fatty acid = C18:2(n6) + C18:3(n3) + C20:2(n6) + C20:3(n6) + C20:4(n6) + C20:3(n3) + C22:4(n6).

[10]SFA: total saturated fatty acid = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

[11]UFA: total unsaturated fatty acid = MUFA + PUFA

[12]AOCS equation (1998): 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).

Table 12. Least square means for the effect of DDGS inclusion level, pig removal program, sex, and fat sampling location on the fatty acid profile and iodine value of pork fat for Subsamples 1 and 3.

	DDGS inclusion level			Removal program[2] (RP)			Sex (S)			Sampling location (SL)			
Item[1]	0%	40%	SEM	Single-group	Multiple-groups	SEM	Gilt	Barrow	SEM	Belly	Jowl	BF 1[3]	SEM
Subsample 1[4]													
Number of fat samples	835	832	-	682	982	-	852	815	-	523	555	589	-
Harvest live weight, kg	128.0^{a}	127.2^{b}	0.45	128.6^{a}	126.6^{b}	0.46	126.6^{b}	128.6^{a}	0.45	127.7	127.6	127.6	0.49
NIR iodine value, g/100 g[5]	69.77^{b}	81.10^{a}	0.271	75.41	75.46	0.271	76.18^{a}	74.70^{b}	0.270	72.56^{c}	77.84^{a}	75.90^{b}	0.280
Subsample 3[6]													
Number of fat samples	85	89	-	96	78	-	86	88	-	60	62	52	-
Harvest live weight, kg	128.46	127.5	0.84	129.1^{a}	126.8^{b}	0.84	127.1^{b}	128.7^{a}	0.84	127.9	128.0	128.1	0.90
Fatty acid, %													
Myritic acid [C14:0]	1.26^{a}	1.13^{b}	0.017	1.17^{b}	1.22^{a}	0.017	1.22^{a}	1.17^{b}	0.017	1.30^{a}	1.15^{b}	1.14^{b}	0.019
Palmitic acid [C16:0]	22.90^{a}	20.02^{b}	0.165	21.25	21.67	0.168	21.66	21.26	0.166	22.51^{a}	20.17^{c}	21.70^{b}	0.196
Palmitoleic acid [C16:1(n7)]	2.32^{a}	2.02^{b}	0.034	2.12^{b}	2.22^{a}	0.034	2.20	2.14	0.034	2.34^{a}	2.33^{a}	1.85^{b}	0.042
Margaric acid [C17:0]	0.33^{b}	0.38^{a}	0.011	0.37^{a}	0.34^{b}	0.010	0.35	0.36	0.011	0.32^{b}	0.38^{a}	0.37^{a}	0.012
Heptadecenoic acid [C17:1(n7)]	0.32	0.31	0.010	0.31	0.31	0.010	0.31	0.32	0.010	0.29^{b}	0.36^{a}	0.29^{b}	0.011
Stearic acid [C18:0]	10.91^{a}	8.76^{b}	0.171	9.71	9.96	0.172	9.80	9.87	0.172	10.23^{b}	8.46^{c}	10.81^{a}	0.192
Oleic acid [C18:1(n9)]	41.05^{a}	38.83^{b}	0.257	39.59	40.29	0.260	39.48^{b}	40.40^{a}	0.258	40.28^{a}	41.08^{a}	38.46^{b}	0.313
Linoleic acid [C18:2(n6)]	17.68^{b}	24.85^{a}	0.377	21.96^{a}	20.57^{b}	0.383	21.48	21.05	0.381	19.53^{b}	22.33^{a}	21.93^{a}	0.455
α-Linoleic acid [C18:3(n3)]	0.60^{b}	0.75^{a}	0.011	0.69^{a}	0.66^{b}	0.011	0.68	0.67	0.11	0.62^{c}	0.73^{a}	0.67^{b}	0.013
Gondoic acid [C20:1(n9)]	0.85	0.82	0.013	0.85	0.82	0.013	0.83	0.84	0.013	0.78^{c}	0.89^{a}	0.84^{b}	0.016
Eicosadienoic acid [C20:2(n6)]	0.78^{b}	1.01^{a}	0.016	0.92^{a}	0.87^{b}	0.016	0.89	0.90	0.017	0.76^{c}	1.02^{a}	0.92^{b}	0.019
Arachinodic acid [C20:4(n6)]	0.24^{b}	0.27^{a}	0.005	0.26	0.25	0.005	0.26^{a}	0.25^{b}	0.005	0.25^{b}	0.29^{a}	0.23^{c}	0.006
Other fatty acids[7]	0.77^{b}	0.79^{a}	0.010	0.80^{a}	0.76^{b}	0.010	0.78	0.78	0.010	0.76^{b}	0.81^{a}	0.77^{b}	0.011
MUFA[8]	44.57^{a}	42.02^{b}	0.282	42.90	43.68	0.285	42.84^{b}	43.74^{a}	0.283	43.70^{b}	44.68^{a}	41.49^{c}	0.344
PUFA[9]	19.60^{b}	27.27^{a}	0.404	24.17^{a}	22.69^{b}	0.410	23.66	23.20	0.408	21.50^{b}	24.74^{a}	24.06^{a}	0.487
SFA[10]	35.87^{a}	30.70^{b}	0.321	32.96	33.62	0.323	33.46	33.11	0.323	34.80^{a}	30.60^{b}	34.47^{a}	0.368
MUFA:PUFA ratio	2.37^{a}	1.57^{b}	0.045	1.92	2.02	0.046	1.95	2.00	0.045	2.20^{a}	1.88^{b}	1.83^{b}	0.055
UFA:SFA[11]	1.81^{b}	2.28^{a}	0.032	2.07	2.02	0.033	2.03	2.06	0.033	1.91^{b}	2.30^{a}	1.94^{b}	0.036
Iodine value, g/100 g													
AOCS equation[12]	70.30^{b}	80.96^{a}	0.586	76.51^{a}	74.75^{b}	0.594	75.71	75.55	0.591	72.89^{c}	78.77^{a}	75.22^{b}	0.681
NIR[5]	70.75^{b}	80.08	0.575	76.42^{a}	74.42^{b}	0.583	75.43	75.40	0.579	72.30^{c}	78.52^{a}	75.43^{b}	0.648

[a,b,c]Means within a row with different superscripts are different ($P \leq 0.05$).

[1]All data (except for harvest live weights) were corrected to a common harvest live weight of 128.2 kg.

[2]Pigs were sent for harvest using two removal programs: single-group = pigs were sent to harvest at the same time; multiple-groups = [Week 1 = Heaviest 10% of pigs removed from group and sent for harvest; Week 2 = Heaviest 20%, Week 3 = Heaviest 20%, Week 4 = Heaviest 20%, Week 5 = Heaviest 10%, Week 6 = Lightest 20% of pigs].

[3]BF 1= backfat from 3rd thoracic vertebra.

[4]Subsample 1 = 15 to 18 pigs (gilts and barrows) per pen were randomly selected to determine iodine value (with near-infrared spectroscopy) from 4 fat sampling locations (belly, jowl, 3rd thoracic vertebra backfat, clear plate backfat) post-mortem.

[5]Iodine value measured using NIR (Near Infrared spectroscopy).

[6]Sbsample 3 = 2 pigs (one barrow and one gilt) with harvest live weight closest to the mean pen live weight from each pen, were selected for fatty acid analysis using gas chromatography.

[7]Other fatty acids = C10:0 + C12:0 + C14:1 + C15:0 + C20:0 + C20:3(n3) + C20:3(n6) + C22:4(n6)

[8]MUFA: total mono-unsaturated fatty acid = C14:1 + C16:1(n7) + C17:1(n7) + C18:1(n9) + C20:1(n9) + C22:1(n9).

[9]PUFA: total poly-unsaturated fatty acid = C18:2(n6) + C18:3(n3) + C20:2(n6) + C20:3(n6) + C20:4(n6) + C20:3(n3) + C22:4(n6).

[10]SFA: total saturated fatty acid = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

[11]UFA: total unsaturated fatty acid = MUFA + PUFA

[12]AOCS equation (1998): 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).

Table 13. *P*-values for the effect of DDGS inclusion level, pig removal program, sex, and fat sampling location on the fatty acid profile and iodine value of pork fat for Subsamples 1 and 2.

	P-value														
Item[2]	DDGS[1]	RP[1]	S[1]	SL[1]	DDGS × RP	DDGS × S	S × RP	DDGS × SL	RP × SL	S × SL	DDGS × S × RP	DDGS × RP × SL	DDGS × S × SL	S x RP × SL	DDGS × S × RP × SL
Subsample 1[3]															
Harvest live weight, kg	0.03	<0.01	<0.01	0.99	0.75	0.01	<0.01	0.97	0.93	0.95	0.12	0.86	0.87	0.94	0.82
NIR iodine value, g/100 g[4]	<0.01	0.73	<0.01	<0.01	0.89	0.08	0.23	<0.01	0.26	0.14	0.04	0.49	0.41	0.70	0.47
Subsample 2[5]															
Harvest live weight, kg	0.53	0.05	0.32	0.87	0.08	0.65	0.44	0.97	0.87	0.99	0.29	0.97	0.98	0.99	0.99
Fatty acid, %															
Myritic acid [C14:0]	<0.01	0.76	0.02	0.02	0.63	0.85	0.29	0.71	0.66	0.68	0.01	0.98	0.71	0.87	0.94
Palmitic acid [C16:0]	<0.01	0.33	0.06	<0.01	0.57	0.31	0.28	0.29	0.49	0.46	0.19	0.57	0.65	0.73	0.66
Palmitoleic acid [C16:1(n7)]	<0.01	0.34	0.06	<0.01	0.21	0.13	0.70	0.51	0.65	0.99	<0.01	0.99	0.27	0.92	0.86
Margaric acid [C17:0]	0.55	0.64	0.14	0.02	0.06	0.06	<0.01	0.65	0.52	0.51	0.96	0.43	0.72	0.99	0.96
Heptadecenoic acid [C17:1(n7)]	<0.01	0.53	0.02	<0.01	0.67	0.02	0.22	0.55	0.61	0.99	0.34	0.41	0.56	0.98	0.98
Stearic acid [C18:0]	<0.01	0.56	0.08	<0.01	0.42	0.01	0.92	0.12	0.98	0.99	0.21	0.46	0.25	0.93	0.65
Oleic acid [C18:1(n9)]	<0.01	0.03	0.50	<0.01	0.54	0.54	0.23	0.32	0.06	0.15	0.46	0.81	0.99	0.81	0.55
Linoleic acid [C18:2(n6)]	<0.01	0.13	0.25	0.07	0.64	0.40	0.25	0.63	0.12	0.33	0.36	0.53	0.59	0.79	0.38
α-Linoleic acid [C18:3(n3)]	<0.01	0.17	0.34	<0.01	0.39	0.33	0.14	0.75	0.45	0.59	0.44	0.47	0.79	0.78	0.60
Gondoic acid [C20:1(n9)]	0.03	0.68	<0.01	0.04	0.50	0.83	0.26	0.76	0.38	0.83	0.24	0.87	0.63	0.93	0.80
Eicosadienoic acid [C20:2(n6)]	<0.01	0.39	0.22	<0.01	0.24	0.34	0.99	0.56	0.58	0.61	0.42	0.15	0.85	0.63	0.72
Arachinodic acid [C20:4(n6)]	<0.01	0.45	<0.01	<0.01	0.57	0.49	0.49	0.85	0.34	0.80	0.35	0.68	0.59	0.97	0.80
Other fatty acids[6]	0.87	0.16	0.10	<0.01	0.59	0.26	0.45	0.16	0.12	0.83	0.60	0.29	0.20	0.49	0.11
MUFA[7]	<0.01	0.04	0.20	<0.01	0.82	0.37	0.23	0.33	0.06	0.20	0.24	0.84	0.96	0.9	0.73
PUFA[8]	<0.01	0.15	0.25	0.04	0.71	0.38	0.27	0.70	0.11	0.35	0.38	0.49	0.60	0.78	0.34
SFA[9]	<0.01	0.93	0.78	<0.01	0.86	0.07	0.63	0.14	0.79	0.78	0.94	0.50	0.47	0.87	0.57
MUFA:PUFA ratio	<0.01	0.02	0.66	<0.01	0.64	0.75	0.15	0.64	0.03	0.13	0.99	0.20	0.5	0.67	0.56
UFA:SFA[10]	<0.01	0.90	0.55	<0.01	0.96	0.72	0.72	0.57	0.78	0.76	0.69	0.59	0.51	0.91	0.53
Iodine value, g/100 g															
AOCS equation[11]	<0.01	0.33	0.39	<0.01	0.67	0.19	0.36	0.28	0.32	0.54	0.58	0.49	0.48	0.81	0.46
NIR[4]	<0.01	0.52	0.58	<0.01	0.57	0.57	0.57	0.25	0.69	0.36	0.20	0.45	0.67	0.90	0.12

[1]DDGS = dried distiller grains with solubles; RP = removal program (single-group or multiple-groups); S = Sex; SL = fat sampling location

[2]All data (except for harvest live weights) were corrected to a common harvest live weight of 128.2 kg)

[3]Subsample 1 = 15 to 18 pigs (gilts and barrows) per pen were randomly selected to determine iodine value (with near-infrared spectroscopy) from 4 fat sampling locations (belly, jowl, 3rd thoracic vertebra backfat, clear plate backfat) post-mortem.

[4]Iodine value measured using NIR (Near Infrared spectroscopy).

[5]Subsample 2 = 2 pigs (one barrow and one gilt) with harvest live weight closest to the mean pen live weight from each pen, were selected for fatty acid analysis using gas chromatography.

[6]Other fatty acids = C10:0 + C12:0 + C14:1 + C15:0 + C20:0 + C20:3(n3) + C20:3(n6) + C22:4(n6)

[7]MUFA: total mono-unsaturated fatty acid = C14:1 + C16:1(n7) + C17:1(n7) + C18:1(n9) + C20:1(n9) + C22:1(n9).

[8]PUFA: total poly-unsaturated fatty acid = C18:2(n6) + C18:3(n3) + C20:2(n6) + C20:3(n6) + C20:4(n6) + C20:3(n3) + C22:4(n6).

[9]SFA: total saturated fatty acid = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

[10]UFA: total unsaturated fatty acid = MUFA + PUFA

[11]AOCS equation (1998): 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).

Table 14. *P*-values for the effect of DDGS inclusion level, pig removal program, sex, and fat sampling location on the fatty acid profile and iodine value of pork fat for Subsamples 1 and 3.

	P-value														
Item[2]	DDGS[1]	RP[1]	S[1]	SL[1]	DDGS × RP	DDGS × S	S × RP	DDGS × SL	RP × SL	S × SL	DDGS × S × RP	DDGS × RP × SL	DDGS × S × SL	S × RP × SL	DDGS × S × RP × SL
Subsample 1[3]															
Harvest live weight, kg	0.04	<0.01	<0.01	0.98	0.86	0.01	<0.01	0.98	0.94	0.90	0.31	0.92	0.99	0.86	0.87
NIR[4] iodine value, g/100 g	<0.01	0.73	<0.01	<0.001	0.41	0.93	0.13	<0.01	0.26	0.13	0.79	0.25	0.56	0.83	0.37
Subsample 3[5]															
Harvest live weight, kg	0.12	<0.01	0.01	0.97	0.33	0.13	<0.01	0.93	0.97	0.97	0.80	0.97	0.95	0.97	0.92
Fatty acid, %															
Myritic acid [C14:0]	<0.01	<0.01	<0.01	<0.01	0.14	0.03	<0.01	0.78	0.24	0.49	0.12	0.35	0.75	0.33	0.25
Palmitic acid [C16:0]	<0.01	0.07	0.07	<0.01	0.56	0.65	0.88	0.52	0.58	0.48	<0.01	0.47	0.86	0.66	0.45
Palmitoleic acid [C16:1(n7)]	<0.01	0.04	0.20	<0.01	0.50	0.05	0.04	0.58	0.64	0.73	0.14	0.79	0.94	0.22	0.41
Margaric acid [C17:0]	<0.01	<0.01	0.34	<0.01	<0.01	0.51	0.02	0.54	0.88	0.62	0.39	0.36	0.84	0.30	0.93
Heptadecenoic acid [C17:1(n7)]	0.19	0.97	0.08	<0.01	0.80	0.56	0.29	0.24	0.56	0.91	<0.01	0.78	0.95	0.74	0.77
Stearic acid [C18:0]	<0.01	0.20	0.70	<0.01	0.96	0.01	0.27	0.18	0.41	0.74	0.03	0.29	0.5	0.94	0.83
Oleic acid [C18:1(n9)]	<0.01	0.06	0.01	<0.01	0.01	0.99	<0.01	0.24	0.79	0.29	0.95	0.73	0.58	0.61	0.87
Linoleic acid [C18:2(n6)]	<0.01	0.01	0.42	<0.01	0.13	0.61	0.09	0.52	0.97	0.93	0.05	0.84	0.52	0.65	0.71
α-Linoleic acid [C18:3(n3)]	<0.01	0.03	0.67	<0.01	0.39	0.63	0.12	0.30	0.99	0.89	0.19	0.89	0.34	0.22	0.75
Gondoic acid [C20:1(n9)]	0.09	0.09	0.50	<0.01	0.02	0.08	0.08	0.39	0.89	0.92	0.12	0.74	0.73	0.91	0.66
Eicosadienoic acid [C20:2(n6)]	<0.01	0.02	0.76	<0.01	0.56	0.94	0.53	0.64	0.98	0.98	<0.01	0.70	0.94	0.68	0.71
Arachinodic acid [C20:4(n6)]	<0.01	0.19	0.02	<0.01	<0.01	0.02	0.84	0.10	0.95	0.29	0.08	0.79	0.47	0.54	0.42
Other fatty acids[6]	0.02	<0.01	0.96	<0.01	<0.01	0.24	0.51	0.10	0.61	0.74	0.39	0.88	0.14	0.96	0.61
MUFA[7]	<0.01	0.06	0.03	<0.01	0.01	0.82	<0.01	0.21	0.82	0.31	0.88	0.75	0.64	0.58	0.91
PUFA[8]	<0.01	0.01	0.42	<0.01	0.16	0.65	0.11	0.49	0.98	0.91	0.05	0.80	0.49	0.65	0.69
SFA[9]	<0.01	0.09	0.36	<0.01	0.56	0.32	0.73	0.34	0.68	0.51	<0.01	0.36	0.74	0.78	0.53
MUFA:PUFA ratio	<0.01	0.12	0.43	<0.01	0.31	0.91	0.21	0.02	0.93	0.85	0.35	0.92	0.36	0.70	0.99
UFA[10]:SFA	<0.01	0.15	0.47	<0.01	0.99	0.24	0.92	0.99	0.86	0.42	<0.01	0.39	0.71	0.74	0.24
Iodine value, g/100 g															
AOCS equation[11]	<0.01	0.02	0.83	<0.01	0.44	0.43	0.29	0.51	0.86	0.93	0.01	0.66	0.56	0.67	0.58
NIR[5]	<0.01	<0.01	0.95	<0.01	0.59	0.18	0.45	0.55	0.67	0.76	0.03	0.81	0.57	0.47	0.43

[1]DDGS = dried distiller grains with solubles; RP = removal program (single-group or multiple-groups); S = Sex; SL = fat sampling location

[2]All data (except for harvest live weights) were corrected to a common harvest live weight of 128.2 kg)

[3]Subsample 1 = 15 to 18 pigs (gilts and barrows) per pen were randomly selected to determine iodine value (with near-infrared spectroscopy) from 4 fat sampling locations (belly, jowl, 3rd thoracic vertebra backfat, clear plate backfat) post-mortem.

[4]Iodine value measured using NIR (Near Infrared spectroscopy).

[5]Subsample 3 = 2 pigs (one barrow and one gilt) with harvest live weight closest to the mean pen live weight from each pen, were selected for fatty acid analysis using gas chromatography.

[6]Other fatty acids = C10:0 + C12:0 + C14:1 + C15:0 + C20:0 + C20:3(n3) + C20:3(n6) + C22:4(n6)

[7]MUFA: total mono-unsaturated fatty acid = C14:1 + C16:1(n7) + C17:1(n7) + C18:1(n9) + C20:1(n9) + C22:1(n9).

[8]PUFA: total poly-unsaturated fatty acid = C18:2(n6) + C18:3(n3) + C20:2(n6) + C20:3(n6) + C20:4(n6) + C20:3(n3) + C22:4(n6).

[9]SFA: total saturated fatty acid = C10:0 + C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C22:0.

[10]UFA: total unsaturated fatty acid = MUFA + PUFA

[11]AOCS equation (1998): 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).

Table 15. Pearson correlation coefficients for iodine value (IV) measured with near-infrared spectroscopy (NIR) between 4 fat sampling locations of pigs from Subsample 1[1].

	Belly	Jowl	Backfat 1[2]	Backfat 2[2]
Belly	1			
Jowl	**0.88**	1		
Backfat 1	**0.86**	**0.92**	1	
Backfat 2	**0.86**	**0.90**	**0.90**	1

Bolded correlation coefficients are significant ($P < 0.001$)

[1]Subsample 1 = 15 to 18 pigs (gilts and barrows) per pen were randomly selected to determine iodine value (with near-infrared spectroscopy) from 4 fat sampling locations (belly, jowl, 3rd thoracic vertebra backfat, clear plate backfat) post-mortem.

[2]Backfat 1 = sample taken at 3rd thoracic vertebra; Backfat 2 = sample taken at clear plate.

Table 16. Pearson correlation coefficients between gas chromatography (GC) predicted iodine value (IV) and near-infrared spectroscopy (NIR) IV on 3 fat sampling locations of pigs from Subsample 2[1].

		GC[2] IV			NIR IV		
	Pooled NIR[3]	Jowl	Backfat 1[4]	Backfat 2[4]	Jowl	Backfat 1[4]	Backfat 2[4]
Number of samples	250	85	91	74	85	91	74
Pooled GC[3]	**0.96**	-	-	-	-	-	-
GC[2] IV							
Jowl	-	1					
Backfat 1[4]	-	**0.94**	1				
Backfat 2[4]	-	**0.88**	**0.89**	1			
NIR IV							
Jowl	-	**0.97**	**0.94**	**0.88**	1		
Backfat 1[4]	-	**0.92**	**0.97**	**0.90**	**0.92**	1	
Backfat 2[4]	-	**0.89**	**0.91**	**0.95**	**0.89**	**0.94**	1

Bolded correlation coefficients are significant ($P < 0.001$)

[1]Subsample 2 = 2 pigs (one barrow and one gilt) with harvest live weight closest to the mean pen live weight from each pen were selected for fatty acid analysis using gas chromatography on jowl, backfat 1, and backfat 2.

[2]GC IV was calculated using AOCS equation (1998): 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).

[3]Pooled NIR = IV average of all fat samples measured with NIR; pooled GC = IV average of all fat samples used for GC analysis

[4]Backfat 1 = sample taken at 3rd thoracic vertebra; Backfat 2 = sample taken at clear plate.

Table 17. Pearson correlation coefficients between gas chromatography (GC) predicted iodine value (IV) and near-infrared spectroscopy (NIR) IV on 3 fat sampling locations of pigs from Subsample 3[1].

		GC[2] IV			NIR IV		
	Pooled NIR[3]	Belly	Jowl	Backfat[3] 1	Belly	Jowl	Backfat 1[4]
Number of samples	251	85	86	80	85	86	80
Pooled GC[3]	**0.96**	-	-	-	-	-	-
GC[2] IV							
Belly	-	1					
Jowl	-	**0.90**	1				
Backfat 1[4]	-	**0.80**	**0.82**	1			
NIR IV							
Belly	-	**0.95**	**0.91**	**0.81**	1		
Jowl	-	**0.87**	**0.97**	**0.82**	**0.88**	1	
Backfat 1[4]	-	**0.78**	**0.82**	**0.96**	**0.81**	**0.81**	1

Bolded correlation coefficients are significant ($P < 0.001$)

[1]Subsample 3 = 2 pigs (one barrow and one gilt) with harvest live weight closest to the mean pen live weight from each pen were selected for fatty acid analysis using gas chromatography on belly, jowl, and backfat 1.

[2]GC IV was calculated using AOCS equation (1998): 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).

[3]Pooled NIR = IV average of all fat samples measured with NIR; pooled GC = IV average of all fat samples used for GC analysis

[4]Backfat 1 = sample taken at 3rd thoracic vertebra; Backfat 2 = sample taken at clear plate.

Table 18. Pearson correlation coefficients between iodine value, dietary iodine value product (IVP), and carcass characteristics of pigs from Subsample 1[1].

Item	NIR iodine value[2]	DDGS level	Phase 5 dietary IVP[3]	Mean dietary IVP[4]	Harvest live weight	Carcass yield	Last rib backfat depth[5]
Belly fat[6]							
NIR iodine value[2]	1						
DDGS level	**0.86**	1					
Phase 5 dietary IVP[3]	**0.84**	**0.98**	1				
Mean dietary IVP[4]	**0.86**	**0.99**	**0.98**	1			
Harvest live weight	-0.02	0.05	0.06	0.06	1		
Carcass yield	**-0.16**	**-0.19**	**-0.18**	**-0.19**	0.03	1	
Last rib backfat depth[5]	**-0.16**	-0.07*	-0.06	-0.07*	**0.29**	0.07	1
Jowl fat[6]							
NIR iodine value[2]	1						
DDGS level	**0.90**	1					
Phase 5 dietary IVP[3]	**0.87**	**0.98**	1				
Mean dietary IVP[4]	**0.90**	**0.99**	**0.98**	1			
Harvest live weight	-0.03	0.04	0.05	0.05	1		
Carcass yield	**-0.19**	**-0.19**	**-0.18**	**-0.19**	0.00	1	
Last rib backfat depth[5]	**-0.20**	-0.09*	-0.08*	-0.09**	**0.30**	0.09*	1
Backfat 1[6,7]							
NIR iodine value[2]	1						
DDGS level	**0.90**	1					
Phase 5 dietary IVP[3]	**0.87**	**0.98**	1				
Mean dietary IVP[4]	**0.90**	**0.99**	**0.98**	1			
Harvest live weight	-0.02	0.03	0.03	0.03	1		
Carcass yield	**-0.23**	**-0.21**	**-0.19**	**-0.21**	0.03	1	
Last rib backfat depth[5]	**-0.21**	-0.09**	-0.08*	-0.09**	**0.29**	0.11**	1
Backfat 2[6,7]							
NIR iodine value[2]	1						
DDGS level	**0.88**	1					
Phase 5 dietary IVP[3]	**0.85**	**0.98**	1				
Mean dietary IVP[4]	**0.88**	**0.99**	**0.98**	1			
Harvest live weight	-0.04	**0.04**	0.05*	0.04	1		
Carcass yield	**-0.21**	-0.21	-0.20	**-0.21**	0.04	1	
Last rib backfat depth[5]	**-0.23**	-0.09**	-0.08*	-0.09**	**0.32**	0.08*	1
Pooled fat sampling locations[6,8]							
NIR iodine value[2]	1						
DDGS level	**0.85**	1					
Phase 5 dietary IVP[3]	**0.82**	**0.98**	1				
Mean dietary IVP[4]	**0.85**	**0.99**	**0.98**	1			
Harvest live weight	-0.03	0.04*	0.05*	0.04*	1		
Carcass yield	**-0.19**	**-0.20**	**-0.19**	**-0.20**	0.02	1	
Last rib backfat depth[5]	**-0.19**	**-0.09**	**-0.08**	**-0.09**	**0.30**	**0.09**	1

Bolded correlation coefficients are significant with $P < 0.001$; **correlation coefficients are significant with $P \leq 0.01$ and > 0.001; *correlation coefficients are significant with $P \leq 0.05$ and > 0.01.

[1]Subsample 1 = 15 to 18 pigs (gilts and barrows) per pen were randomly selected to determine iodine value (with near-infrared spectroscopy) from 4 fat sampling locations (belly, jowl, 3rd thoracic vertebra backfat, clear plate backfat) post-mortem.

[2]Iodine value measured using NIR (Near Infrared spectroscopy).

[3]IVP of last dietary phase (5) fed to pigs before harvest. IVP = % of ingredient lipids × iodine value of the lipids × 0.1.

[4]Mean dietary IVP = (phase 1 diet IVP + phase 2 diet IVP + phase 3 diet IVP + phase 4 diet IVP + phase 5 diet IVP) ÷ 5.

[5]Measured on slaughter line.

[6]Number of samples of: belly fat, 727; jowl fat, 791; backfat 1, 828; backfat 2, 777; pooled sampling locations fat (belly, jowl, backfat 1 and backfat 2 samples), 3123.

[7]Backfat 1 = sample taken at 3rd thoracic vertebra; Backfat 2 = sample taken at clear plate.

[8]Pooled fat sampling location = average of all fat samples analyzed on all locations.

Table 19. Selected equations to predict iodine value (IV), measured with near-infrared spectroscopy (NIR), of pork fat from 4 sampling locations based on the dietary and carcass characteristics using pigs from Subsample 1[1].

		Diet characteristics			Carcass characteristics						
Equation No.	Intercept	DDGS inclusion level, %	Phase 5 dietary IVP[2,3]	Mean dietary IVP[2,4]	Live harvest weight, kg	Carcass yield, %	Last rib backfat depth, cm	R^2	Adjusted R^2	C(p)	RMSE
Belly fat IV											
1	67.35	0.26	-	-	-	-	-	0.75	0.75	42.73	3.40
2	71.57	0.26	-	-	-	-	-1.51	0.76	0.76	13.91	3.34
3	73.96	0.34	-0.08	-	-	-	-1.45	0.76	0.76	7.51	3.32
4	83.29	0.61	-0.07	-0.26	-	-	-1.46	0.76	0.76	5.62	3.31
5	84.78	0.58	-0.07	-0.23	-0.02	-	-1.32	0.76	0.76	5.22	3.31
Jowl fat IV											
1	72.99	0.24	-	-	-	-	-	0.81	0.81	96.52	2.61
2	77.31	0.24	-	-	-	-	-1.54	0.83	0.83	33.53	2.51
3	79.94	0.33	-0.08	-	-	-	-1.50	0.83	0.83	15.61	2.48
4	91.13	0.65	-0.08	-0.31	-	-	-1.52	0.84	0.83	6.50	2.47
5	92.55	0.63	-0.08	-0.29	-0.02	-	-1.40	0.84	0.84	5.00	2.46
Backfat 1 IV[5]											
1	70.06	0.29	-	-	-	-	-	0.81	0.81	104.20	3.09
2	75.75	0.28	-	-	-	-	-1.96	0.83	0.83	28.57	2.96
3	78.38	0.38	-0.09	-	-	-	-1.93	0.83	0.83	14.06	2.93
4	91.13	0.74	-0.08	-0.35	-	-	-1.94	0.83	0.83	5.17	2.91
5	96.56	0.72	-0.08	-0.34	-	-0.08	-1.91	0.84	0.83	5.01	2.91
Backfat 2 IV[5]											
1	67.80	0.29	-	-	-	-	-	0.78	0.78	104.35	3.44
2	74.60	0.28	-	-	-	-	-2.43	0.80	0.80	15.59	3.25
3	77.46	0.38	-0.09	-	-	-	-2.38	0.81	0.80	3.78	3.23

[1]Subsample 1 = 15 to 18 pigs (gilts and barrows) per pen were randomly selected to determine iodine value (with near-infrared spectroscopy) from 4 fat sampling locations (belly, jowl, 3rd thoracic vertebra backfat, clear plate backfat) post-mortem.

[2]Iodine value product (IVP) = % of ingredient lipids × iodine value of the lipids × 0.1. Iodine value of the dietary lipids was predicted using gas chromatography.

[3]IVP of last dietary phase (i.e., phase 5) fed to pigs before harvest.

[4]Mean dietary IVP = (phase 1 diet IVP + phase 2 diet IVP + phase 3 diet IVP + phase 4 diet IVP + phase 5 diet IVP) ÷ 5.

[5]Backfat 1 = sample taken at 3rd thoracic vertebra; Backfat 2 = sample taken at the clear plate.

Table 20. Equations to predict pork fat iodine value (IV), measured with near-infrared spectroscopy (NIR), and from 4 sampling locations based on the dietary iodine value product (IVP) using pigs from Subsample 1[1].

Fat sampling location	Intercept	Mean dietary IVP[2,3]	R^2	Adjusted R^2	RMSE
Belly	58.32	0.25	0.74	0.74	3.42
Jowl	64.54	0.27	0.81	0.81	2.65
Backfat 1 (3rd thoracic vertebra)	60.13	0.27	0.81	0.81	3.12
Backfat 2 (clear plate)	57.96	0.27	0.77	0.77	3.48

[1]Subsample 1 = 15 to 18 pigs (gilts and barrows) per pen were randomly selected to determine iodine value (with near-infrared spectroscopy) from 4 fat sampling locations (belly, jowl, 3rd thoracic vertebra backfat, clear plate backfat) post-mortem.

[2]Iodine value product (IVP) = % of ingredient lipids × iodine value of the lipids × 0.1. Iodine value of the dietary lipids was predicted using gas chromatography.

[3]Mean dietary IVP = (phase 1 diet IVP + phase 2 diet IVP + phase 3 diet IVP + phase 4 diet IVP + phase 5 diet IVP) ÷ 5.

Table 21. Equations to predict belly fat iodine value (IV) based on the IV, measured with near-infrared spectroscopy (NIR), from other 3 sampling locations using pigs from Subsample 1[1].

Fat depot	Intercept	IV g/100 g	R^2	Adjusted R^2	RMSE
Jowl	-5.04	1.00	0.78	0.78	3.16
Backfat 1 (3rd thoracic vertebra)	10.64	0.82	0.75	0.75	3.37
Backfat 2 (clear plate)	13.05	0.81	0.73	0.73	3.48

[1]Subsample 1 = 15 to 18 pigs (gilts and barrows) per pen were randomly selected to determine iodine value (with near-infrared spectroscopy) from 4 fat sampling locations (belly, jowl, 3rd thoracic vertebra backfat, clear plate backfat) post-mortem.

Table 22. Least square means of the effect of number of pigs selected from a pen on the mean and standard deviation of NIR iodine value (IV) of fat from at 3 sampling locations using data from Subsample 1[1].

Pig removal program	Single-group[2]								Multiple-groups[2]							
Sample size	Number of pigs sampled[3]								Number of pigs sampled[3]							
Item	2	4	6	8	10	12	SEM	*P*-value	2	4	6	8	10	12	SEM	*P*-value
Jowl																
Mean IV, g/100 g	79.3	80.1	80.2	80.0	80.0	80.0	0.99	0.99	78.5	78.0	78.0	78.0	78.1	78.0	1.58	0.99
Standard deviation of IV, g/100 g	1.49[b]	2.76[a]	2.59[a]	2.52[a]	2.44[a]	2.44[a]	0.155	<0.001	2.53	2.04	2.00	2.21	2.28	2.29	0.238	0.63
Backfat 1[4]																
Mean IV, g/100 g	78.8	79.1	78.8	78.8	78.7	79.0	1.19	0.99	76.4	75.8	75.7	75.7	75.9	75.9	1.80	0.99
Standard deviation of IV, g/100 g	2.22[b]	3.07[a]	2.92[a]	2.88[a]	2.78[a]	2.89[a]	0.236	0.01	2.31	2.97	2.85	2.78	2.84	2.83	0.339	0.61
Backfat 2[4]																
Mean IV, g/100 g	77.2	76.8	76.6	76.5	76.7	76.9	1.22	0.99	73.9	73.2	73.2	73.5	73.5	73.8	1.80	0.99
Standard deviation of IV, g/100 g	2.70	3.02	3.04	3.09	3.10	3.01	0.212	0.83	3.81	3.10	2.98	3.00	3.14	3.31	0.365	0.50

[a,b]Means within a row with different superscripts are different ($P \leq 0.05$).

[1]Subsample 1 = 15 to 18 pigs (gilts and barrows) per pen were randomly selected to determine iodine value (with near-infrared spectroscopy) from subcutaneous fat.
[2]Pigs were sent for harvest using two removal programs: single-group = pigs were sent for harvest at the same time; multiple-groups = [Week 1 = Heaviest 10% of pigs removed from group and sent for harvest; Week 2 = Heaviest 20%, Week 3 = Heaviest 20%, Week 4 = Heaviest 20%, Week 5 = Heaviest 10%, Week 6 = Lightest 20% of pigs].
[3]Number of pigs: Initially, the 2 pigs (one barrow and one gilt) closest to the pen mean live weight when they were taken off test were selected for analysis (i.e., the same 2 pigs that were used for Subsample 2); subsequently, the next 2 pigs that were closest to the pen mean live weight at time of harvest were selected, and so on.
[4]Backfat 1 = sample taken at 3rd thoracic vertebra; Backfat 2 = sample taken at the clear plate.